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Shared water resources in the western Asia region: An inventory of shared aquifers and aquifer systems

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ABSTRACT

Shared water basins play a significant role in linking populations and cultures, and creating hydrological, social and economic interdependencies between riparian ESCWA member states as well as neighbouring non-ESCWA countries. Enhancing cooperation between riparian member states on shared water issues is one of the main objectives of the ESCWA-BGR Water Project. Presently, all available information is being compiled in an inventory which will be the first systematic effort to comprehensively "map" shared groundwater systems and surface water basins in Western Asia, including second- and third-order sub-basins with emphasis on hydrology, hydrogeology, water resources development and use, as well as the status of cooperation and water resource management.

The regional inventory of shared waters is comprised of basin-level chapters and is enriched by in-depth analysis of issues relevant to shared waters in Western Asia (thematic chapters). It targets a wide range of stakeholders including decision-makers and non-technical government representatives responsible for water resource management and related sectors, the general public, media and international organizations. The inventory aims at: (1) activating and creating awareness among decision-makers and a broader audience; (2) improving the knowledge base and facilitating access to information on shared water resources; (3) establishing a link between this knowledge base and the management practices at both the national and inter-state levels; and (4) supporting regional processes towards improved dialogue and cooperation on shared water resources. The main findings of the inventory are to be disseminated through expert group meetings and a comprehensive report, which is to be reviewed and discussed with member states before being published.

This paper deals only with shared aquifers / aquifer systems. It describes the work process through which the inventory of these systems is being achieved in a systematic manner so as to provide regional information on the extent of the resources, their uses, as well as the status of cooperation and management of the resource. It also describes the structure of the report and specific information obtained on each aquifer system, and identifies some of the most common groundwater issues prevailing in the different aquifer systems. Most importantly, the paper outlines how the aquifer systems are classified into different groups, the criteria used for this purpose, the problems encountered in delineating the boundaries of some of these systems, the discrepancies in the available data/information, and some of the terminology used to describe the different aquifer systems.
Key words: shared aquifers; riparian; cooperation; inventory; Western Asia

1. INTRODUCTION

The United Nations Economic and Social Commission for Western Asia[1] (ESCWA) has been actively engaged in research, capacity development of national institutions and initiatives for cooperation on shared water resources in Western Asia for more than 20 years. Interest in shared water issues in Western Asia has grown tremendously since ESCWA's first attempt to compile a preliminary

[1] Western Asia in this paper refers to the region comprised of Member States of the United Nations Economic and Social Commission for Western Asia (ESCWA) which lies entirely within the Arabian Plate, geologically speaking, and have common geo-tectonic setting, physiography, and climatic conditions that contributed to the development of aquifer systems extending across political boundaries.

water resources database in the region, which identified about 25 major water basins shared between at least two riparian countries (UN-ESCWA, 1992). These shared water basins play a significant role in linking populations and cultures, and creating hydrological, social and economic interdependencies between riparian ESCWA member states as well as neighbouring non-ESCWA countries.

Enhancing cooperation between member countries on shared water issues is one of the main objectives of the on-going cooperation between ESCWA and the Federal Institute for Geosciences and Natural Resources of Germany (BGR). Presently, the project is compiling available information in an inventory which will be the first systematic effort to comprehensively "map" both shared groundwater systems and surface water basins in Western Asia. The approach, objectives, scope, structure and work process of the inventory are outlined in section 2 below.

The focus of this paper is placed on shared aquifers and aquifer systems[2] in the Western Asia region, many of which extend not only across political borders but also beyond the boundaries of major geo-tectonic plates. Most of them belong to the Arabian Sedimentary Basin and occur in the extremely arid Arabian Peninsula covering most of the Arabian Plate, which lie to the east of the Arabian Shield, to constitute shared aquifers between Saudi Arabia and neighbouring countries. Those that occur along the relatively unstable northern boundaries of the Arabian Plate, however, have been developing under different geological and climatic conditions. These aquifers / aquifer systems are much smaller in size but more complex, compared with those that develop further south, and often extend to non-ESCWA countries, namely Israel, Iran, and Turkey.

Section 3 of this paper defines groundwater provinces in which the shared aquifers / aquifer systems in the region develop, and categorize such systems into different groups. We hope to stimulate discussion on the proposed approach and the overall activity being undertaken by ESCWA-BGR to ensure that it constitutes an added value towards a better understanding of shared water systems in the region.

2. APPROACH OF THE INVENTORY

2.1. Scope and objective

The inventory the first systematic effort to comprehensively "map", compile and explore shared groundwater systems and surface water basins in Western Asia, including second- or third-order sub-basins with emphasis on hydrology, hydrogeology, water resources development and use, as well as status of cooperation and management. In providing a regional inventory of shared waters, enriched by in-depth analysis of issues relevant to shared waters in Western Asia (thematic chapters), the study targets a wide range of stakeholders including decision makers and non-technical government representatives from water and other sectors, the general public, media, donors and international organizations.

The inventory thereby aims at (1) activating and creating awareness among decision makers and a broader audience; (2) improving the knowledge base and facilitate access to information on shared water resources; (3) establishing a link between this knowledge base and the management practices at both the national and inter-state levels; and (4) supporting regional processes towards improved dialogue and cooperation on shared water resources.

[2] An aquifer system *"means a series of two or more aquifers that are hydraulically connected"* (United Nations, 2009)

2.2. Structure of the inventory

The inventory builds on two major pillars: the actual inventory of shared waters in Western Asia, consisting of mostly descriptive chapters on each of the shared water basins, and an analytical part consisting of 4-6 thematic chapters that shed light on various issues of shared water resources in Western Asia such as in the context of groundwater, the issue of shared coastal aquifers.

For the part of the inventory dealing with shared aquifers, an introductory chapter with an overview map of shared aquifers / aquifer systems in Western Asia will introduce the approach used to compile relevant information. This is followed by basin chapters on the identified groundwater systems/units. Each basin chapter will consist of a map introducing the groundwater system, a table of basic facts & figures (see Table 1), a brief summary text and a more detailed, illustrated description of the basin covering the following issues:

Table 1: Basic information to be collected on each aquifer /aquifer system

Basin introduction	*Riparian countries, areal extent, boundaries, climate, population.*
Hydrogeology	*Aquifer geometry, outcrop areas, subsurface extent, litho-stratigraphy, thickness, depth, recharge/discharge, flow regime, confined/unconfined, etc.*
Groundwater use and development	*timeline of development, areas and sector of use, abstraction, changes in storage, return flows, impact on quality, trends, demand issues, future supply plans, etc.*
Agreements and cooperation	*Agreements, existing cooperation mechanisms, timeline of cooperation, issues of conflict.*

2.3. Methodology and work process

The inventory is originally a desk study that gains added value through a comprehensive review and validation process. Information for the basin chapters is first collected and summarized from ESCWA reports, regional literature, scientific publications, country papers, media reports and other secondary literature. After an internal review, information in the basin chapters will be discussed, validated and/or reconciled with the experts from respective member countries. This consultation process is considered crucial to enhance ownership of the compilation process and stimulate discussion on shared water resources among member countries, concerned expert circles and academia.

3. SHARED AQUIFERS / AQUIFER SYSTEMS IN WESTERN ASIA

3.1. Delineation of groundwater provinces

The sedimentary provinces containing the main aquifers across Western Asia are controlled by the major geological structures of the Arabian Plate, including those that are still actively developing in its northern and north-eastern edges where the Arabian Plate is subducting beneath the Turkish (Anatolian) and Iranian plates. For the purpose of this paper, four different *groundwater provinces* with shared aquifers / aquifer systems are differentiated within the sedimentary provinces: A mega-basin spreading across the main Arabian Plate with extensive regional aquifer systems (the *Arabian Peninsula Groundwater Province*) and three smaller basins along the northern periphery of the Plate with localized (the *Euphrates-Tigris Groundwater Province*) and complex aquifer systems (the *Mashrek-Sinai Groundwater Province* and the *Taurus-Zagros Groundwater Province*).

Table 2 - Groundwater Provinces in Western Asia region as defined in this paper

Arabian Peninsula *Groundwater Province*	This mega-basin extends across the Peninsula from the Indian Ocean to the Jordan Uplift, the Palmyride Mountains, and Rutba Highs along the northern Arabian Plate. The existence of structurally-positive land masses along the Red Sea and the Gulf of Aden rifts (Basement Massifs), which have been amazingly stable since Precambrian time (Powers et al., 1966), and the extension of a 400 km-wide gentle plain along their periphery (Interior Homocline) provided the perfect setting for the deposition of extensive sedimentary strata from the Paleozoic to the Neogene eras. These strata extend from Saudi Arabia to neighboring countries along its boundaries to the north, east and south across some of the most arid desert areas in the world: the *Rub' al Khali* in the south and southeast, and the *Nafud-Hamad* in the north.
Mashrek-Sinai *Groundwater Province*	Comprises the region between the Levant (Dead Sea) rift and the Mediterranean sea, which constitutes a subplate (Sinai Peninsula-Levant subplate) sandwiched between the Arabian and Nubian plates (Mahmoud et al., 2005). The northern part (Mashrak) is characterized by high precipitation falling on extremely well exposed karstic carbonate rocks of Early Jurassic to Late Cenozoic (Walley, 1998), extending mainly along the boundaries of Lebanon with neighboring countries to constitute shared aquifers in several zones. Many springs issue from these rocks, which rise up to about 3 000 meters in Lebanon to sustain important river systems, some of which flow across political boundaries. The southern (Sinai) part is a much more arid land through which important groundwater systems flow across political boundaries to the Mediterranean Sea.
Euphrates-Tigris *Groundwater Province*	Essentially comprises the Mesopotamian Foreland Basin extending across the Euphrates-Tigris Rivers, and is bounded by two major faults (Euphrates Boundary Fault and Kirkuk Fault) that belong to the Najd Fault System. It is characterized by Mio-Pliocene formations overlain by Quaternary fluvial sediments, which extend from the Euphrates-Tigris alluvial plains to the foothill areas further north.
Taurus-Zagros *Groundwater Province*	Lies within the High Folded and Suture Zones and follows the Iraq frontier with turkey in the north and with Iran in the northeast. It comprises elevated areas built by karstified Tertiary and older carbonates with many springs discharging good-quality water, and younger clastics which form isolated to semi-isolated aquifer systems (Krasny et al., 2006).

3.2. Categorization of shared aquifers / aquifer systems

From the management point of view, and for the purpose of this paper, the aquifer systems can be categorized on the basis of:

(1) Whether or not they receive significant[3] recharge,

[3] In this paper, we consider recharge to be significant if it is observed in rising groundwater levels and insignificant if it is deduced from isotopic signatures only.

- *Renewable:* Localized and/or complex aquifers / aquifer systems receiving significant present-day recharge, i.e. those that may not be vulnerable to mining if used wisely,
- *Non-renewable:* Regional aquifers / aquifer systems receiving no significant present-day recharge, i.e. those that are vulnerable to mining regardless of how they are used;

(2) How water is retained within them (i.e. in inter-granular spaces, or in fissures, or a combination of both),

- *Porous:* Aquifer systems dominated by primary voids (pores); these are mainly alluvial sediments along river/wadi channels and foothill areas,
- *Fractured/karstic:* Aquifer systems dominated by secondary fractures and karstic features; these are mainly carbonate rocks occurring in mountain areas along the northern zone,
- *Mixed:* Aquifer systems of mixed pores and fissures; different types of rocks occurring in relatively unstable areas in which sedimentation is interrupted by magmatic activities and/or volcanic events, and

(3) The groundwater province in which they develop (see Section 3.1. above).

Applying these criteria, twenty one shared aquifers / aquifer systems are identified in the Region as shown in Table 3.

Table 3: Shared aquifers / aquifer systems occuring in the Western Asia region

Groundwater Province		**Mode of occurrence**		
		Porous	Fractured /karstic	Mixed
Arabian Peninsula	renewable	▪ Wadi Sirhan ▪ Al Hasa-AlDahira ▪ Asir-Nejran		
	non-renewable	▪ Sakaka-Rutba ▪ Mahra-Tawila/ Cretaceous Sands ▪ Biyadh-Wasia ▪ Saq-Ram ▪ Wajid	*Umm er Radhuma-Dammam:* ▪ Dibdiba ▪ Gulf ▪ Rub' al Khali-Nejd-Hadhramaut	▪ Central Hamad
Mashrek-Sinai	renewable	▪ Coastal Aquifer Basin	▪ Anti Lebanon ▪ Western Mountain Aquifer ▪ Western Galilee Basin	▪ Jebel Al Arab (Basalt aquifer)
Euphrates-Tigris	renewable	▪ Bai Hassan	▪ Jazira Tertiary Limestone	▪ Fatha/Injana (prev. L./U. Fars)
Taurus-Zagros	renewable		▪ Bekhme-Pila Spi	
Number of systems		5 renewable, 5 non-renewable	5 renewable, 3 non-renewable	3 renewable

3.3. Major constraints

A number of problems were encountered during the compilation of data/information and the literature review. Further issues emerged during the delineation and mapping of the aquifer systems. Important constraints include the following:

Limited accessibility of information: Most data/information relevant to understanding shared aquifers / aquifer systems in the region is either outdated, and in many cases obsolete, or in government files that are not accessible to the public and international organizations. Most ESCWA member states continue to update their knowledge on shared aquifers / aquifer systems without sharing it, sometimes even not among national organizations.

Data discrepancies: Since available data/information was not collected through coordinated efforts or comparable methodologies, there are often discrepancies that hinder the integration of information and interpretation beyond political boundaries. For example, recharge to the Wajid aquifer system inside Saudi Arabia was estimated at 114 MCM (British Arabian Advisory Company, 1980), 240 MCM (Ministry of Agriculture and Water, 1984), and 500 MCM (Prince Sultan Research Center for Environment, 2007). In contrast, estimates inside Yemen were 7.2 MCM (DHV, 1993), 10 MCM (Van der Gun, 1983) and 17.7 (Al Shami and Al-Dubby, 2004). As it is not known how the recharge intake areas were delineated in these different studies, and since recharge is not translated into a rate value per area unit, it s extremely difficult to reconcile the results reported in these studies.

Geographical basin VS geological formation: Shared aquifers / aquifer systems are often defined by geological formations that extend beyond geographical basins, and it is not usually known whether or not the aquifer units are hydraulically connected across such basins. This creates some discrepancy in terminology such that some studies refer to a groundwater basin[4]; others describe a specific aquifer unit as a shared aquifer. For example, ACSAD (1983) treated the Hamad plateau as one basin extending across the boundaries of four countries (Iraq, Jordan, Saudi Arabia, and Syria) although there are 6 hydrogeological regions within the plateau that constitute separate basins not extending to all the countries. In contrast, Al-Jawad et al. (2008) described individual Cretaceous formations along the south-western desert of Iraq as shared aquifers extending into Saudi Arabia.

Defining "effective" shared aquifers / aquifer systems in extensive sedimentary basins: Many non-renewable aquifer systems in the Arabian Peninsula Groundwater Province extend over thousands of kilometres inside one country before crossing its border into one or more neighbouring countries. Do we consider the entire system as shared or delineate 'effective' zone(s) within the system and, if so, how? What would this imply in terms of assessing the use (or right of use) of the different riparians and its impact on the resource? In some cases, an aquifer system is found to be too deep or too saline on one side of the political borders, which limits its present use by one or more riparian countries. Can it still be considered a shared system even if it is not really an 'effective' one?

Delineation of "individual" shared aquifers / aquifer systems in localized complex sedimentary basins: In localized basins, particularly those in folded and faulted zones such as the Anti Lebanon or the Taurus-Zagros, there are usually numerous small aquifers that exist as individual units within a political boundary in some areas, while merging with others in other areas to constitute a shared aquifer system. It becomes too difficult to delineate zones where these units act as aquifer systems and where they don't, or to define the boundaries between such systems.

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[4] A groundwater basin is defined as *"physiographic unit containing one large or several connected or interrelated aquifers, whose waters are flowing to a common outlet, and which is delimited by a groundwater divide"* (UN-ESCWA and BGR, 2009)

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The ISARM/South Eastern Europe (SEE) Programme:
Sharing Data and Information

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ABSTRACT

Approximately 90% of the territory in South Eastern European (SEE) countries lies within shared water basins and therefore the effective management of transboundary waters is of particular importance for the region. Transboundary aquifer resources are also vital sources of freshwater. 65 Transboundary Aquifers (TA) were identified in the region in an inventory developed in 2007 by the UNESCO Chair and International Network of Water/Environment Centres for the Balkans (www.inweb.gr) at the Aristotle University of Thessaloniki, in cooperation with UNESCO/IHP, as part of the UNESCO/ISARM worldwide initiative. TA in SEE, and especially those which are karstic, are highly vulnerable to pollution from different pressure factors (agriculture, industry, mining, sewage/waste disposal and tourism). In this paper, the WEB-based metadata inventory on transboundary aquifers in SEE (the Balkans) is described. This inventory is the first step towards implementing the UNESCO/ISARM (Internationally Shared Aquifer Resources Management) programme in the region. This programme uses a multidisciplinary methodological approach and is based on an effective cooperation mechanism between countries in order to reduce groundwater and ecosystem vulnerabilities and contribute to sustainable management of transboundary groundwater resources in the SEE region. Together with the Global Environmental Facility (GEF) and other partners the cooperative project DiKTAS (Dinaric Karst Transboundary Aquifer System) was formulated specifically for the Dinaric region. The project preparation phase was completed in December 2009, and the FSP (Full Size Project) is expected to effectively start in 2010.

Key words: transboundary aquifers, inventory, databases, South Eastern Europe.

1. INTRODUCTION

The existing inventory and database of internationally shared aquifers in the Balkans has been developed in two successive steps:

(1) Following the UNESCO-ISARM global initiative coordinated by UNESCO IHP, Paris, the first inventory on transboundary aquifers in SEE was prepared by INWEB and presented at the UNESCO/ISARM consultative workshop organised in Thessaloniki, Greece, in October 2004 entitled «Key Issues for Sustainable Management of Transboundary Aquifers in the Mediterranean and in South Eastern Europe (SEE) », Thessaloniki, 21-23 October 2004. In total, this assessment identified 47 transboundary aquifers but there was no clear distinction made between karst and porous aquifer types. Also the hydrogeological boundaries of all these aquifers were not determined and the location of the aquifers was just indicated using circles or ellipses. As part of the conclusions of the Thessaloniki meeting this first assessment identified priorities for future case studies, including the Dinaric karst, which was considered to be a particularly important case warranting coordinated further investigation.

(2) An improved version of the inventory resulted in cooperation with the United Nations Economic Commission for Europe (UNECE), Geneva in 2007 (INWEB, 2007). The main objective was to collect additional data with special reference to transboundary karst aquifers. This particular type of transboundary aquifer dominates South Eastern Europe (SEE) in terms of number, quantity and quality of water. Karst aquifer water resources are important not only for different human uses but also for sustaining the environment and maintaining biodiversity of ecosystems. The inventory was based largely on responses to a specially designed data collection questionnaire prepared by the UNECE/Groundwater Core Group and distributed in July 2006 to the national UNECE focal points. The information obtained was supplemented by existing information from the previous UNECE

inventory of transboundary groundwaters and from the one developed in 2004 by UNESCO/INWEB. The assessment methodology followed the DPSIR[1] framework (DIRECTIVE 2000/60/EC; DIRECTIVE 2006/118/EC; Ganoulis, 2009) to describe the pressures acting on the transboundary groundwaters resulting from human activities, the status in terms of both quantity and quality of the groundwaters, the impacts resulting from any deterioration in status, and the responses in terms of management measures that have already been introduced and applied, that need to be applied or that are currently planned. The results were presented and discussed during a regional meeting organised by UNESCO/INWEB in April 2007 in Thessaloniki entitled «Transboundary Groundwaters in South-Eastern Europe: Assessment and Future Perspectives», Thessaloniki, 23-24 April 2007.

Some transboundary groundwaters in the region had been identified and reported in earlier UNECE (1999) and INWEB (2007) inventories. However, the region of South Eastern Europe has seen major conflict and political change in the last fifteen years. Aquifers and groundwaters that for many years were located within a single country are now shared between new countries. Thus while the 1999 UNECE inventory recorded 23 transboundary aquifers in the region and INWEB reported 47 in 2004, the 2007 assessment identified 65 transboundary aquifers

The aim of the present version of the inventory was to improve the existing database in the Balkans using Google Map and Google Earth technologies, in order to make the Balkans inventory compatible with that developed in the MENA region. The new database on transboundary aquifers in the Balkans powered by Google Earth is now available on INWEB's website. The interactive map allows you to take a tour of 65 locations in different river basins in the Balkans, zoom into selected aquifer locations, and access information on aquifer properties, hydrology, hydrogeology, water uses and policy

This project also aims to provide support to a major ongoing regional GEF project called DiKTAS (Dinaric Karst Transboundary Aquifer System). The main objective of DiKTAS is to help countries establish a regional cooperation mechanism for integrated management of water and land resources. The fragmental distribution of karst aquifers across political boundaries and the differentiation between river basins and karst hydrogeological units mean that cooperation and mutual understanding are very important factors for sustainable development and environmental protection in the region.

2. OBJECTIVES AND METHODOLOGY

2.1. Geographic Scope

The Balkan Peninsula lies in South-East Europe, covers an area of around 520,000 km² and has about 45 million inhabitants (Fig.1). The "Balkan Region" is defined for the purpose of this study as the area south of the Sava River sub-basin (starting west of Ljubljana) and further downstream south of the Danube River, i.e. including the territories of Romania and the European part of Turkey. This means that the following 11 countries are involved:

- Slovenia (from the line Triest – Ljubljana eastward but south of the Sava River)
- Romania
- Croatia (the region south of the Sava River up to the Adriatic coast, but not the islands)
- Bosnia & Herzegovina (the region south of the Sava River up to the Adriatic coast)
- Serbia
- Montenegro
- Former Yugoslav Republic of Macedonia
- Albania
- Greece (only the mainland)
- Bulgaria
- Turkey (the European part of the country)

[1] DPSIR: Driving forces of environmental change (e.g. industrial production), Pressures on the environment (e.g. discharges of waste water), State of the environment (e.g. water quality in rivers and lakes), Impacts on population, economy, ecosystems (e.g. water unsuitable for drinking), Response of society (e.g. watershed protection).

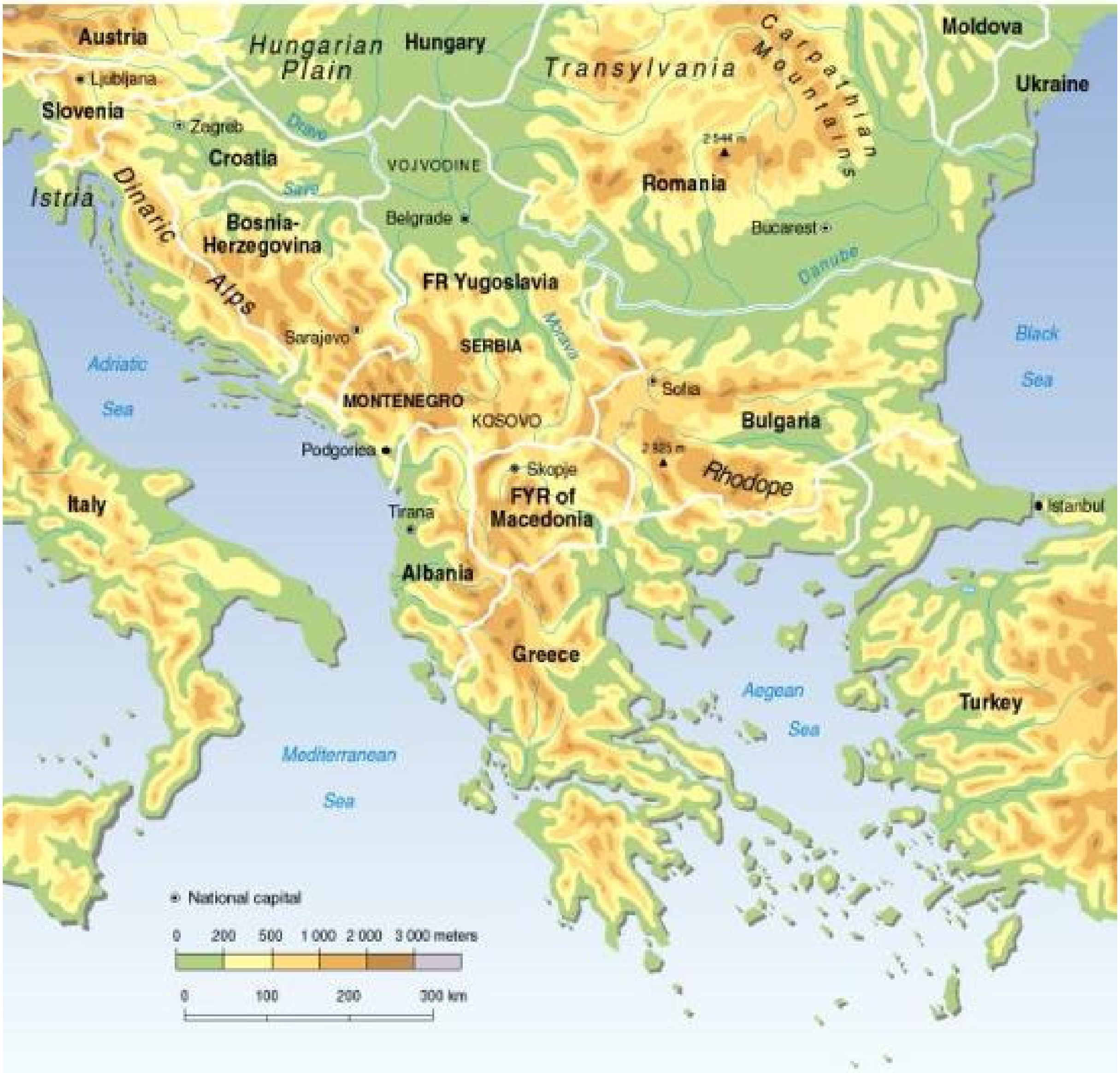

Figure 1. Topographical and political map of the Balkan region.

2.2. Methodology

The methodology of interactive maps, which can be dynamically changed, was used for the revised assessment. An interactive map may contain a single GIS dataset (e.g. satellite imagery, networks of rivers or roads or land cover) or a collection of several GIS datasets. Map services allow users to access GIS data directly over the web just like any other local data set. This makes the sharing of GIS data easier and much more flexible. Nowadays, map service technology has been dramatically improved by the development of Earth browsers such as Google Earth and Google Maps, which can make the presentation of interactive maps very attractive and user-friendly.

INWEB's interactive map for transboundary aquifers in SEE is a Google Map based application combined with GIS technology. By clicking on the arrows and symbols, this map allows users to pan (move) up/down/left/right and to zoom in/out on a political map of the Balkan region, which shows all transboundary aquifers marked with their approximate hydrogeological boundaries. The areas in green refer to karst aquifers, and those in indigo to alluvial/sedimentary aquifers (see Fig. 2).

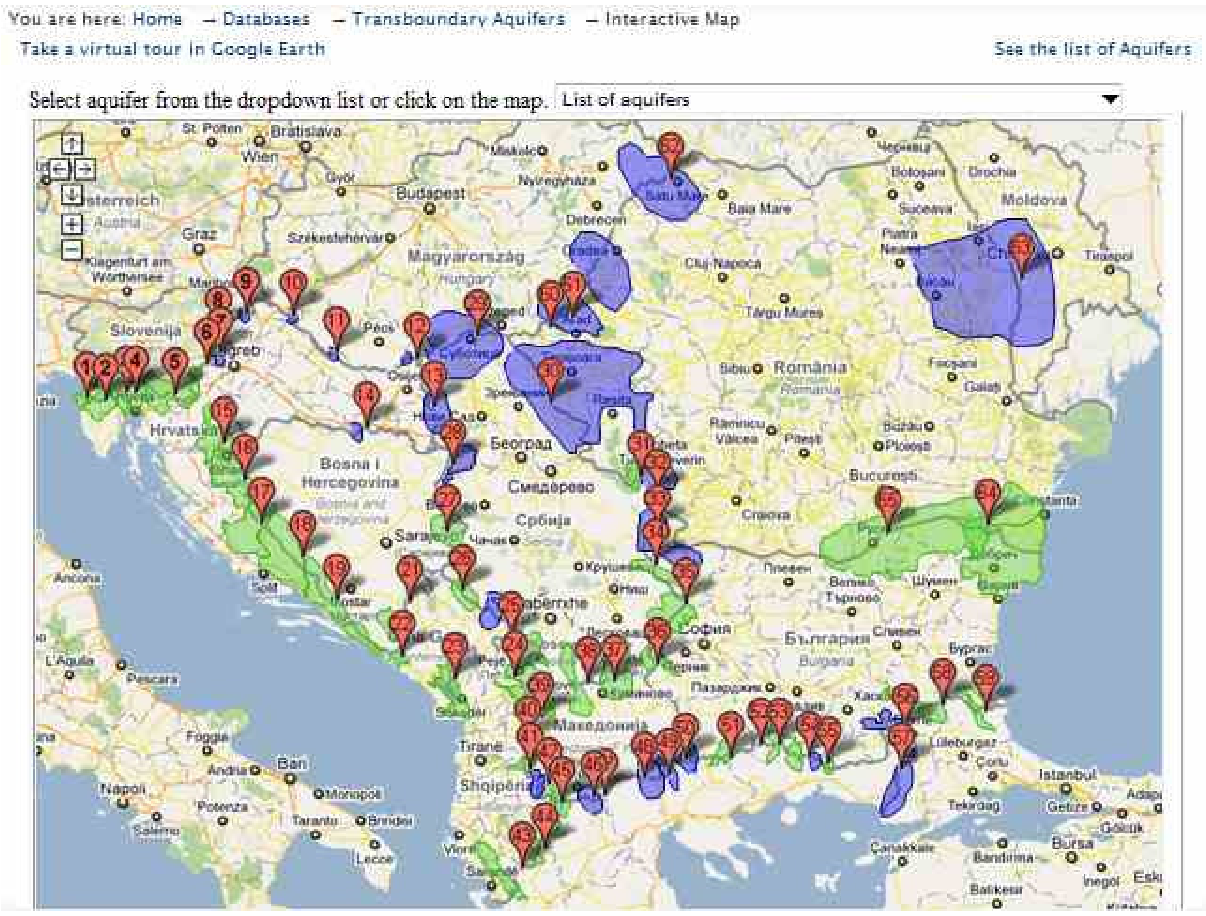

Figure 2. Interactive map of transboundary aquifers in SEE.

INWEB's interactive map offers users the following options:

Take a virtual tour in Google Earth:

This activates the «transboundary aquifers.kmz» which is a Google Earth KML file. KML files (a file format used to display geographic data in an Earth browser) use a tag-based structure with nested elements and attributes and are based on the XML standard. Google Earth then presents a tour of the 65 different transboundary aquifers in the Balkans. By clicking one of these aquifers Google Earth zooms in to the selected location.

See the list of Aquifers:

This opens the complete list of the 65 transboundary aquifers in SEE in a new window.

Select aquifer from the dropdown list or click on the map:

The map on the screen is a political map of the Balkans with all the transboundary aquifers marked with their approximate hydrogeological limits. Those in green refer to karst aquifers, and those in indigo to alluvial/sedimentary aquifers. The "tear drop" marker shows the reference number of each aquifer. There are two options to obtain further information on the aquifer:

- By clicking on the tear drop
- By selecting the aquifer name from the drop down list

Both these options open a balloon with the aquifer's name, the type of aquifer and the names of the countries to which the aquifer belongs and three interactive links as follows:

- Summary information (opens a new window with information on aquifer properties, hydrology, hydrogeology, water uses and policy)
- Descriptive information (open a new window with more information)
- See the aquifer in Google Earth (activates Google Earth and zooms in automatically to this aquifer). The user has the option either to open this KML file or to save it to disk, and then by clicking on the blue symbol next to the aquifer name can open a new window with information on aquifer properties, hydrology, hydrogeology, water uses and policy (as above).

3. TRANSBOUNDARY AQUIFERS CHARACTERISTICS

3.1. Groundwater Use

Transboundary groundwater resources play a significant role in the SEE region. The physical environment of the region – the geology, topography and major catchments – is such as to promote the occurrence of productive aquifers. These aquifers are of two distinctive main types – the limestones of the karstic type area of the Dinaric coast and its mountainous hinterland, and the thick alluvial sedimentary sequences of the Danube basin, mainly those associated with the Danube River itself and its tributaries. In some locations the alluvial sediments overlie and are in hydraulic contact with the limestones or comprise relatively thin aquifers in river or lake sediments overlying ancient metamorphic rocks.

The geographical distinction between the two main aquifer types and the fact that much of the national borders of several of the countries of the region are traversed by transboundary groundwaters can be clearly seen in the map in Fig. 2.

Transboundary karstic groundwater aquifers were reported to provide 60 to 80 per cent of total water usage in their respective areas, and for some of the Dinaric karstic aquifers of Bosnia, Serbia, Croatia, Montenegro and Albania this figure was as much as 90 or even 100 per cent.

Compared to surface waters, alluvial aquifers exhibit a greater range of use varying from only 15 per cent for some, and up to 70 per cent for the important Banat, Backa and Srem alluvial aquifers along the River Danube in Serbia, Croatia and Hungary.

3.2. Main pressures

The majority of transboundary aquifers, except for those located in remote, sparsely populated areas, are very vulnerable to anthropogenic pollutants emitted from both point and non-point sources. Karstic aquifers, with their lack of soil cover and rapid flow paths leaving little time for attenuation, are almost invariably classified as highly vulnerable. Alluvial aquifers are also likely to be considered as vulnerable, unless they contain a high proportion of clay-rich material to reduce their permeability, are overlain by a protective confining layer of clays and/or the water table is relatively deep. The transboundary groundwaters of the SEE region are likely, therefore, to be highly vulnerable to pollution if the pressure factors outlined below produce significant loadings of mobile and persistent pollutants.

In general, both alluvial and karstic aquifers have reported groundwater quality problems. Of the questionnaires received, only two specifically reported that there were no groundwater quality issues at all.

Agricultural activities provide some of the major pressures on freshwater systems in SEE in terms of both quantity and quality. Some 70% of overall water use is for agriculture and severe problems can result when this heavy usage depends on groundwater abstractions. Moreover, intensive cultivation, both with and without irrigation, uses heavy applications of fertilisers and pesticides. Intensive cultivation and animal production can produce increased levels of nutrients and pesticides in groundwaters, due to infiltrating surface run-off from agricultural land, leaching from the soil through the unsaturated zone and sometimes from return waters from irrigation channels.

Overall, industrial pressure factors for transboundary groundwaters in the region appear to be quite limited. Tourism and recreational activities, especially in summer, create a huge demand for drinking water and water for recreational activities.

4. CONCLUSIONS

The importance of shared groundwater resources in the Mediterranean and Balkan regions becomes most apparent when plans to combat water scarcity and to adapt to climate change are needed and when there is increased pressure for economic development and water related activities on either side of the border (Margat, 2004; MEDITERRANEAN GROUNDWATER REPORT, 2007). Transboundary groundwater protection plans and sustainable management of shared groundwater resources in the Balkan region should be based on strong cooperation between countries involved, and joint projects should be developed. Of primary importance are:

- development of common monitoring systems
- sharing of data
- establishment of multi-lateral and multi-disciplinary aquifer commissions
- development of common research projects with harmonised methodology

For karst transboundary aquifers, which are very important in the region, the main difficulties are related to the following:

- karst aquifers are heterogeneous with anisotropic surface and underground formations; and have well developed, complex, deep and unknown underground karst conduits, fissures, joints and cracks
- a strong interaction exists between the circulation of surface water and groundwater; and between inflow (ponors) and outflow (karst springs)
- there are significant and rapid variations in groundwater level
- the influence of man-made structures (e.g dams and reservoirs) and human activities.

Future case studies in the region, like DiKTAS should aim to:

- Develop regional groundwater governance in order to ensure effective management of transboundary groundwater resources, taking into account environmental risks associated with various water pollutants and risks from potential conflicts over sharing transboundary aquifer resources.

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Assessment of transboundary aquifers in the context of the second Assessment of transboundary waters in the United Nations Economic Commission for Europe

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ABSTRACT

The key goal of UNECE second Assessment of Transboundary Rivers, Lakes and Groundwaters, currently prepared under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention), is to facilitate informed decision-making on the management of shared water resources in Europe, Caucasus and Central Asia, provide the basis for continuous bilateral and multilateral cooperation under the Water Convention, and support all actors involved at the national, transboundary and regional levels. In the second Assessment, a holistic, integrated approach is applied, looking at both surface and groundwaters within each transboundary basin. Pressures on transboundary water resources are identified and their relative importance in the transboundary context evaluated. Legal, institutional and socioeconomic aspects are highlighted and cross-cutting themes that are a challenge for managing transboundary waters — such as predicted impacts of climate variability and change — are emphasized. The extent of transboundary cooperation (joint bodies, joint monitoring etc) currently in place and measures taken are also described. The assessment report will provide information on more than 140 transboundary rivers, more than 30 transboundary lakes and some 200 transboundary aquifers. The Assessment is prepared in close cooperation with national experts nominated by environment administrations of the participating countries. In this paper, the approach and some preliminary results of the second Assessment in South-Eastern Europe, Eastern and Northern Europe, and the Caucasus are described, with focus on transboundary aquifers.

Key words: transboundary waters, assessment, monitoring

1. INTRODUCTION

1.1. Objectives and scope

The key goal of the second Assessment of Transboundary Rivers, Lakes and Groundwaters, currently under preparation in the framework of the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention), is to keep the state of shared water resources in Europe, Caucasus and Central Asia under scrutiny, facilitate informed decision-making on their management, provide the basis for continuous bilateral and multilateral cooperation under the Water Convention, and support all actors involved at the national, transboundary and regional levels. High attention is being devoted to the countries with economies in transition which are facing the biggest challenges.

In this paper, the approach applied is described and some preliminary results of the second Assessment in South-Eastern Europe, Eastern and Northern Europe, and the Caucasus are reported on, with focus on transboundary aquifers. This groundwater part of the assessment is carried out in cooperation with UNESCO and the International Groundwater Resources Assessment Centre (IGRAC). IGRAC has a key role in describing the key physical characteristics of the transboundary aquifers and delineating them. A number of challenges that have emerged in the process of preparing this regional inventory are also highlighted in the article.

1.2. Background and mandate

The first Assessment (UNECE, 2007) – prepared in response to the decision of the third Meeting of the Parties to the Water Convention in 2003 – was presented to the sixth Ministerial Conference "Environment for Europe" (Belgrade, October 2007). At the request of the appreciative Ministerial Conference, a second edition is prepared for the next (Seventh) Ministerial Conference, which is to be held in September 2011 in Astana, Kazakhstan. Like the first one, the second Assessment covers the Eurasian part of the UNECE region[1].

For transboundary groundwaters, the second Assessment builds on earlier inventorying efforts such as the 1999 inventory of transboundary groundwaters in Europe by the UNECE Task Force on Monitoring and Assessment as well as UNESCO-supported work, by IGRAC in particular.

In accordance with the Water Convention, the riparian Parties shall, at regular intervals, carry out joint or coordinated assessments of the conditions of transboundary waters and the effectiveness of measures taken to prevent, control and reduce transboundary impact. To this end, UNECE has developed over the years a number of guidance documents on monitoring and assessment of transboundary waters (for example, UNECE, 2006), also specifically on transboundary aquifers (UNECE Task Force on Monitoring and Assessment, 2000).

2. APPROACH

In the second Assessment, a holistic, integrated approach is applied, looking at both surface and groundwaters within each transboundary basin. Pressures on transboundary water resources are identified and their relative importance in the transboundary context evaluated. Legal, institutional and socioeconomic aspects are highlighted and cross-cutting themes that are a challenge for managing transboundary waters - such as predicted impacts of climate variability and change — are emphasized. The extent of transboundary cooperation (joint bodies, joint monitoring etc) currently in place and measures taken are also described. The assessment report will provide information on more than 140 transboundary rivers, more than 30 transboundary lakes and some 200 transboundary aquifers. The Assessment is prepared in close cooperation with national experts nominated by environment, water and hydrometeorological administrations of the all countries in the UNECE region. The International Water Assessment Center, the Water Convention collaborative center, plays a crucial role in the assessment preparations. Moreover, cooperation is also established with a number of international organizations including UNEP, UNESCO, Global Water Partnership Mediterranean, Regional Environment Centres etc.

The Assessment is carried out using a questionnaire and the filling out of the information concerning each riparian country's share of the basin or aquifer is coordinated by the nominated national focal points based on official data from the countries. As a parallel and complementary means of information collection, sub-regional workshops on transboundary management of water resources are organized, where the representatives of riparian countries have an opportunity to work together to develop an accurate picture of all transboundary waters in the sub-region. The workshops provide a forum for government officials, as well as representatives of non-governmental organizations to discuss pressing themes in each particular sub-region, allowing differences between them to be reflected in the assessment.

The methodology for the assessment of groundwaters broadly follows the Driving Forces-Pressures-State-Impact-Responses (DPSIR) framework adopted by the European Environment Agency (UNECE, 2006) to describe i) the pressures resulting from human activities, ii) the status in terms of

[1] UNECE has 56 Member States located in the European Union, non-EU Western and Eastern Europe, South-East Europe and Commonwealth of Independent States (CIS) and North America. A full list is available at http://www.unece.org/oes/nutshell/member_States_representatives.htm

both quantity and quality of groundwaters, iii) the impacts resulting from any deterioration in status and iv) management measures (i.e. responses) that have already been introduced, need to be applied, or are currently planned.

The information collected about groundwater includes physical characteristics of the transboundary aquifers (extent, thickness, lithology etc), delineations, main uses and functions, main pressures on groundwater quantity and quality, and predicted impacts of climate change. For consistent information collection by the questionnaire, transboundary groundwaters were classified according to general conceptual models describing the flow regime and the transboundary relationship between the countries sharing the aquifer.

3. PRELIMINARY RESULTS

In South-Eastern Europe[2], according to the information reported by the countries, groundwater is mainly used for drinking water, but there is some use for agriculture and industry also. Agriculture together with sewage and waste disposal is the most important pressure factor acting on groundwater resulting from human activities. Groundwater abstraction, industry and solid waste disposal are other significant pressure factors affecting groundwater, and mining or gravel extraction and tourism are also significant in the case of some transboundary aquifers.

In the Caucasus[3], the main pressure impacting on groundwater resources is sewerage and waste disposal, followed by agriculture and solid waste disposal. Mining is a notable pressure factor only in the case of some individual aquifers.

In general, transboundary cooperation related to groundwater is at a low level in the region, but there are good examples of cooperation, one being between France and Switzerland on the Geneva aquifer. In the Danube and Rhine basins, identifications of transboundary aquifers have been carried out in the framework of river basin commissions. Many bilateral and multilateral agreements on transboundary waters between or with participation of countries in the Eastern Europe, Caucasus and Central Asia region do not explicitly refer to groundwater, but there are also many that mention groundwater in their scope but their application to groundwater remains very low. It is a constraint to assessing the status of transboundary aquifers in many part of the region that recent groundwater monitoring data is very scarce or in some cases no monitoring activities are currently performed. This limits identifying appropriate management responses, and groundwater being covered by different legislation from surface waters for historical reasons in many countries of the former Soviet Union does not support integration. Cooperation between riparian countries in monitoring and assessment may provide an starting point for cooperation, and therefore joint characterization of groundwater bodies according to the requirements of European Union's Water Framework Directive (WFD) is encouraging, even if there are relatively few cases (for example, Austria and Slovenia characterized jointly the Karstwasser-Vorkommen Karawanken/Karavanke aquifer).

The principle of integrated management of surface and groundwater is missing in water laws in a number of countries of the former Soviet Union assessed so far. Monitoring groundwater resources in general is in the region commonly not part of the responsibilities of environmental authorities. Due to historical developments of the legislation (Soviet Union's water code as the basis), groundwater is treated separately, similarly to mineral resources.

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[2] Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Hungary, Montenegro, Romania, Serbia, Slovenia, the former Yugoslav Republic of Macedonia and Turkey.
[3] The countries covered by this sub-regional assessment are Armenia, Azerbaijan, Georgia, the Islamic Republic of Iran, the Russian Federation and Turkey.

4. DISCUSSION: CHALLENGES

The outer border of the European Union represents a certain divide in the approach to assessment, concepts and regulatory obligations. Within EU, the member states are obliged to transpose the EU legislation, including the WFD, which has harmonized approaches.

In the EU, the WFD requires characterization of groundwater bodies. Nevertheless, at least from the parts assessed to far, it appears that also in the EU joint characterization of transboundary groundwater bodies remains limited. The knowledge in general about the location and extent of transboundary aquifers is limited. In some cases this seems to be influenced by local and limited use of groundwater resources and consequently low awareness or possibly perception of insignificant transboundary influence. In other cases, the provision of information provided by the countries is limited to aquifers the transboundary nature of which has been formally agreed upon between the sharing countries. The quality and detail of the information provided for the second Assessment depends also on the organization of water resources management in each country and the extent to which administration responsible for groundwater is involved in providing input to the Assessment.

From a technical point of view, the assessment of "invisible" groundwater is more complex than the assessment of the surface watercourses. While the presence and extent of surface water is usually a given fact, in the case of groundwater it is one of the main issues to be agreed upon between riparian countries.

A complete harmonisation of information is difficult to achieve because of differences in the scope and level of detail of assessment, its purpose or the assessment methodology used. For instance, the most recent information collected in many countries of South-Eastern and Eastern Europe is about transboundary groundwater bodies[4] (and not transboundary aquifers). Guidelines for definition of groundwater bodies are not unambiguous, which has led to somewhat different interpretations. Therefore, harmonization between transboundary groundwater bodies (as management units) and aquifers (as hydrogeological units) is not always easy.

In the second Assessment, the initial information on presence and extent of transboundary aquifers is collected from various sources (usually previous inquires and assessments) and harmonized, prior to sending it to countries that share the aquifer. Figure 1 shows a working map of transboundary aquifers in South-Eastern Europe. Various shadings are used to indicate aquifers the presence and extent of which need to be discussed and agreed upon by the aquifer countries. The working maps of this kind are used in the second Assessment in the face-to-face sub-regional workshops to assist the countries sharing the aquifers countries to reach agreements. Country representatives are encouraged to provide additional material for discussion. The response from the countries varies substantially.

[4] Groundwater body is defined as ''a distinct volume of groundwater within an aquifer or aquifers'' in the Water Framework Directive.

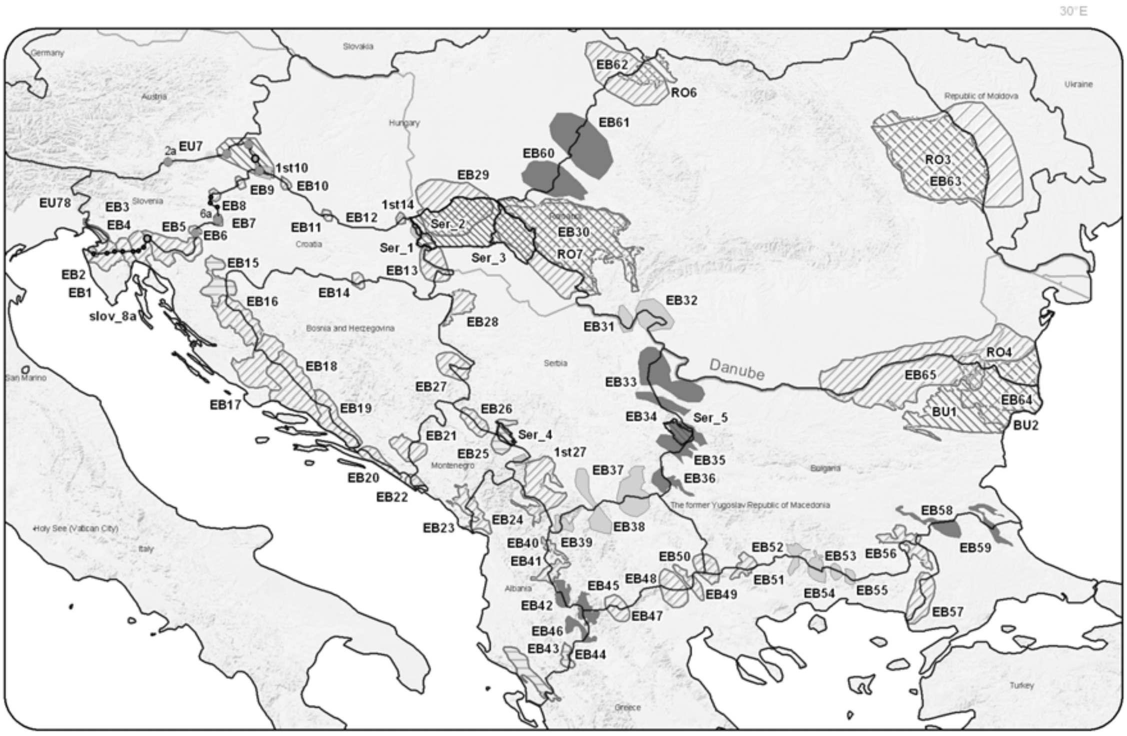

Figure 1. Transboundary aquifers in the South-Eastern Europe (a working map)

Due to these challenges, not the same level of information is systematically available. The information from different sides of the border can be asymmetrical. Socio-economic and for example population data are not commonly available at aquifer level. The remaining gaps indicate where additional information collection effort is needed.

Even if the limits of mandates of organizations as such can affect the effectiveness of data collection in such a regional assessment, the cost of data between them at the national level has emerged as a potential additional constraint.

The effort to discuss surface and groundwater in an integrated way in the assessment workshops was not initially fully successful: because of the prominence of surface water related issues, groundwater received less attention in general discussions. Therefore, some opportunity in the process has been reserved for groundwater experts to exchange bilaterally to refine the aquifer information before reporting it to the wider body of experts involved for a more holistic basin-level overview.

In some of the areas assessed so far, the transboundary aquifers are strongly linked to surface waters and therefore already for delineating the aquifers it is important to look at the river network and groundwater information jointly. This is the case for example in Eastern Europe, where a number of transboundary aquifers consisting of alluvium deposits of transboundary rivers were identified. The contribution of groundwater to the flow in a number of transboundary rivers is mentioned in several country reports. Also because of the interaction between surface water and a number of transboundary aquifers, surface water quality and quantity have important implications to the groundwater situation.

One of the aims of the Assessment is to identify situations where support is needed for extending cooperation. UNECE experience has demonstrated that technical cooperation on projects can pave the way for expansion into more institutional domain. UNECE strategy is to seek partners for the mobilization of necessary resources to support the riparian countries in their common efforts.

5. CONCLUSIONS AND THE WAY AHEAD

There is a pressing need for harmonizing approaches to characterizing and assessing the status of transboundary aquifers across the region. Regional assessment processes like UNECE's second Assessment can contribute to information exchange and discussion among the representatives of countries to develop a common understanding of the quantity and quality status of transboundary aquifers and the main pressure factors potentially affecting them.

The provisions of the UNECE Water Convention have been used as basis or inspiration in preparing most of the bilateral agreements on transboundary waters in the region. The Water Convention applies to all transboundary waters — surface waters and groundwaters alike. The Legal Board of the Water Convention is in the process of looking in detail into how the Convention applies to groundwater.

There is a need to establish transboundary mechanisms (e.g. joint bodies) for improved cooperation and data exchange. Where joint bodies on transboundary waters exist, expansion of activities to groundwater is recommendable. These structures facilitate cooperation, opening perspectives for seeing beyond the national (ground)water demands. River basins commissions such as International Commission for the Protection of the Danube River and the International Sava River Basin Commission have recently inventoried or are presently in the process of inventorying transboundary groundwater bodies, respectively. Capacity-building focused on transboundary groundwater resources, especially for more scarcely-resourced regional or transboundary institutions would help raising awareness at transboundary level.

Attention needs to be devoted to land-use planning and the joint management of surface and groundwater. This is particularly pressing in the countries where monitoring and management of surface and groundwaters fall into the mandates of different organizations. There is a need for policy and institutional reforms that support integration.

Upgrading of the existing infrastructure for monitoring and assessment of transboundary groundwaters and building the capacity in the countries' administrations is sorely needed. The second Assessment is making a valuable contribution to this end by identification and drawing attention to the management issues and cases related to (possible) disagreements and disputes about the use of transboundary water resources or where there are transboundary impacts on them. On the basis of this information, relevant transboundary interventions can be planned. UNECE is encouraging preparation of pilot projects for monitoring and assessment of transboundary groundwaters and engagement of development partners to support the countries in improving management of transboundary waters, including groundwater.

At the end of 2010 and at the beginning of 2011, transboundary aquifers in Central Asia and Western Europe, respectively, will be inventoried in the framework of the second assessment.

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TOPIC 1
Global overview of transboundary aquifer systems

Transboundary Aquifers of Azerbaijan: Current Conditions, Challenges and Mitigation Possibilities

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ABSTRACT

This study aims to describe current status of transboundary groundwaters in Azerbaijan. Fourteen out of eighteen aquifers in the territory of Azerbaijan Republic are transboundary. Majority of surface water courses and part of groundwaters from Georgia and Armenia have natural tendency to flow towards the territory of Azerbaijan.

Average annual rates of surface run-off and potential groundwater sources are approx. 31-32 billion m^3 and 9 billion m^3, respectively.

In mountainous areas, groundwater is basically found in the areas of weathering and tectonic faults. Piedmont and intermountain troughs are much richer in fresh and low-mineralised groundwater. The lowlands of the Republic typified for unfavourable hydrogeological conditions.

No serious and critical problems exist between Azerbaijan and the neighboring countries in respect of the use of transboundary groundwaters. The main problem is that the rivers Kura and Araz (with their tributaries), as the most significant recharge sources of groundwater, are heavily contaminated in the territory of Georgia and Armenia i.e. the wastewater from industrial and domestic sources as well as irrigation waters containing chemical infiltrates are discharged into the rivers almost without any treatment. These rivers and their tributaries are used for disposal of irrigation waters contaminated with. Even in the territory of Azerbaijan, such contamination is enhanced by discharge of various contaminants. Local contamination of transboundary groundwater is also a matter of concern.

The authors propose several mitigation measures including but not limited to independent monitoring of river and groundwater sources under supervision and direction of international organizations, such as UNESCO, IAH, IAHS etc; comprehensive study of the conditions of recharge, chemical and biological content of groundwater sources, considered as vulnerable due to the impact of contaminated rivers; preparing an action plan for restriction contamination process; developing a scheme for integrated use of water resources in aquifers; ensuring compliance with Helsinki Convention 1992 by OSCE member-countries; technical modernization of water treatment plants and avoidance of disposal of untreated wastewater into the rivers; constructing drainage facilities and well as plants for entrapment and neutralization of infiltrates in heavily contaminated irrigation waters.

Keywords*:* aquifer, groundwater contamination, piesometric levels, mitigation.

1. INTRODUCTION

Located in the South Caucasus, the territory of Azerbaijan plays a role of transit land for surface and ground water flowing from the Mountain Ranges of the Greater Caucasus and the Lesser Caucasus down to the Caspian Sea. Groundwater resources are limited and unevenly distributed across the country. Main stock of groundwater is cumulated in piedmont sedimentary troughs. Significant parts of rural settlements situated downstream of the main transboundary rivers of Azerbaijan, Kura and Araz, meet their minimum water supply needs using untreated water from rivers, irrigation canals and even drain lines. The Kura River is one of the three existing water supply sources of Baku. In the territories of Georgia and Armenia, the Kura and Araz rivers are exposed to heavy contamination, which in turn impacts groundwater sources. It is necessary to prevent contamination of surface and ground water resources in the catchment areas of the Kura and Araz rivers, and to achieve integrated use of water resources in river basins.

2. OBJECTIVE

The purpose of this study is to disclose problems related to transboundary groundwater sources of Azerbaijan outlining the current conditions of existing aquifer systems, the quality of groundwater and the status of their contamination. Comprehensive study of the current status of transboundary groundwater sources encouraged the authors to propose a number of mitigating solutions.

3. CURRENT STATE OF TRANSBOUNDARY GROUNDWATER RESOURCES

From geological-structural point of view, the territory of Azerbaijan Republic is represented by the Greater Caucasus (Fig.1 – A), the Lesser Caucasus (Fig.1 – B) Mountain Ranges and the Kura-Araz Lowland (Fig.1 – C) lying between these two mountain ranges. Altogether there are 18 hydrogeological basins, of which 14 have immediate borders with neighbouring countries (Fig.1):

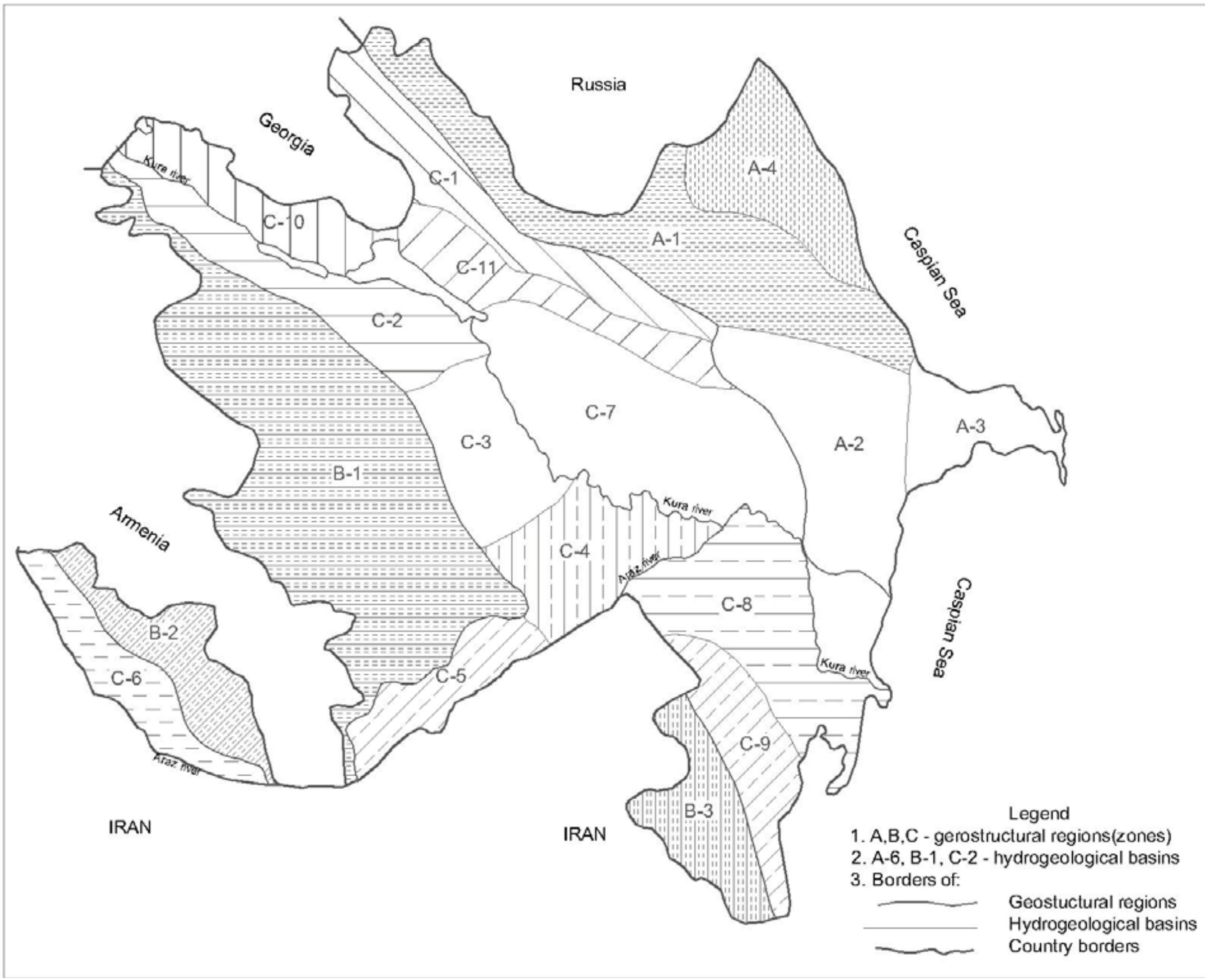

Figure 1. Structural-hydrogeological zoning scheme of Azerbaijan

With Georgia - Gyanja-Gazakh (Fig.1: C-2), Alazan-Eyrichay (Fig.1: C-2), Jeiranchel (Fig.1: C-10), Ajinour porous-stratal water basins (Fig.1: C-11) and partly the Greater Caucasus porous-fractured water basin (Fig.1: A-1);

With Armenia – Nakhchivan porous-stratal water basin (Fig.1: C-6), the Lesser Caucasus porous-stratal water basin (Fig.1: B-1) and Nakhchivan porous-fractured water basins (Fig.1: B-2);

With Iran – Nakhchivan (Fig.1: C-6), Jabrail (Fig.1: C-5), Mil (Fig.1: C-4), Mugan-Salyan (Fig.1: C-8), and partly Lenkoran porous-stratal water basins (Fig.1: C-9); porous- stratal water basins of the Lesser Caucasus (Fig.1: B-1) and porous-fractured water basins of *Mountainous Talysh* (Fig.1: B-3).

With Russia – the Greater Caucasus porous-fractured water basin (Fig.1: A-1) and Samur-Gusarchay porous-stratal water basin (Fig.1: A-4).

Due to downstream position of Azerbaijan's territory, huge volumes of surface water and part of groundwater from Georgia and Armenia have natural tendency to flow towards the territory of Azerbaijan. The territory of Azerbaijan plays a role of transit country for flow of surface waters and groundwaters from the Greater and the Lesser Caucasus Mountains into the Caspian Sea.

3.1. Aquifer systems

The mountain structures of the Greater Caucasus and the Lesser Caucasus are composed of Meso-Kainozoic and Palaeo-Kainozoic rock formations, respectively. Thick weathered, fractured rock formations and intermountain troughs with soil content of alluvial and fluvioglacial sediments are specific features of both mountain ranges. A distinguishing geological feature of the Azerbaijani part of the Greater Caucasus is higher prevalence of sedimentary deposits. The layers composed of fractured and Karstic formations are much richer in water reserves, whereas volcanogenic and intrusive rock formations have lower water content. Natural groundwater discharge locations / springs with approximate yields of 5-10 l/s are seen at the foothills. The springs with flow rates of 60-100 l/s are encountered mostly in the areas with karstic limestone rocks (Alekperov et al., 2008).Confined and unconfined aquifers have been penetrated by exploratory wells with depths varying from 40-50 to 200-250 m. (Table 1).

Table 1. Several hydrogeological parameters of aquifers

Geoogical-structural region	Surveyed depth, m	Aquifer	Groundwater level relative to ground surface, m	Flow rate, l/s	Permeability of water bearing strata, m/day
Mountainous Zone of the Greater Caucasus	200-250	unconfined	0,5-57	0,8-5,5	0,01 - 14,2
		confined	+14-8	0,8 - 10	0,01 - 22
Mountainous Zone of the Lesser Caucasus	200-250	unconfined	0,1-89	0,1-4,2	0,01 - 9,1
		confined	+12- 55	0,8 – 12	0,01 - 25
Kura-Araz Lowland	350-400	unconfined	0,2-150	0.06-57	0,006 -150
		confined	+50-81	0,01-98	0,01 - 246

Piedmont and intermountain troughs (Fig.1 –C) forming the Kura-Araz lowland are considered to be basins of porous-stratal waters and are rich in fresh and low-mineralized (up to 3 g/L) groundwater. They are formed by confluent fans of alluvial and alluvial-dealluvial sediments. Effective thickness of such sedimentary layers reaches 300-500 m, and seldom 1000-1500 m (Listengarten, 1987). All of these basins contain one unconfined and several confined aquifers. Occurrence depth of non-artesian aquifers varies from 60-80 meters at foothill parts of alluvial fans down to several centimeters at discharge zones. Confined aquifers lie further downstream of the contact zone of parent rocks and alluvial sediments. Top of confined aquifer can be penetrated at depths varying from 10-20 m up to 110-300 m. Yields of springs are generally high (Table 1.), roughly varying from 0,1-0,3 up to15-20 l/s, and rarely reaching 200-250 l/s (Alekperov et al., 2008).

Scanty groundwater sources within the boundaries of Jeiranchel and Ajinohur basins are associated with local confined structures. Hydrogeological conditions of the lowlands composed of continental marine sediments are unfavourable.

3.2. Water resources

Average annual volume of surface water resources of Azerbaijan is estimated to be approximately 31-32 billion cubic meters, over 70% of which is formed beyond the country borders. Average annual volume of potentially usable fresh and low-mineralized groundwater in Azerbaijan is approx. 24 mln m^3/day. Contribution by transboundary basins is approximately 80 percent. Significant recharge sources of transboundary groundwater resources are located within the borders of the country.

Annual groundwater production till 1980s and between 1980 -1990 was 2.5-2.9 bln m^3 and 1.3-1.5 bln m^3, respectively. Over recent years, however, annual groundwater production has increased again up to 3,0-3,5 billion cubic meters.

3.3. Groundwater quality

Groundwater in the mountainous zones is of drinking quality with calcium-hydrocarbonate content. Fresh and low-mineralized waters are widely spread in *piedmont troughs* depending on specific features of their geological structure, inflow rate, and the discharge conditions of the aquifers. In the lowlands, however, fresh waters are shifted by saline waters. Groundwater resources within Alazan-Eyrcihay and Samur-Gusarchay plains are of good quality. Fresh waters seldom occur in Jeiranchel and Ajinour plains, while saline waters with higher TDS content (50-70 g/l) are rather extensive. Groundwater in the lowlands is much saltier. TDS content varies between 100-200 g/l (Alekperov et al., 2008).

4. MANAGEMENT AND MONITORING OF GROUNDWATER RESOURCES

All water structures (e.g. rivers, aquifers etc.) in the territory of Azerbaijan are owned by the State. All legal and natural entities have the right to consume groundwater. The organizations involved in management of water resources are *Azersu* Joint Stock Company (JSC), which supplies water for drinking and other household purposes and *Melioration and Water Industry* JSC, which is in charge water supply for agricultural purposes. The Ministry of Ecology and Natural Resources carries out groundwater investigation, monitoring and coordinates arrangements associated with groundwater use.

Groundwater monitoring system has been valid since 1940s and 1950s. The monitoring system, composed of 900 Nos boreholes, draw wells, kahrizes (horizontal tapping) covers all hydrogeological regions incorporated in piedmont troughs and lowlands. Due to land reforms some of the monitoring sites happened to be parts of private lands and this lead to problems associated with maintenance and monitoring. Many observation wells have collapsed and become unfit for further investigation purposes.

5. PROBLEMS

There are no serious and critical problems between Azerbaijan and the neighboring countries in respect of the use of transboundary groundwaters. The major problem, however, is that the rivers Kura and Araz (with their tributaries), being the most significant recharge sources of groundwater, are heavily contaminated in the territory of Georgia and Armenia.

In the territory of Georgia every year around 330 billion cubic meters of contaminated water is discharged into the Kura River and its tributaries without any treatment. The Kura River's right tributary Akstafachay River (flowing through Armenia) contains chemical dye, oil products, phenol, ammonia nitrogen and other contaminants that are discharged into the river together with wastewater. The rivers Alazan and Iori (left tributaries of the Kura River) also enter Azerbaijan already containing contaminants discharged in the territory of Georgia. While crossing the borders of Azerbaijan, the Kura River already contains oil products, phenols, and other contaminants in volumes exceeding admissible norms by 2-6 times depending on periods: phenols 3-20 times, copper 7-14 times, sulfate 2-3 times. In the territory of Azerbaijan, contamination is enhanced by agricultural pollutants, wastewater discharged from industrial premises and cattle farms as well as via local tributaries (Alekperov et al., 2006).

Araz, Azerbaijan's second biggest river in terms of length and flow rate has huge contamination concerns. Left tributaries such as Razdan, Arpachai, Okhchuchai etc. of the Araz River contain hazardous substances (nitrite nitrogen, ammonia nitrogen, heavy metals and other pollutants exceeding the sanitary norms dozens of times), which come from Armenia with water flow. Volume of annual wastewater disposal into the Araz River in the territory of Armenia exceeds 350 mln m^3. In the periods of huge disposals, Armenia discharges highly contaminated wastewater into the Okhchuchai River, which flows into the Araz River making it red-brown and almost black. The red-brown liquid contains high concentration of aluminum, zinc, manganese, titanium, bismuth and other components. After the confluence of Okhchuchay with Araz River, microflora content of the river is reduced by 65-80%. The main reason for this situation is the lack of effective drainage system, treatment facilities as well as technical insufficiency of existing plants in most towns and settlements of not only Georgia and Armenia, but also Azerbaijan. Therefore, in most residential areas wastewaters originating from households are discharged directly into rivers.

In huge parts of the lowland, subsoil and aeration zones are exposed to natural pollution and salinization. Salinization rises sharply in poorly drained and drainless areas. Salinization rate in irrigated areas ranges from 0.25% to 1-2%.

Groundwater pollution of regional scale has not observed in Azerbaijan. Pollution is of domestic, industrial and agricultural nature. As already note, the main factor causing domestic pollution is the lack of effective drainage system and treatment facilities in most communities. Domestic wastewater is being disposed into the rivers, the sea, natural or manmade pits. Groundwater pollution is caused by infiltration of contaminated river water or migration of chemical agents via the zones of aeration. For instance, high concentrations of aluminum, iron, phenol, high as well as nitrites, nitrates, ammonia and sulphates were encountered in groundwater at the sludge pit of Ganja aluminum plant. Nitrites, nitrates, ammonia and sulphates are also observed in higher concentrations. Groundwater sources in occupied lands of Azerbaijan also undergo contamination due to discharge of entire wastewater from Khankendy and Askeran towns into the rivers, which feed the aquifers in the immediate vicinity of groundwater recharge sources.

Groundwater contamination with agricultural contaminants is observed mostly around fertilizer storages. Groundwater contaminants here include nitrate, nitrite and phosphate, which exceed admissible rates by 2-5 times. Concentrations of nitrites and nitrates in irrigable lands do not exceed the admissible norms, while around cattle farms such concentrations may reach 10-19 mg/L and 12-145 mg/L, correspondingly. Evidences of bacteriological pollution of groundwater have been recorded in irrigable areas, cities, cattle farms and near wastewater treatment plants.

Another problem of transboundary nature is natural transformation of river banks of transboundary rivers Araz (Iran) and Samur (Russia), though it is not reflected significantly in the conditions of groundwater under riverbeds. However, with certain states it is possible to balance existing conditions.

6. MITIGATION POSSIBILITIES

A number of solutions can be proposed for mitigating above problems. These include but are not limited to:

- organising and maintaining independent monitoring of river and groundwater under supervision and direction of international organizations, such as UNESCO, IAH, IAHS etc.

- carrying out a comprehensive study of the conditions of recharge, chemical and biological content of groundwater sources, considered as vulnerable due to the impact of contaminated rivers;
- preparing an action plan for restriction of contamination process;
- developing a scheme for integrated use of water resources in aquifers;
- ensuring compliance with Helsinki Convention 1992 by OSCE member-countries;
- taking steps for technical modernization of water treatment plants and avoiding disposal of untreated wastewater into the rivers, at least, in large cities and settlements;
- constructing drainage facilities;
- building facilities for entrapment and neutralization of infiltrates in heavily contaminated irrigation waters.

Acknowledgements

Over the last 10 years, owing to various programmes and projects supported and implemented by UNDP, UNESCO, OSCE, NATO and other international organizations, progressive work has been done in respect of reduction of the scale of degradation in the catchment areas of the Kura, Araz and other rivers of the South Caucasus; coordination of investigations and activities undertaken by the countries located along the catchment areas; integrated use of transboundary water resources etc. The authors of this article wish to thank all contributing organizations for their challenging and laborious efforts. Although outstanding issues are not easily solvable, harmonisation of relevant approaches and solution methods becomes apparently evident during implementation of each and every programme.

The authors of the article have been steadily involved in implementation of similar programmes by preparing consolidated reports for Azerbaijan and the catchment areas of the Kura and Araz rivers. The authors are gratefully prepared to share their knowledge and expertise for such a noble and necessary mission.

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Preliminary results of detailed inventory of transboundary aquifers in Benin (West Africa)

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ABSTRACT

Benin transboundary aquifers are inventoried in the framework of the UNESCO-ISARM project entitled "Inventory of transboundary aquifers in West Africa". Data and information collected through this project will enable to establish the database of UNESCO-IGRAC Centre of the transboundary aquifers in West Africa. They will also help to develop a GIS inventory of transboundary aquifers of the West Africa as a contribution to ISARM Africa. This inventory will lead up to elaboration of specific cooperative projects. Identification of transboundary hydrogeological layers was based on hydrogeological cross-sections used to verify the continuity of different aquifers across international borders. In addition, characteristics of each transboundary aquifer were investigated.
The results of this study show that Benin has transboundary continued aquifers in two sedimentary basins: the coastal sedimentary basin in the Southern and the sedimentary basin of Kandi in the North-East. In the first basin, there are four aquifers shared with the Togo in the West and Nigeria in the East. From the bottom to top, we are: the Turonian-Coniacian (Upper Cretaceous) aquifer (sands and sandstones), the Paleocene aquifer (limestones and sands), the Continental terminal aquifer (sands) and the Quaternary (the coastal and alluvial sands). In the second basin, there are two aquifers shared with Niger in the North and Nigeria in the East: The Paleozoic (Cambrian-Ordovician) aquifer (conglomerates and sandstones) at the base and the Silurian and Quaternary aquifer (sandstone and alluvial sands of Niger River) at the top. These inventoried aquifers are of varied hydrodynamic type (free, captive or semi-captive) and of varied quality (including facies and total mineralization).

Keywords: Inventory, transboundary Aquifer, coastal sedimentary basin, basin of Kandi, Benin

1. INTRODUCTION

This study results from recommendations of the different ISARM workshops on inventory of transboundary aquifers in West Africa. It concerns inventory of aquifers that Benin shares with others countries of the Guinea Gulf (Togo, Nigeria, Niger and Burkina Faso).

Guinea Gulf is one of the most populated regions in West Africa. This region experiences a rapid demographic growth worsened by the internal rural exodus and migration of people coming from the hinterland (Sahelian countries). Moreover, it records, a rapid urbanization and economic growth of which a substantial part escape the regional countries planning (informal sector). This causes an important pressure on water resources. The results are a tendency of groundwater over extraction, aquifers pollution and loss of wetland ecosystems. Water demand becomes more and more important and will be likely to create conflicts between various users as already observed between breeders and farmers during transhumance period.

As surface water catchments, aquifers stretch often over two or several countries. But contrary to the surface water, these aquifers are yet not well known in West Africa with regard to their nature and as their functioning. This is the interest of the paper.

In terms of geology, the figure 1 shows that Benin country extends essentially on a crystallophyllous and crystalline socle of Proterozoic age. This base which takes up the central part of the country is covered on its north-western, north-eastern and south peripheral areas with layers more or less recent. These are respectively transgressive layers from the ending Proterozoic of Atacora, Paleozoic basin of Kandi and Cenozoic to coastal Quaternary sedimentary basin.

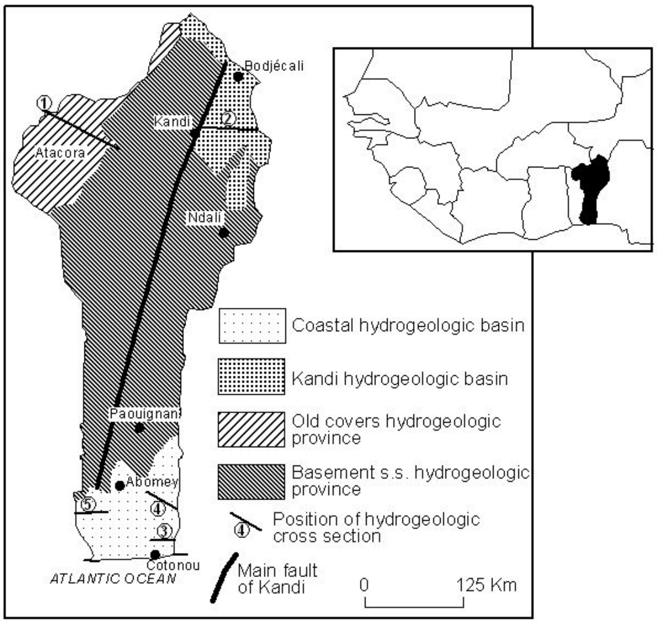

Figure 1: Location map of hydrogeological areas in Benin

This geological structure in Benin is divided into four distinct main hydrogeologic provinces (Boukari, 2007). There are: (i) a vast central province, with intermittent aquifers of fractures and crack (hydrogeologic province of the socle ss.), (ii) a north-western province, with intermittent aquifers, with on its western borders an sedimentary type aquifer more or less continuous (hydrogeologic province of the ancient atacora layers), (iii) a north-eastern province with continuous aquifer (hydrogeologic province of Kandi basin) and at last, (iv) a province in the south, with continuous aquifers (hydrogeologic province of the coastal basin).

2. OBJECTIVES AND METHOD

All the hydrogeologic provinces of Benin seem to be extended beyond its international borders to stretch more or less widely inside of either of the boundaries countries. So, it is to show the extension modalities of the hydrogeological zones that the structure even the geometry of their various aquifers is briefly described. Each aquifer description is completed by synthetic data on its chemical quality. Finally crossed results will enable to implement a mechanism of integrated and concerted transboundary water resources management in common countries.

The study is based on knowledge compilation on the different hydrogeologic provinces of the country, in order to identify and characterize the shared aquifers. This method allowed to collect or to realize hydrogeological section on the border areas of these provinces. So, the shared aquifers are briefly described according to the geological and structural context. It's the same for their geometry as well as their hydrodynamic and hydrochemical parameters. About 350 geological boreholes section of drillings, piezometers and nicked drillings distributed on the sedimentary coastal basin were exploited.

3. RESULTS

3.1. Hydrogeologic provinces with intermittent aquifers

The hydrogeologic provinces with intermittent aquifers take up about 83% of the beninese territory. They are often structured in many small hydrogeologic basins. Their typical hydrogeologic section (Guiraud, 1987; Boukari, 1982) and their study should take a local character in the cross-border approach. Interconnections between basins are nevertheless possible by the means major faults. The hydrogeologic province of the socle s.s. is shared with Nigeria in the East and Togo in the West.

Water type of the intermittent aquifers is usually calcic or magnesium bicarbonate. If the mineralization of the province waters of the socle s.s. is average to strong (average conductivity on the order of 400 µS/cm), with a pH close to neutrality (Zimé Mora and Mondja Chabi, 2006), the one of old provincial layers is weak, with an acidic pH (TurkPak/SCET-Tunisie, 1991). This differentiation proves that the nature of the first reservoirs is meanly migmatito-gneissic and granitic and that of the second ones is quartzo-sandstone.

However, it is necessary to specify that on the old layers of the hydrogeologic province in the north-west part of Benin, shared with Burkina (north and west) and Togo (south), the aquifer of the old sedimentary basin of Pendjari, in the west part of this province (Fig. 2), could present more or less regional character, as of those of the recent basin of Kandi and the coastal basin. Present embryonic knowledge of the hydrogeology on this old basin doesn't yet allow us to conclude.

Therefore attention is focused on the two hydrogeologic provinces with continuous aquifers, i.e. the hydrogeologic coastal basin and the hydrogeologic basin of Kandi.

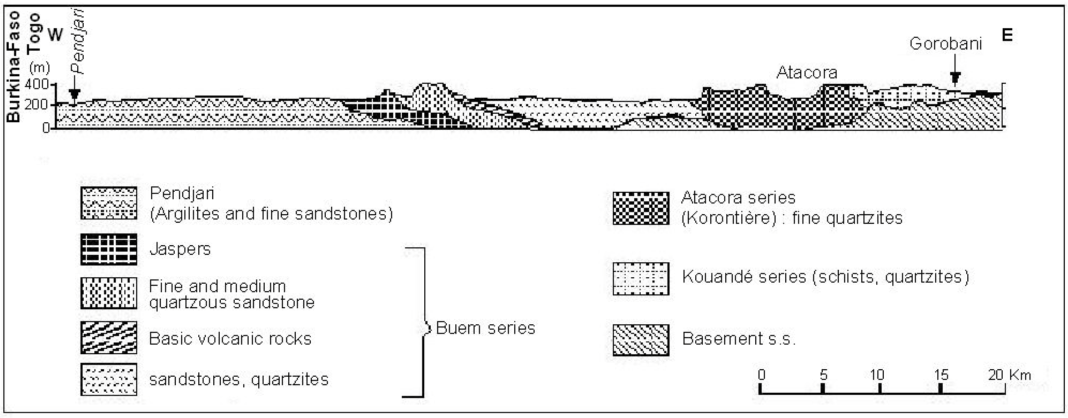

Figure 2- Geological section through Atacora series and its forward country (IRB, 1982)

3.2. Hydrogeologic provinces with continuous aquifers

They are the hydrogeological coastal basin of Benin and the hydrogeological basin of Kandi.

The **coastal sedimentary basin** of the Benin occupies roughly 10% of Benin territory, but contains about 35% of the whole country groundwater (Direction de l'Hydraulique, 2000). Its current population is approximately 65% of the whole in Benin. It estimated by 6 752 569 inhabitants (INSAE, 2003). These coastal sedimentary deposits of Benin are part of the vast sedimentary basin of the Guinea gulf which extends from Ghana (in the west) to Nigeria (in the east) (Slansky, 1968). These deposits have a monoclinal structure characterized by a growing differential subsidence towards the SSE (Dray *et al.*, 1988). Eight stratigraphical units were counted based on the lithological and sedimentary marks that indicate the successive variations of the sea level (Affaton *et al.*, 1985, IRB, 1987, Lang *et al.*, 1990, Oyédé, 1991).

On the whole, there are four aquifers in this basin (Upper Cretaceous aquifer, Paleocene aquifer, Continental terminal aquifer and Quaternary aquifer), separated one to the other by clayey and marls layers. Several authors described these aquifers which are ones of the relevant drinking water supply sources in Benin (Bouzid, 1971; GIGG, 1983; Pallas, 1988; Turkpak International/SCET-Tunisie, 1991; SOGREAH/SCET -Tunisia, 1997). The mean are those of the Upper Cretaceous and of the Continental terminal. Figure 3 to 5 show their respective structure and geometry at the international borders of Benin. Figure 3 describes the geometry of the Continental terminal aquifer of the plateau of Sakété while the figure 4 and 5 show the geometry of the Upper Cretaceous aquifer (Turonien-Coniacien) respectively at the east of the plateau of Ketou and at the west of the plateau of Aplahoué.

According to their lithological nature, aquifers reservoirs of the coastal sedimentary basin are sandstones and sand of quartz nature with, consequently water of weak mineralization (Continental terminal and Cretaceous). However a very long stay in the reservoir, frequent water table presence, clayey or marls layers or multi-layers, as well as the nearness of saline reservoirs, can sometimes raise this mineralization. On the other hand, waters of limestone Palaeocene reservoir usually have an average mineralization.

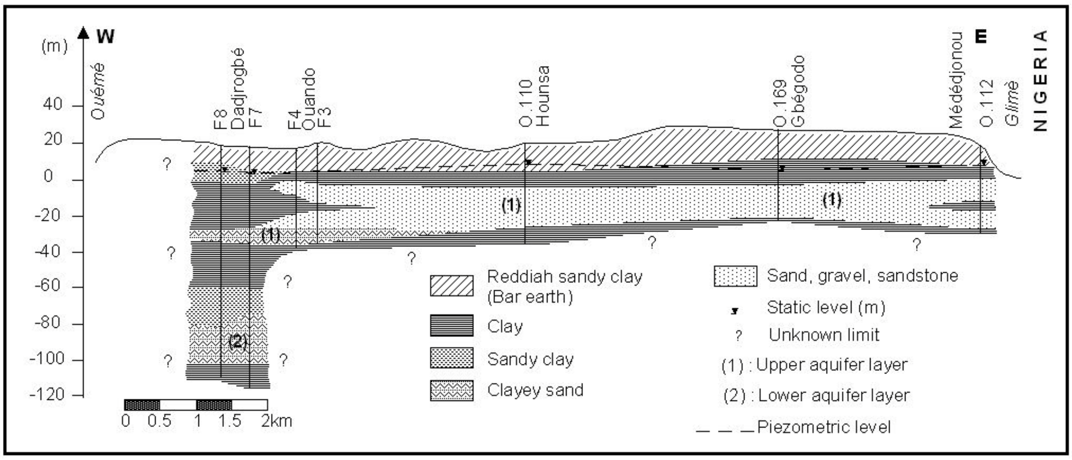

Figure 3: Hydrogeological section of the plateau of Sakété following the trace n°3 of the figure 1, showing the continuity of the Continental terminal aquifer towards Nigeria in the East (Alassane, 2004).

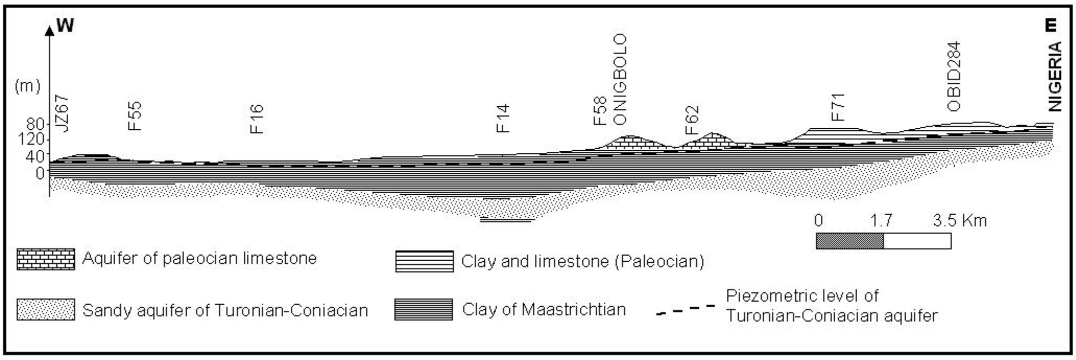

Figure 4: Hydrogeological section following the trace N°4 of the figure 1, showing the continuity of the Paleocene and Upper Cretaceous aquifers towards Nigeria in the East.

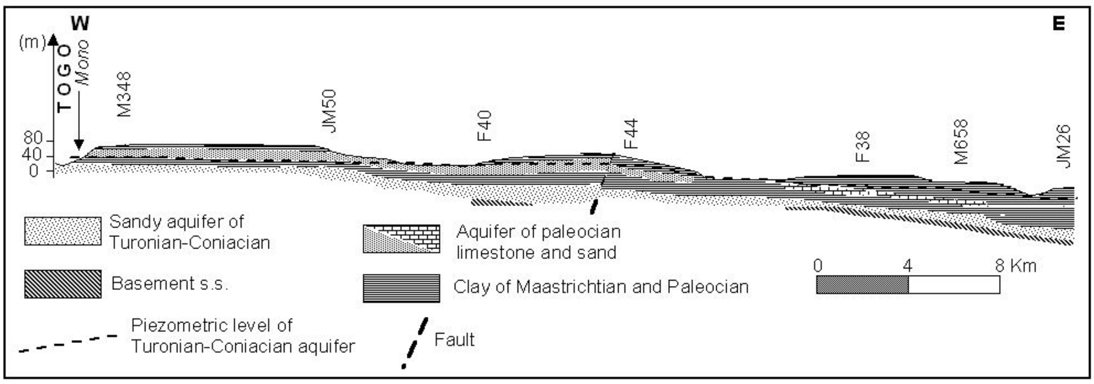

Figure 5: Hydrogeological section of the plateau of Aplahoué following the trace N°5 of the figure 1, showing the continuity of the Paleocene and Upper Cretaceous aquifers towards Togo in the West

The **sedimentary basin of Kandi** is the extension in Benin of the bigger basin named Sokoto basin in Nigeria and Illumenden in Niger. This is a continental basin, of Paleozoic to Secondary age, with Tertiary relics. It locates in the extreme northeast part of Benin (Fig. 1) and covers an area about 8 000 km² which represents 7% of the whole territory. It is subdivided in two compartments by an oriented SW-NE horst where the medium Proterozoic base (revived by the panafricain orogenesis) appears.

The north-western compartment appears more vast (more than 2/3 basin) than the south-eastern compartment. In the whole basin, the Paleozoic sediments usually have a slope of 10º in general towards the WNW (Konaté *et al.*, 1994). Six stratigraphical units were identified in since the Cambrian until the relics of Continental terminal, based on the lithological, sedimentary and paleontological indicators (IRB, 1982, Alidou, 1983, TECHNOEXPORT, 1984 and Konaté, 1996).

This is the more productive hydrogeologic zone after the coastal zone. But contrary to the latter, it still remains less populated and not very known. Although, it is from Paleozoic age, its aquifers layers are comparatively continuous and research of cracking using photo-interpretation by geophysics is not usually necessary (BURGEAP and BRGM, 1986) especially for current flows in rural hydraulic.

According to our current knowledge, two main aquifers can be distinguished (Fig.6). The first aquifer, unconfined is constituted by coarse sandstones of the Cretaceous (Unit IV). It is in continuous hydraulic with the Niger River deposits in its extreme northern. Its substratum is constituted by the fine sandstones and argillite of the Silurian (Unit III), which are considered as impervious or very little permeable.

Under the fine sandstones and Silurian argillite, the second aquifer reservoir is constituted by the layers with coarse granularity of the Cambro-Ordovician (Units I and II). Confined, it become unconfined in the west and south peripheral areas of the basin (transition zone between the basin and the layers of the Proterozoic panafrican basement) where these Cambro-Silurian layers raised to the surface. Its reservoir, relatively indurated, is usually not very productive (BURGEAP-BRGM, 1986; Turkpak International-SCET-Tunis, 1991), with flows rarely higher of 5m^3/h. It can present a gushing artesian aspect in the north towards the River Niger deposits (boreholes of Bodjécali). It is shared with Nigeria to the northwest and Niger to the north. Total mineralization of the upper aquifer of Kandi

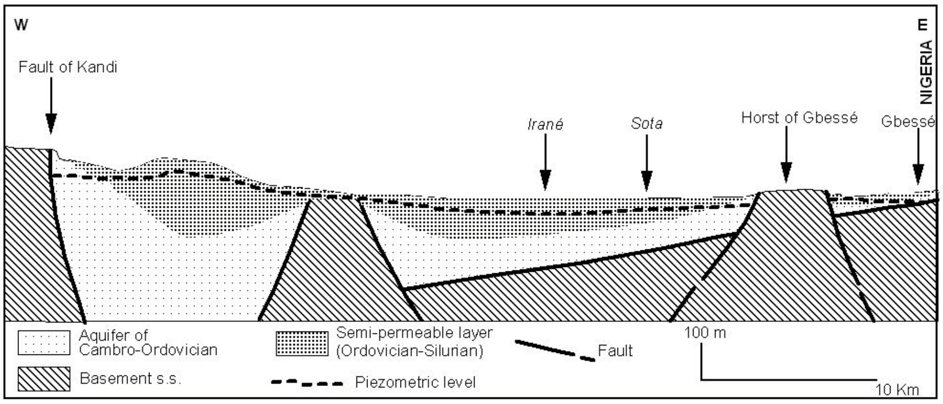

Fig. 6- Hydrogeological section of the sedimentary basin of Kandi following the trait N°2 of Figure 1, showing the continuity of the Cambro-Ordovician aquifer towards Nigeria in the North-West. (Boukari, 2007, according to interpretative section of Konaté, 1996).

basin is, as expected, very weak; the reservoir being particularly constituted of sandstone quartz. Electric conductivity of water frequently lies between 25 and 60 µS/cm. On the other hand, regarding the lower aquifer, this mineralization is average (conductivity lying between 131 and 425 µS/cm), because of the relatively long stay of water in the reservoir. The type of this water is bicarbonate calcium and magnesium; its quality is good for drinking (TurkPak/SCET-Tunisie, 1991).

4. DISCUSSION

According to the four hydrogeologic provinces of Benin, the basement s.s. province and that of the old layers have intermittent aquifers. Even, if they cover more than 80% of Benin territory and they cross the borders countries, they still present a special hydrogeology context that limits the use conflict risks on either side of these borders. Regarding the coastal province, the transboundary problems are more or less important according to the kind aquifer. The Continental terminal aquifer is the most exploited in the southern plateaus (Comè, Allada and Sakété), those of the Upper Cretaceous and Palaeocene being more or less deep. The concerned area is the plateau of Sakété which is itself shared with Nigeria in the east. The Cretaceous and Palaeocene aquifers become superficial or flushing to the North, where they are shared, not only with Nigeria in the East (plateau of Ketou), but, also, with Togo in the West (plateau of Aplahoué).

As for the hydrogeologic province of Kandi, it is shared with Nigeria in the east (basin of Sokoto) and with Niger in the north (basin of Iullemeden). Under all these conditions, concerted transboundary approach, is recommended for the Guinea gulf aquifer, specially the continuous aquifers management.

5. CONCLUSIONS

Benin have four hydrogeologic provinces, with two provinces of intermittent aquifers and two provinces of continuous aquifers. Regarding the structure and geometry of their aquifers, these provinces are all shared with the boundary countries.

The chemical quality of the aquifers is naturally good. However, the intermittent aquifers show a special hydrogeology that limits the use conflict risk in the boundary area. For the continuous aquifers, the shared countries must to implement the collective plan to exploit and manage groundwater of the sub-region of the Guinea gulf, in order to prevent the use conflict risks.

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Transboundary Groundwater Sharing and Contamination:
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ABSTRACT

This is a proven fact that water plays pivotal role in economic development of a country like Pakistan. There is no substitute for water, water is finite, has economic value and least immune to misuse, underuse, pollution and poor management. Pakistan can be classified as one of the most arid countries of the world with average rainfall of 240 mm a year. Its population and economy heavily depend on the annual influx into the Indus System (including the Indus, Jhelum, Chenab, Kabul and some un-captured flows by India of Ravi, Sutlej and Beas rivers) of about 190 BCM of water mostly derived from snow-melt in the Himalayas. In addition, Pakistan has 16 mha of aquifer with a total potential of 68 BCM of groundwater, mostly getting recharged through canals network and partially through some limited structural arrangements. The 81% of the surface water is available in the wet season (Kharif) which runs from April to September. Seventy seven percent (77%) of Pakistan's population is located in the Indus basin – 40 million People in Pakistan depend on irrigation water for their domestic use especially in areas where groundwater is brackish. In general Pakistan is a water scarce country, has high precipitation variation, high water stress indicators, high ecosystem deterioration, extremely low water use efficiency, poor access to clean drinking water and sanitation, poor conflict-management capacity and deferred maintenance of water infrastructure. Trans-boundary aquifer mining and trans-boundary surface water pollution are factors which adversely affect water resources of Pakistan, both surface and ground water.

Pakistan is extracting 50 MAF of groundwater against total resource of 59 MAF. The remaining 9 MAF has already reached its economic limits. The over-mining of aquifer has resulted in secondary salinization along with presence of fluorides and arsenic. This is degrading the quality of agricultural land and resulting in multiple diseases.

The major issue of Transboundary groundwater sharing and contamination is faced by Pakistan because of the fact that the very liberal policy of groundwater extraction with very subsidized electricity tariff for farmers of the Eastern Punjab in India and release of industrial effluents in the Ravi River which enters in to Western Punjab in Pakistan not only cause fast declining groundwater table but also contaminating the groundwater reserves of Pakistan.

This paper will thoroughly review the Transboundary groundwater occurrence, uses in both neighbouring countries India and Pakistan, groundwater reserves health in Pakistan, factors contaminating and declining groundwater resources, possible suggestions to improve the situation without compromising relations with the neighbouring country. The paper would also suggest some measures to be adopted to improve groundwater management on sustainable basis.

Key words: Transboundary Groundwater, Shared River Flows, Contaminating Groundwater, Health Hazard.

1. INTRODUCTION

The Indian Sub-Continent carries a long history of irrigated agriculture practiced by locals living along the water bodies including rivers, lakes, ponds, etc. and tapping seasonal inundations. This traditional irrigation practices changed into perennial irrigation in the 1880's through the advent of hydraulic structures and vertical pumps.

Pakistan can be classified as one of the most arid countries of the world with average rainfall of 240 mm a year. Its population and economy heavily depend on the annual influx into the Indus System (including the Indus, Jhelum, Chenab, Kabul and some un-captured flows by India of Ravi, Sutlej and Beas rivers) of about 190 BCM of water mostly derived from snow melt in the Himalayas. In addition, Pakistan has 16 Mha of aquifer with a total potential of 68 BCM of groundwater, mostly getting recharged through canals network and partially through some limited structural arrangements. Season wise 81% of the surface water is available in the wet season (Kharif) which runs from April to September. Seventy seven percent (77%) of Pakistan's population is located in the Indus basin – 40 million People in Pakistan depend on irrigation water for their domestic use especially in areas where groundwater is brackish. In general Pakistan is a water scarce country, has high precipitation variation, high water stress indicators, high ecosystem deterioration, extremely low water use efficiency, poor access to clean drinking water and sanitation, poor conflict-management capacity and deferred maintenance of water infrastructure. Trans-boundary aquifer mining and trans-boundary surface water pollution are factors which adversely affect water resources of Pakistan. Pakistan therefore, falls in the category of high vulnerability to climate change.

During the British Rule in India, the joint Punjab (East Punjab in India and West Punjab in Pakistan) was considered food basket not only for the subcontinent but also for the Asia continent because of its fertile lands, groundwater resources and hardworking farmers. This land was called Golden Sparrow.

2. RISE OF PROBLEM

Groundwater resources of Punjab were being recharged with annual water flows of five major rivers namely Jhelum, Chenab, Ravi, Sutlej and Beas. However partition of the sub continent in August 1947 cut across the Indus irrigation network whereby control structures on eastern rivers fell within the territory of India and rivers/canals remained within Pakistan. Soon after the partition, India conveyed its intention of diverting the waters of eastern rivers. This would have meant strangulating the agro-based economy of a newly created Pakistan whose 75% of GDP was solely dependent on agriculture as other sectors of the economy were non-existent. This not only was impacting the flow of surface water to Punjab but also to extremely decline the recharge of groundwater resources which were major source of irrigation during Kharif (Winter) season when surface flows become very thin.

With stoppage of water from the three eastern rivers by India, Pakistan's 3 million hectare of fertile land of West Punjab, the food basket of Pakistan would have gone barren. This created a serious water dispute between India and Pakistan. However, over a period of 8 years of exhaustive negotiations under the auspices of the World Bank from 1952 to 1960 the famous Indus Waters Treaty between India and Pakistan was signed in September 1960. The World Bank was also a signatory to this transboundary water allocation. Under the Treaty, India was given exclusive rights to the uses of water of three (3) eastern rivers with limited uses of waters of western rivers and Pakistan got exclusive rights on the waters of three (3) western rivers. Pakistan was given a grace period of 10 years to complete its Indus Basin Replacement Works. This Treaty though extensively lauded internationally as an example of resolving transboundary water issues between two sovereign states, created some serious hydrological shocks and challenges for Pakistan. The first challenge as stated earlier arose because the lines of partition of the Indo-Pak subcontinent separated the irrigated heart land of Punjab from the life-giving waters of the three eastern rivers. The second challenge was that there was a serious mismatch between the location of Pakistan's water (in the western rivers) and the major irrigated areas in the east. To overcome major water challenges, Pakistan had to undertake major engineering works within a fixed time period of 10 years. The initial works included construction of mega rock and earth fill dam on one of the western rivers i.e. Jhelum River at Mangla, construction of inter-river link canals to transfer the waters of western rivers to eastern rivers with a number of Head-works and Barrages and later the world largest volume rock and earth fill dam i.e. Tarbela Dam was also built on River Indus, the largest river of the Indus Basin Rivers System.

With additional storage water available at Tarbela, additional canals and control structures were constructed in all the four Provinces of Pakistan. With the construction of Tarbela, Mangla and Chashma Multi-purposes storage dams, storing close to 20 billion cubic meters of water and water distribution network consisting of 19 barrages, 60,000 km of main canals and 1.60 million km of secondary and distributary canals, the Indus Irrigation System became the largest contiguous irrigation system in the world. The interlink canals provided a source of recharge to the groundwater of Punjab which was earlier recharged by the three eastern rivers. If this situation was maintained, there was no harm to the groundwater aquifer of West Punjab in Pakistan.

3. DISCUSSIONS

Unfortunately, India adopted very liberal policy towards extraction of groundwater from the adjacent aquifers of East Punjab in India. This is causing over-mining of sweet water and causing degradation of the groundwater aquifer. On the other hand, India is also releasing its industrial waste of Hadiara Drain into the River Ravi which not only pollutes the un-captured rainwater which it carries to Pakistan after entering into its boundaries. This mixing of untreated industrial waste into the un-captured freshwater of River Ravi causing havoc to the fertile lands of West Punjab in Pakistan. This attitude on part of India is extremely dangerous not only for the meagre flows of Ravi River but also putting the whole groundwater aquifer on stake. This is also a serious violation of all international norms and ethics.

On the other hands, a part from the above-mentioned serious transboundary issues, though groundwater is an important resource, there is no firm policy in place for regulation of groundwater in Pakistan as well. It is causing groundwater level to fall rapidly in many fresh groundwater areas of West Punjab. Mining of groundwater is leading to intrusions of saline water into fresh groundwater and increasing deterioration of groundwater quality in many areas. In addition, pumping cost of groundwater increases as the water table goes down. This implies that more expensive and poor quality groundwater will now be drawn for agriculture, domestic and industrial use. The sweet water volume is 43 MAF and saline water volume is 3 MAF. This also results in lateral or vertical movement of saline interface which limits its use primarily due to unsystematic and unplanned exploitation. Site specific and in-depth analysis of data is required for further or on-going exploitation of groundwater resources and its use has to be based on a very scientific formula for sustainability of this valuable resource.

4. CONCLUSIONS

It is quite evident from the above discussions that:

1) There should be a firm policy on groundwater regulation should be in place in both India and Pakistan to give space of living to each other.
2) Release of untreated industrial waste in water bodies which are being shared with other neighbours should be avoided to keep the water bodies alive.
3) Deterioration and degradation of groundwater aquifer will not only cause damage to West Punjab but in the long run it will also impact on the groundwater quality of East Punjab, therefore in the wider interests it is necessary to save the aquifer from deterioration and degradation.
4) Liberal groundwater mining policy would not pay in the long run and ultimately it will impose problems for East Punjab in India. Therefore, a strict and determined policy to regulate groundwater resources commensurate to the need of agriculture would have to be implemented.
5) Fair play is necessary to guarantee regional cooperation on transboundary waters and aquifers in South Asia. Both India and Pakistan have to discuss their issues on the table to reach amicable solutions for wider interests of both nuclear powers.
6) Finally Pakistan should regulate its groundwater resources wisely and there should be some regulatory mechanism so that it could be possible to make optimum use of the groundwater

resources together with the surface water to increase productivity to higher levels imparting wellbeing to its poor farmers who mostly are living below poverty line.

7) Both India and Pakistan should maintain inventories of tube wells installed in their respective area to extract groundwater a there should some checks on extraction. The free electricity tariff allowed in India should be withdrawn.

Acknowledgements

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Remote Sensing in Service of Concerted Management of a Major Transboundary Water Basin

The North West Sahara Aquifer System

AWF[1]/SSO[2]

ABSTRACT

This paper presents the main outcomes of the GEOAQUIFER project. Implemented with funding from the African Water Facility (AWF) and executed by the Sahara and Sahel Observatory (SSO) in cooperation with Algeria, Tunisia and Libya, GEOAQUIFER shows the contribution of satellite images in the concerted management of a major trans-boundary water basin: the North West Sahara Aquifer System (NWSAS).Periodically, studies have been conducted to assess the quantities of useable water in the NWSAS. The accuracy of these estimates hinges on several factors, including the estimation of the quantities actually drawn, for which sound knowledge and mutual information underpin the objective, equitable and sustainable operation of the consultation mechanism established by countries around the NWSAS. Such knowledge can be obtained by analyzing earth observation satellite imagery, which allows for a precise digital and updated mapping of the land occupancy and irrigated areas, and for estimating the amount of water used for irrigation, by comparing them to the volumes detected underground by the national water management agencies. Between the teams and stakeholders from the three countries, the activities collectively undertaken throughout the three years of the project provided exceptional opportunities for sharing experiences, learning practically how to take collective decisions and thereby strengthening the spirit of cooperation.

Key words: Aquifer –Sahara –Remote sensing –Consultation - Soil

1. INTRODUCTION

The GEOAQUIFER project covers the North Western Sahara Aquifer System (NWSAS) and the Tunisian and Libyan Djeffara coastal aquifer. NWSAS extends over one million km^2 in Algeria, Tunisia and Libya. The system extension and layer thickness have facilitated the accumulation of considerable water reserves, which are hardly renewable and only partly exploitable. Over the past 40 years, NWSAS's annual exploitation has grown fivefold, up to 3 times the average level of its natural recharge, exposing the aquifer to several major risks: heavy trans-boundary water salinity, end of artesian outflow, natural discharge depletion, increased excessive drawdown, etc. Therefore, the three countries concerned by the system's future naturally had to jointly search for some form of common management of the basin. Thus was born the "NWSAS Consultative Mechanism", a formal institutional framework for the joint management of shared groundwater resources.

The region's water authorities conduct regular resource assessment studies. These studies have faced the ever-increasing needs for more knowledge of groundwater systems. Such needs include estimating the amounts abstracted, the knowledge of which underpins the objective, equitable and sustainable operation of the consultative mechanism. In fact, National water agencies need to better locate areas where water is drawn for agricultural use and identify unlisted water consumption areas. This facilitates decisions within the consultative mechanism framework, based on objective, transparent, neutral and comparable data. These objectives can be achieved through analyzing earth observation satellite imagery, which allows for the preparation of a precise digital map and update of the land occupancy status.

2. OBJECTIVES

The GEOAQUIFER project aims to: (i) optimize the use of satellite data for understanding and managing the NWSAS shared aquifer; (ii) provide national water management agencies with tools to help enhance and improve the consultative mechanism for effective and sustainable management of the shared water resource; (iii) build the capacity of national agencies in the use of satellite data, and ownership of new technologies; and (iv) ensure replication of the project to other basins in Africa.

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[1] African Water Facility (African Development Bank)
[2] Sahara and Sahel Observatory (SSO)

As main long-term results, the GEOAQUIFER project will help promote:

1 - Sustainable development of the region through enhanced consultation; and
2 - Better understanding of the exploitation and rational management of resources:

3. OUTCOMES

1 – Production of land cover maps: the study focuses on a number of model zones considered of major importance to be mapped at a scale of 1:50000. The study of land cover in model zones was also carried out earlier on two occasions (shot in 1990 and 2000) to monitor the evolution of the corresponding irrigated areas. The photo-interpretation was confirmed by field visits to the model zones. In total, 22 previous and current land cover maps of the model zones at 1:50000 were produced. GeoCover LC coverage acrSSO the Djeffara NWSAS was obtained, which is part of the global land cover map derived from the EarthSat Moderate Resolution cover. The adjusted data were used to produce the current general land cover map on the NWSAS-Djeffara at 1:200000.

2 - Production of Digital Terrain Models (DTM) and derivatives on the basin: knowledge of the terrain at an excellent definition has allowed for accurately determining the altitudes of water points and more reliable measurement of piezometric levels. It has also contributed to better understanding of land use planning in the Sahara regions.

3 - ***Creating a hydro-geographic repository, a regional virtual globe and a data dissemination tool:*** national agencies do not have a homogeneous national geographic repository to reference or organize all data. Topographic and geological maps at 1:250000 and 1:1000000 covering the region were scanned, geo-referenced and entered into the map server. This allowed for: (i) integration of hydrographic and water points data; (ii) creation of hydro-geographic repository and superimposition on a virtual regional globe; and (iii) online posting of metadata and a demonstration dataset: http://prog.SSO.org.tn/geoaquifer/index.php.

4-Capacity building: training in geospatial data management: the objective is to develop the skills of water, environment and agriculture service officials in the area of GIS, remote sensing, GPS and data base management. Eight training sessions of two weeks each were conducted, covering: ArcGIS, 3D Analyst, GEOAQUIFER products, remote sensing bases, GPS initiation, geographic and hydrologic modeling.

4. DISCUSSIONS (INTERPRETATION)

4.1. Land Cover Maps in Model Zones

Given the scale and dispersal of farmlands in the Saharan regions, the study focuses on eleven model zones to be mapped at 1:50000: four in Libya, three in Tunisia and four in Algeria. The study of land cover in model zones was conducted on two dates the shots taken (circa1990 and circa2000) to monitor groundwater exploitation.

In addition to the SPOT data used at 20 m resolution, it was pSSOible to back up the photo-interpretation of current images with data at very high resolution (75 cm) taken from Google Earth. The photo-interpretation was subsequently confirmed by fact-finding missions to eleven model zones. Twenty-two (22) former and current land cover maps of the model zones at 1:50000 were produced. Figure 1 provides an example: current land cover map in Jufrah, Libya. From the joint analysis of satellite earth observation images and field verification campaigns, fourteen categories were selected to represent different types of land cover identified (Figure 1).

To obtain the land cover picture from the photo interpretation of remote sensing images for each pilot area, a vector layer has been created to cover the model zone studied and accommodate polygons whose borders are the boundaries of plots with some land cover significance vis-à-vis the legend. All this work is done manually. Following the delineation of the detailed survey plan, the tributary area table of the land cover layer thus created is filled in accordance with the legend adopted (Figure 1).

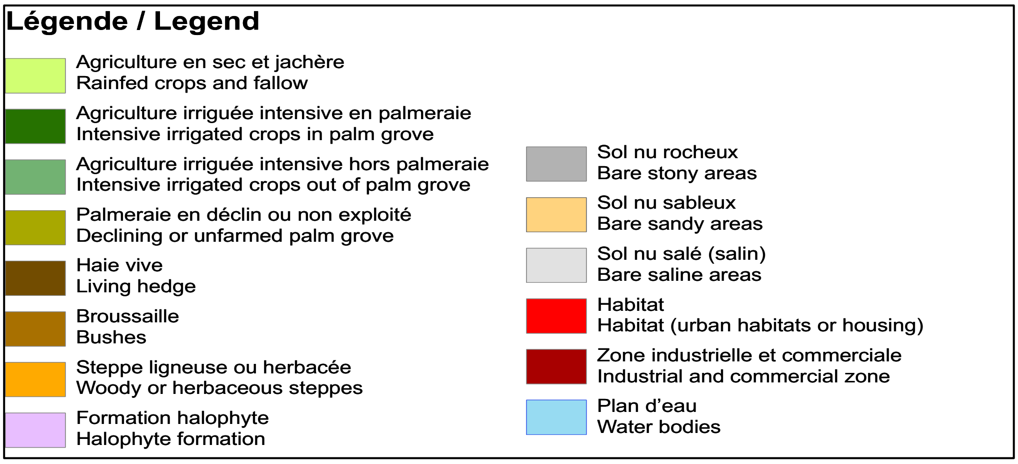

Fig.1: Classification and Legend adopted for the different categories represented on the land cover maps.

4.2. Land Cover Trend from the 80s to the 2000s:

Analysis of satellite images at two different times and verification missions on the ground have served to highlight the changes undergone by the land cover maps in the intervening time. The most significant and most demonstrative change was registered on the El Oued Souf pilot area, with an upsurge in the number of small-scaled and traditional irrigation pivots over the last fifteen years.

The pivot technique is recent: a comparison of images taken in 1987 and 2007 (Figures 2 and 3) shows a significant proliferation of this type of operation in the period in-between. Figure 2 shows clearly that the cultivation method in 1987 (SPOT image) was limited almost exclusively to Ghouta (traditional process where the palm tree abstracts the quantities it requires by directly tapping into the groundwater), while in 2007 circular pivots had become more extensive (Figure 2).

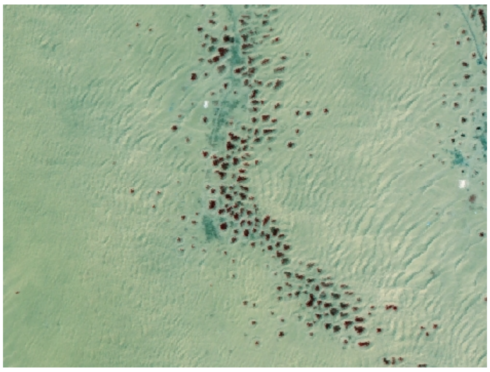

Fig.2: Series of Ghouta at El Oued in 1987

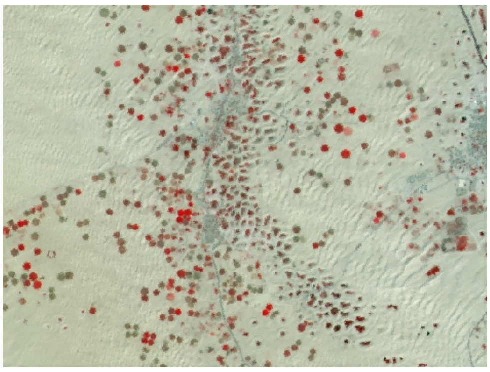

Fig.3: Image of the same sector taken in 2007

4.3. Land Cover map of the NWSAS-Djeffara Zone

GeoCover LC[3] Coverage acrSSO the NWSAS-Djeffara zone was obtained. This is part of the global land cover map derived from EarthSat at Moderate Resolution. This map is produced and marketed by MDA Federal[4] in the form of 1-degree square tiles. Our area is covered by one hundred and fourteen (114) homogeneous tiles according to the legend, which have been assembled into a vector raster layer. Adapted to the region, the legend[5] comprises 9 classes: (i) rainfed agriculture; (ii) irrigated agriculture; (iii) bush and thicket; (iv) woody or herbaceous steppes; (v) halophyte formations; (vi) bare stony or sandy areas; (vii) bare saline areas; (viii) habitat and industries; and (ix)

[3] ***http://www.mdafederal.com/geocover/geocoverlc/gclcoverview/***
[4] ***http://www.mdafederal.com/home***
[5] ***http://www.mdafederal.com/geocover/geocoverlc/geocover_legend/***

water bodies. The adjusted data were used to obtain the current general land cover map over the NWSAS-Djeffara area at 1:200000.

From the hydrologic point of view, this map has a huge theoretical pSSOibility: it allows for quick, accurate, transparent and scalable information for all the irrigated areas in the NWSAS-Djeffara region and, thereby, for an immediate estimate of the amounts abstracted at any point in the aquifer. The comparison with maps obtained at 1:50000 for the model zones shows that the map obtained at 1:200000, established from the GeoCover LC coverage, would be very useful for initial estimates of irrigated area in the NWSAS area. On Djeffara, the mapped areas have been systematically over-estimated because of the automatic classification method adopted by GeoCover.

4.4 DTM and Derivatives on the Basin

A Digital Terrain Model of the NWSAS-Djeffara with its derivatives was prepared from an SRTM source at 90 m resolution: 100 m equidistant contours, drainage system, watersheds.

In the model zones, eleven DTMs at 1:50000 with their derivatives were obtained through: (i) digital terrain modeling at 30 m resolution in two model zones (Ouargla, Zab) from ASTER images; (ii) acquisition of Spot Dem digital terrain models at 30 m resolution on the 9 remaining model zones. Derivatives relate to contours at 10 m equidistance, watersheds and river systems.

4.5 Hydro-geographic Repository, Virtual Regional Globe

A hydro-geographic repository comprising: (i) 87 topographic maps at 1:250000 and 1:1 000000 covering the NWSAS and Djeffara; (ii) a geological map; these maps were scanned, geo-referenced and entered into the map server; and (iii) the integration of Africa Data Sampler vector geographic databases; remediation of inadequacies; updating of the road network, administrative divisions and demographic and environmental data.

A meta database comprising: (i) integration of hydrographic, hydrogeologic and environmental data, and creation of a hydro-geographic repository; (ii) data description using the 9115 norm; and (iii) the online posting of metadata and data sets on the GeoAquifer portal. (http://prog.SSO.org.tn/geoaquifer)

This portal has typical GeoPortal features: access to data catalogue, ability to view metadata, data and metadata download, map navigation. Its originality lies in the use of the WorldWind virtual globe in the browser. There are still few applications that use a virtual globe that do not require installation. For the most part, the technologies used are innovative: OpenLayers/MapFish, AJAX, WorldWind JAVA Virtual Globe.

5. CONCLUSIONS

1. The GEOAQUIFER Project recorded significant progress in terms of mastery and processing of geo-scientific data. The project's two flagship products: (i) the land cover maps of the eleven pilot zones at 1:50000; and (ii) the website for dissemination of project data, are technological success stories evidencing remarkable technological expertise.

2. Despite the project's complexity, the diversity of stakeholders, the dispersion of activities over a very vast area and the transnational nature of the project, the Sahara and Sahel Observatory (the Executing Agency) was able to coordinate activities and guide various stakeholder institutions to adequately accomplish the tasks assigned them in implementing an operation fraught with difficulties.

3. The innovative nature of the project was highly integrated at the level of top water management officials in each country and water sector engineers, technicians and officials. This is reflected in the high number (fifty national officials) that participated in and took ownership of arguably the most popular activity of the project: the "capacity building and training in geo-scientific data management" component.

4. Upon completion of the project, a number of challenges remain: better knowledge of irrigated areas throughout the Libyan Djeffara, better knowledge of water removal on the NWSAS and the Djeffara, improved access by all interested parties to the opportunities offered by the remarkable GeoAquifer website, improved use of geo-scientific data and satellite images for water resource management and the ordinary operation of the NWSAS consultation mechanism. All these challenges, which are natural offshoots of the GeoAquifer project, should be part of future cooperation programmes between the Sahara and Sahel Observatory and the African Water Facility.

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Karst Transboundary Aquifers: Challenges for Management

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ABSTRACT

The karst has very different characteristics than all other environments. Water circulation in karst is more heterogeneous than in non-karst areas. Karst terrains show strongly different hydrological and ecological characteristics than non-karst terrains. One of the main characteristics of karst water circulation is strong interaction between surface water and groundwater and high and fast oscillations of groundwater levels in karst (often hundred or more meters during few hours). Conditions for water circulations and storage in karstified medium are strongly dependent on space and time scales. Precise catchment area is the essential information which serve as a bases for hydrological and water resources management purposes. In karst landscape the definition of catchment area and boundaries is a difficult and complex task, which very often remains unsolved. The catchment areas in karst may vary with variation in groundwater levels, i. e. change with time. Heavy rainfall causes fast and high rising of groundwater. Very often fossil and inactive channels and springs are activated, causing the interbasin overflow and/or large and instantaneous redistribution of the catchment areas. Human intervention, especially construction of dams and reservoirs as well as interbasin transfers through long tunnels and pipelines can introduce instantaneous and distinct changes in catchment areas and boundaries and by this way in hydrological, hydrogeological and ecological regimes. Due to the above mentioned reasons the most precise models and/or approaches in karst are only temporally valid.
For karst surface water and groundwater management, water crises are increasingly serious all over the world. In karst terrains man's interventions very often are uncontrolled, and result in hazardous consequences. In cases of transboundary shared karst surface water and groundwater catchments they can be a trigger for serious international conflicts. Due this reason water resources management in them is very complex and hardly predictable. The case of the Trebišnjica River catchment, which is internationally shared between Croatia and Bosnia-Herzegovina, will be described in detail. There are some large projects (tunnels, hydroelectric power plants etc.) planned to be constructed by both countries. Consequences of Croatian and Bosnian and Herzegovinian projects will change hydrological, hydrogeological and ecological regime in a very complex and not enough known transboundary karst aquifer system of the Trebišnjica River. These changes could open serious problems in water management between two neighbouring countries which shared the Trebišnjica River catchment. Karst catchments and aquifers display the extreme heterogeneity, variability and vulnerability of their hydrologic, hydrogeologic, hydraulic, ecological and other characteristics in time and space. Such complex systems need careful interdisciplinary co-operation among numerous experts in the broad field of karstology.

Key words: karst aquifer, karst catchment, interbasin overflow, karstology, Timavo karst spring

1. INTRODUCTION

A wide range of closed surface depressions, a well-developed underground drainage system, and a strong interaction between circulation of surface water and groundwater typify karst (Field 2002). Due to very high infiltration rates, especially in bare karst, overland and surface flow is rare and water circulation is more heterogeneous in comparison with non karst terrains. They represent extremely vulnerable and hardly predictable hydrological-hydrogeological as well as ecological systems. Oscillations of groundwater levels in karst are high and fast (often hundred or more meters during few hours). Conditions for water circulations and storage in karstified medium are strongly dependent on space and time scales.

For karst surface water and groundwater management, water crises are increasingly serious all over the world. In karst terrains man's interventions very often are uncontrolled, and result in hazardous consequences (Bonacci 2004). In cases of transboundary shared karst surface water and groundwater catchments they can be a trigger for serious international conflicts. Due this reason management of the internationally shared karst water resources should be performed with special caution.

There are many large projects (construction of tunnels, hydroelectric power plants, railway networks and motorways, interbasin water transfer, massive karst groundwater pumping etc.) planned to be constructed by the countries which shared karst catchments and aquifers. Consequences of these projects will change definitely regional hydrological, hydrogeological and ecological regime. These changes could open serious problems in water management between neighbouring, and especially downstream located countries.

The goal of the paper is to point out specific characteristics of karst aquifers, which can represent the main and real trigger for possible conflicts when they are internationally shared.

2. CATCHMENT AREA IN KARST

One of the key issues for better understanding, protecting and managing any system, and especially karst system is precise determination of karst aquifers, springs and rivers catchment areas. In karst landscape the definition of catchment area and boundaries is a difficult and complex task, which very often remains unsolved (Bonacci 1987). The differences between the topographic and hydrologic catchments in karst terrain are, as a rule, so large that data about the topographic catchment are useless in hydrological and hydrogeological analyses and water management practice. Karst catchment represents complex water transport system in which heterogeneity of surface and underground karst forms, serving for flow circulation and storage, makes discovering and quantification of water through them difficult. Numerous and extremely different surface and underground karst forms make possible unexpected connections of water in karst medium space, which changes in time.

Determination of a karst catchment is an unreliable procedure due to unknown morphology of underground karst features (mainly karst conduits and characteristics of karst aquifers) and their connections with surface karst forms. The variability, in time and space, of karst aquifer as well as conduit parameters make this process extremely sensible and complex.

The catchment areas in karst may vary with variation in groundwater levels. Heavy rainfall causes fast and high rising of groundwater. Very often fossil and inactive channels and springs are activated, causing the interbasin overflow and/or large and instantaneous redistribution of the catchment areas. Limited maximum outflow capacity of karst springs (Bonacci 2001) and limited inflow capacity of swallow-holes (ponors) cause overflow from one catchment to the other in large karst space. Complex conduit organisation is an inherent characteristic of a karst aquifer (Perrin and Luetscher 2008). The full characterisation of the conduit network is the only way to find accurate karst aquifer catchment and to protect their water resources.

Human intervention, especially construction of dams and reservoirs with large grout curtains (Bonacci et al. 2009) as well as interbasin water transfers through long tunnels and pipelines can introduce instantaneous and distinct changes in catchment areas and boundaries and by this way in hydrological, hydrogeological and ecological regimes.

3. KARST AQUIFER

Karst aquifer is built by soluble rocks. Its triple permeability (matrix, fissures and fractures and conduits) results in its heterogeneity and anisotropy. Water flowing through karst aquifer continuously dissolves surrounding rocks and spreads the dimensions of preferable voids. Each karst aquifer has its specific hydrogeologic, hydrologic and hydraulic characteristics. In karst aquifer generally it is not possible to define representative elementary volume, as it is case in other non-karstic aquifers.

Karst aquifers are generally continuous. However, numerous subsurface morphologic features in karst (caves, jamas, fractures, faults, impermeable layers, karst conduits) strongly influence the continuity of the aquifer, so that an aquifer commonly does not function as a continuum in a catchment especially during periods of abrupt groundwater rise. One of the most important characteristics of karst aquifers is the high degree of heterogeneity in their hydraulic properties. Karst aquifers can be very deep (hundreds of meters) with endless cracks, fractures, joints, bedding plains, and conduits serving as groundwater pathways. In karst aquifer investigations, problem is that subsurface water is highly heterogeneous in terms of location of conduits, location of vertically moving water, and flow velocities. Karst aquifers are some of the most complex and difficult systems to decipher. The highly heterogeneous nature of karst aquifers leads to the inability to predict groundwater flow direction and travel times. For karst aquifers' investigation special challenge represent existence of concurrent fast turbulent flow through large karst conduits and slow, diffuse laminar flow through small karst fissures, joints, cracks and bedding plains. In order to define exactly the hydrologic catchment boundaries, it is necessary to carry out extensive geologic, hydrologic and hydrogeologic investigations. Delimitations based on geological considerations could not be reliable.

Karst aquifers as well as karst underground are extremely susceptible to contamination. The surface and especially subterranean environment in karst provide a range of habitats with very different chemical and biological processes. Karst ecosystems are sensitive to environmental changes. Karst species often are extremely endangered because of the extreme vulnerability of karst terrains and due to fact that populations are small.

Great variability of surface and underground karst forms as well as interplay of pervious and impervious layers in karst massif create practically endless possibilities of contact between two or more karst aquifers which can belong and feed to different karst springs and rivers. In last about hundred years and especially in recent time anthropogenic influences created new and very fast redistribution of surface water and groundwater in karst areas, which had caused changes of connections between aquifers of neighbouring (in some cases distant) karst springs (Bonacci 2004). Karst morphology and underground water pathways within the karst massif govern the feeding of the karst aquifers, springs and rivers. It changes in time and space in function of groundwater level. Due to very special, complex and generally unknown underground and surface karst forms there are very different cases.

Figure 1 shows one relatively simple example of groundwater level (GWL) changes in karst aquifer. With number 1 is designated situation when GWL is in minimum. Number 2 shows situation when GWL is in average. Maximum GWL is designated with number 3. In this situation the depressions in karst (mostly poljes in the karst) are flooded. Karst spring is designated with A. The swallow-hole (ponor) B during the flood can act as spring. In this case it is an estavelle. In case when a state boundary crosses this terrain situation with water management can be very complex, and potentially dangerous, especially during extreme hydrological situations, shortages of water and floods. It should be stressed that in reality situation can be mach more complex than this showed in Figure 1.

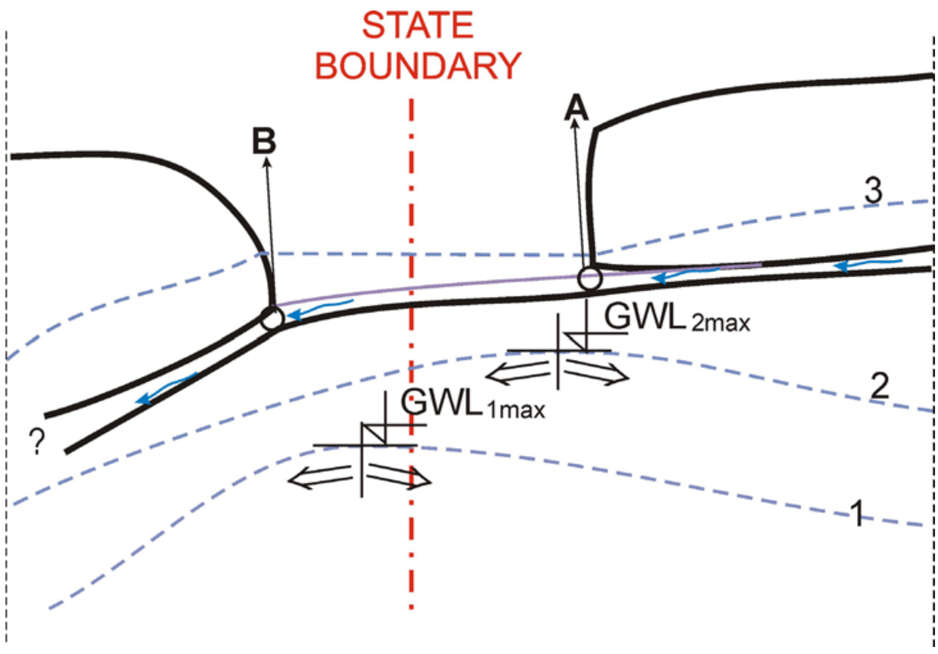

Figure 1

First example of transboundary shared karst catchment and aquifer explained in the paper is the case of the Ohrid and Prespa Lakes (Figure 2). The Ohrid Lake catchment is shared by Macedonia and Albania, and the Prespa Lake by Macedonia, Albania and Greece (Popovska and Bonacci 2007). These lakes are the largest tectonic lakes in Europe. Because of its biodiversity and unique cultural heritage, the Ohrid Lake is a resource of tremendous local and international significance. UNESCO declared it a World Heritage Site in 1980. The Prespa Lake does not have surface outflow. The waters from it outflow through karst underground massif into the Ohrid Lake. Therefore, from the hydrological as well as transboundary water management aspect, both lakes cannot be analysed separately. The lakes are influenced by permanent and strong natural changes that are poorly monitored, but also by uncoordinated, uncontrolled and mainly dangerous anthropogenic impacts. For the sustainable development and the protection of such ecologically, economically and politically sensitive and valuable karst transboundary water resources, it is very important to establish prerequisites for the definition of a reliable water balance. This will provide conditions for integrated and sustainable management of transboundary water resources and avoid potential conflicts related to water use. This is the way to prevent an ecological catastrophe, which is a real treat manly to the Prespa Lake which water level decreased 7.8 m in 1963-1995 period.

Figure 2

Second example is the catchment of the karst river Reka (in Slovenian) or the Timavo River (in Italian), which map is given in Figure 3 (Galli 1999). This river crosses borders and has aquifer in three countries: Croatia, Slovenia and Italy. The catchment of spring is partly in Croatia and partly in Slovenia. Its end represents abundant coastal karst spring Timavo (Q_{min}≈9 m^3/s, Q_{av}≈30 m^3/s, Q_{max}≈140 m^3/s) (Ford and Williams 2007) situated in the bay of Trieste (Italy). Except this one there are many permanent and temporary coastal and submarine karst springs along the Adriatic Sea coast. It is losing, sinking and underground stream. Few of springs in its catchment as well as its karst aquifer serve for water supplying in all three countries. Water management of so complex and not enough hydrologically and hydrogeologically explained system should be controlled with special caution.

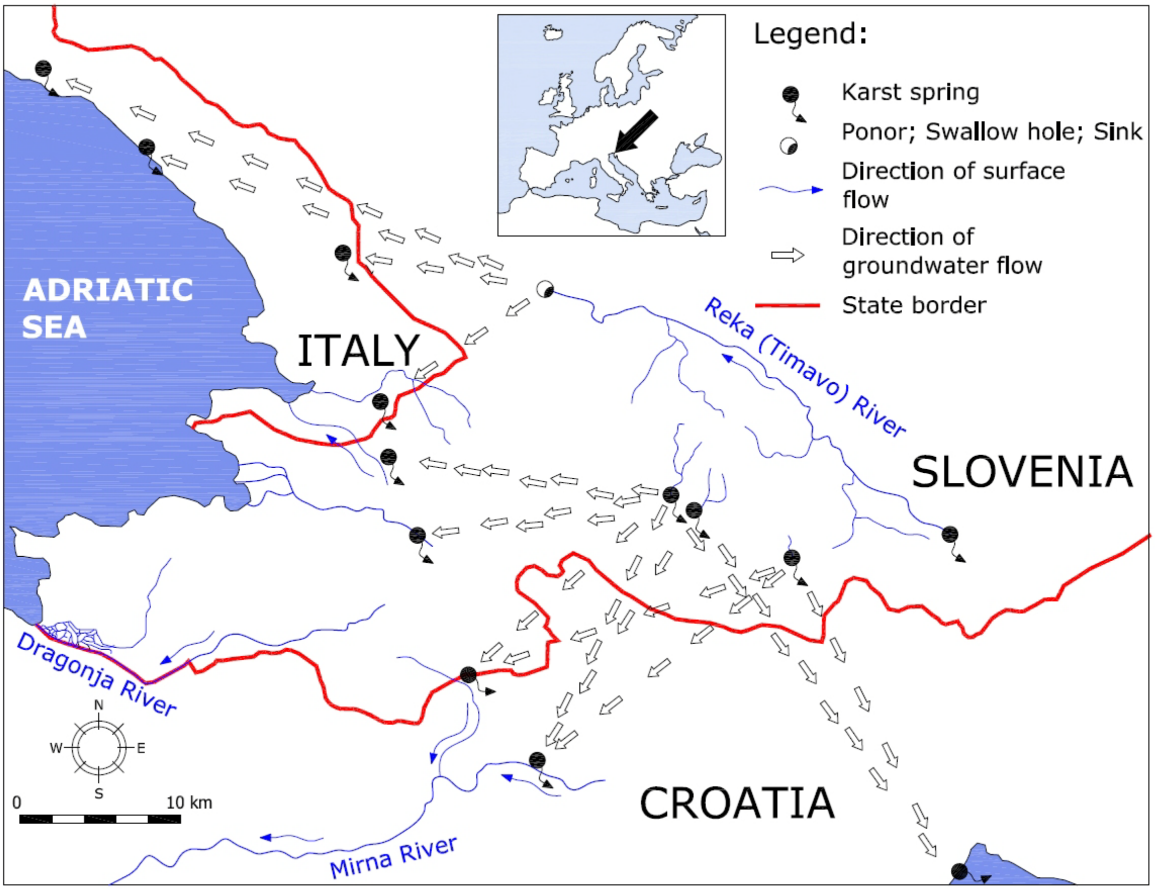

Figure 3

4. CONCLUSIONS

To obtain a harmonious, reliable and sustainable development, it is necessary to take the complex, interactive, technical, social, economic, environmental and cultural aspects of water resources management into account in decision-making. In the case of the transboundary karst water resources management it is especially hard and dubious task. Karst catchments and aquifers display the extreme heterogeneity, variability and vulnerability of their hydrologic, hydrogeologic, hydraulic, ecological and other characteristics in time and space. Such complex systems need careful interdisciplinary co-operation among numerous experts in the broad field of karstology.

Karstology can be defined as the science of integrating hydrological, geomorphological, hydrogeological, ecological, biological, socio-economics, political and all others processes over varied spatial and temporal scales in specific karst regions. The cooperation between all above mentioned disciplines could help in solving many critical problems dealing with sustainable developments of society and environment in vulnerable karst terrains.

The new global problems in karst regions connected with water and environment need a new scientific and administrative framework which will be able to solve them more efficiently. Of special importance is the establishment of firm network of contacts with leading independent scientists, who promote new ideas and concepts independently of mainstream directions. Transfer of information across spatial and/or temporal scales is one of the most fundamental issues in the water hazard and risk management investigation. Each country, region and catchment has particular natural characteristics, but the hydrological laws of water circulation are the starting point of any further understanding of the ecological relationships that govern productivity and biodiversity within it. Understanding these relationships is vital to successful and cost-effective nature conservation and restoration, and water hazard and risk management. Transboundary karst water resources management should use principles and experience of conflict resolution as an essential management component.

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Transboundary Resource and Good Neighbourhood: Case of joint management of fossil water layer in the South

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Abstract

Algeria, a vast territory, has border with nine countries. It shares with some of them, such as Tunisia, Libya and Marco, natural (water) resources. These resources are of two types, in the north, they are superficial and are the waters of Oued Medjerda in the East, and Tafna in the West of the country; in the south, they are groundwaters which constitute the fossils water layers shared between Algeria, Tunisia and Libya. The first category cannot be considered interesting except during rainy periods because that could provide water to downstream dams such as Ain Dalia at Souk Ahras. At Oued edjerda, in the east, water flows in the direction Algeria - Tunisia. The water flowing in the Oued Tafna, in the West, are in the direction Morocco - Algeria. On the waters enclosed by the basement of the South, they make an important reservoir that must be carefully managed because they are not easily renewable. For information, the stored volume reached 50 000 billion m^3. However, this resource is used by the three countries and is threatened by an over-use. For instance, the extracted volume in 1970 was 0.6 billion m^3, at the present time it is around 6 billion m^3. This requires the establishment of the SAS (Sahara Aquifer System), the managing system of this resource. For instance, in Algeria the use of this resource has begun slowly. Nowadays, the launch of various agricultural development plans which has trained the putting in value of farmland, requiring large amounts of water. At present, the Sahara Aquifer System is recognized and is used by nearly 9,000 water points : drillings, springs and foggaras. By country, these points are distributed as follows: 6500 in Algeria, 1300 in Tunisia and 1200 in Libya. This use, if not regulated, might cause problems such as the increase of water salinity is important, this resource will not be used; the water level has declined steadily, and its cost increases, as many farmers increase their depth of drilling; the natural outlets: artesian wells and springs dry up, it is the example of Tolga where the irrigation was done by the springs. The interference between different parts of the basin are sometimes important, there is often a change in the direction of flow. To avoid these constraints, the three countries should opt for the effective management of this resource.

Keywords: Resource, transboundary, SAS, CT, CI.

1. INTRODUCTION

The scientific studies have shown that the Sahara does not contain only the black gold, it contains also the blue gold with large amount. In fact, nowadays the Sahara does not evoke only the large arid and desert areas; the area is less watered and very hot. The few mm of water that fall (50-100 mm annual average), evaporate immediately. Thus, the surface water is almost nonexistent, but instead, it is very much in depth. It is the North Western Sahara aquifer, which extends over one million km^2 in Algeria, Tunisia and Libya. It contains about 31,000 billions m^3 of water. This water is used for more than a century; it is the cause of urban and agricultural development in the region, particularly the cities of the Saharian Atlas. From the seventies, and facing the agricultural and industrial development of southern cities, the demand of groundwater has increased which could lead to an over-use of the aquifer.

For information, deep wells and drillings (down to more than 1000 m) proliferated over the last thirty years. At the rate of nearly 10,000 work each year, more than 2.5 billion m^3 of water are aspirated, against only 600 million in 1970. To avoid destocking of the water layer (CI and TC), the use of shared management of the resources between the three countries became inevitable.

2. MAIN FORMATIONS AND WATERSHED BOUNDARIES

An examination of the geological outcrop map (Fig. 1) defines the Continental Intercalary (CI) as the continental whole included between the Hercynian folds, which drove the sea from the Saharan platform, and the marine invasion of the Upper Cretaceous. This whole includes continental sandstone-clay formations of the Lower Cretaceous, marine or lagoon sediments, post-Paleozoic and pre-Cenomanian interspersed within the CI (Busson, 1970). This definition of CI, which is the most extensive aquifer in the region, determines the limits assigned to the study area of North-Western Sahara Aquifer System. These are:

- In the Northwest, the southern versant of the Saharan Atlas,
- At the west-south-west, the limit of the Paleozoic outcrops,
- In the South, the limit of the CI outcrops with the the Paleozoic
- In the North, the Southern Atlas accident in the north of the salt lakes, relayed to the Gulf of Gabes by the El Hamma - Medenine fault.
- In the North East, the outcrops of the Continental midsole at the Dahar and Jebel Nefusa.
- To the east, and passing to the Sirte Basin, the CI waters become briny: That is the passage which has been adopted as the limit of the aquifer's freshwater CI (Oss, 2003b).

The Terminal Complex (CT) group under the same name several aquifers situated in different geological formations (Senonian, Eocene and Miopliocene) because these layers are clearly part of a single hydraulic unit (Bel and Cuche, 1969), (Oss, 2003a,b), (Babasy, 2005). The interconnections between Senonian, Eocene and Mio Pliocene are evident throughout the basin, except the region of salt lakes where the impermeable middle and upper Eocene is interposed. The Turonian water layer is more individualized through the impermeable cover of the lagoon Senonian, but its levels compound with those of Senonian or Mio Pliocene at the border of the basin (Bouzian. M.T. et Labadi, A. (2009), Chebbah, M. (2007)..

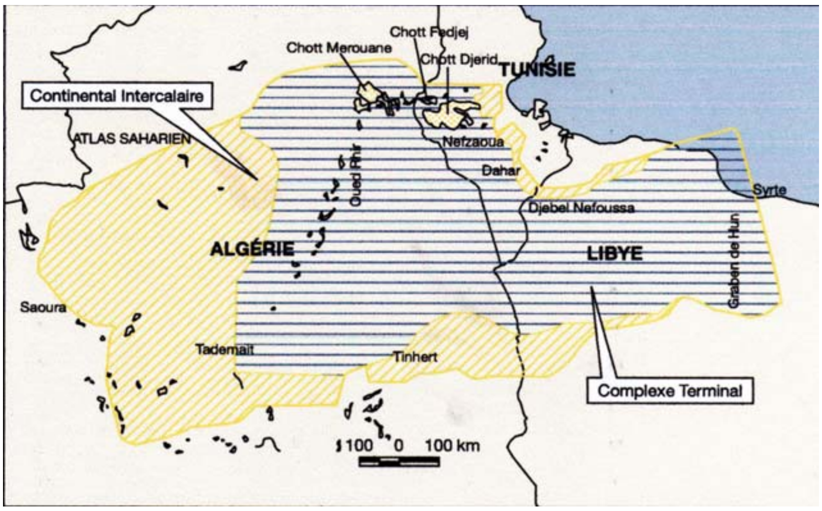


Fig. 1: Extension of the SASS formations

3. COMMUN MANAGEMENT OF TRANSBOUNDARY BASIN

Aware of the fragility of the system, Algeria, Tunisia and Libya, have opted for transboundary management of the aquifer system. This management is provided by the Sahara and Sahel Observatory, based in Tunis. The objective of this management is double:

- To master the individual explotation of each country,
- To Collect measurements made in drillings and wells (high level, amount of water pumped, salt content, etc..) integrate them into a numerical model simulating the evolution of the aquifer to control in real time takings and launch any alerts when pumping is excessive Fontes, J.C. (1976), Mamou, A. (1990) . All the challenge of this management is to adjust the supply to the demand, taking into account the demographics changing and the needs of water for drinking, industry and agriculture. However, this collaborative management will not save the aquifer, it will only increase a bit its longevity. From now, other solutions must be considered to fill the needs of a population which will reach about 8 millions by 2030.

4. PRESENT STATES OF THE EXPOITATION SYSTEM

The Saharan Aquifer System is recognized and exploited by nearly 8,800 water points, drillings and springs: 3500 at the Continental Midsole and 5300 Terminal Complex. By country, these points are distributed as follows: 6500 in Algeria, 1200 in Tunisia and 1100 in Libya.

The evolution of the number of drillings and their operating regime indicates very important increase of the exploitation (Fig. 2). It has now reached 2.2 billion m^3 /year [i.e, 1.33Milliard in Algéria1, 0.55 in Tunisia and 0.33 in Libya](**SASS, (2003)**. Because of this big large use, the first signs of water resources deterioration have already been noticed.

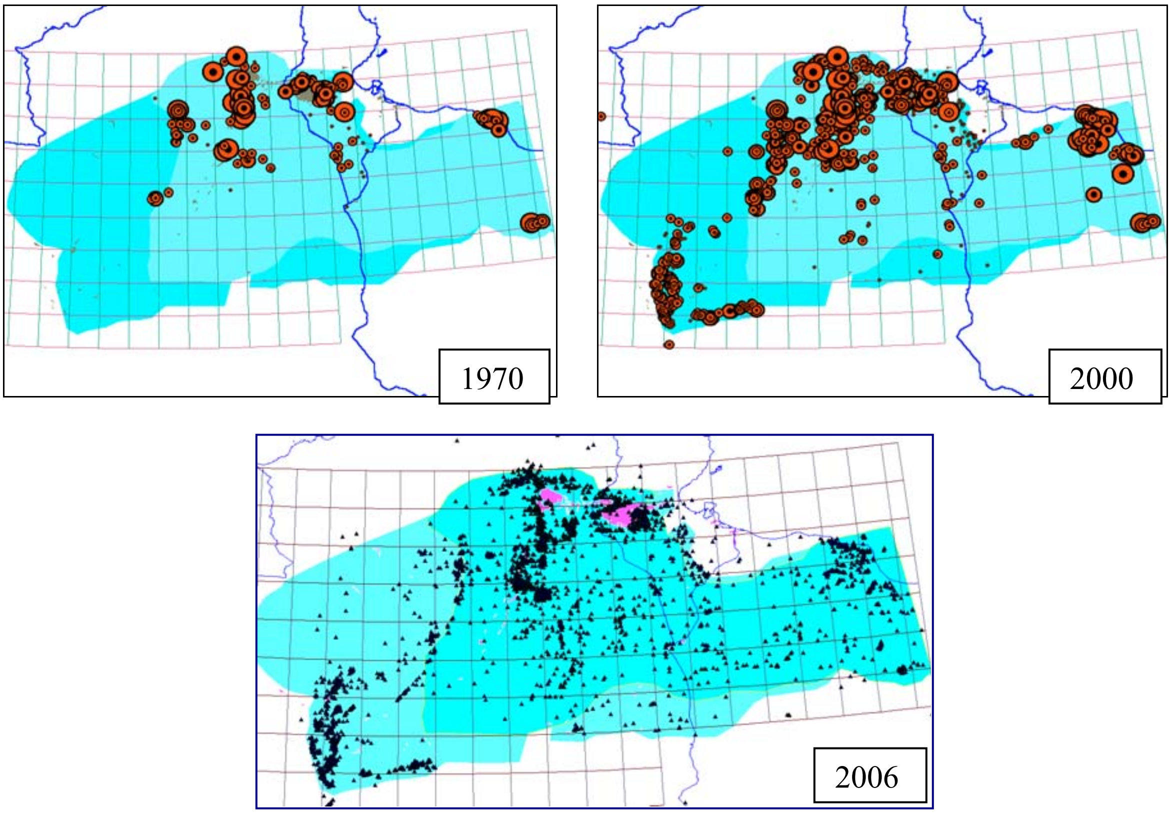


Fig. 2: Withdrawal by drilling in the SASS (1970 - 2000-2006)

In detail, we notice a significant increase of the use. This latter has increased in the early 80s especially in Algeria where it is estimated at 1.33 Billion, it is of 0.55 in Tunisia and 0.33 in Libya (Fig. 3).

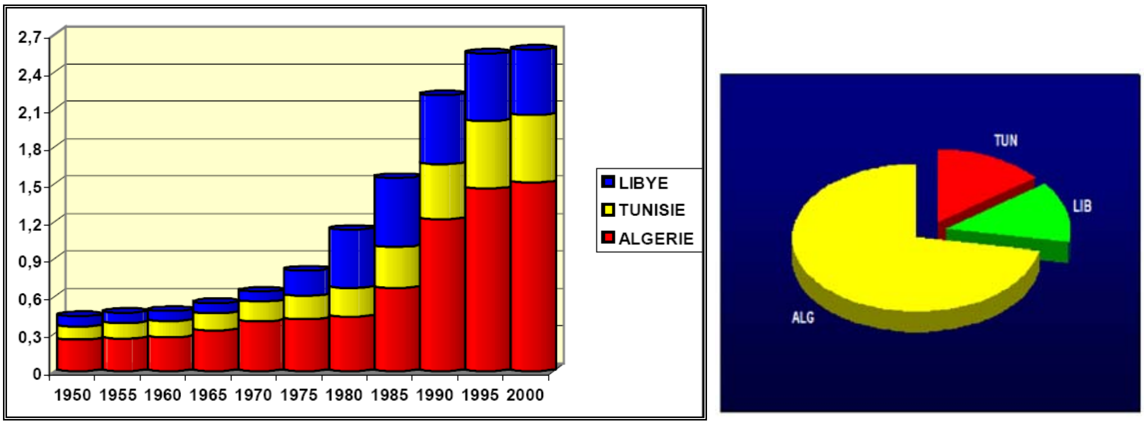


Fig. 3: Temporal variation of the aquifers use

The large use of the aquifers has prompted the three countries to opt for a joint management of this resource. However, it must be done according to the scheme developed by the three partners (Fig. 4). The diagram drawn by the ministers' board is known as SAS. In act, the three SASS countries have decided to create a permanent tripartite consultation mechanism for joint management of the aquifer. Its duties are multiple and focussed on the production of monitoring indicators. In detail, each country has designated a focal point for SAS; this will develop the databases and the promotion of study, research and training, and the reflection on the future evolution of the mechanism.

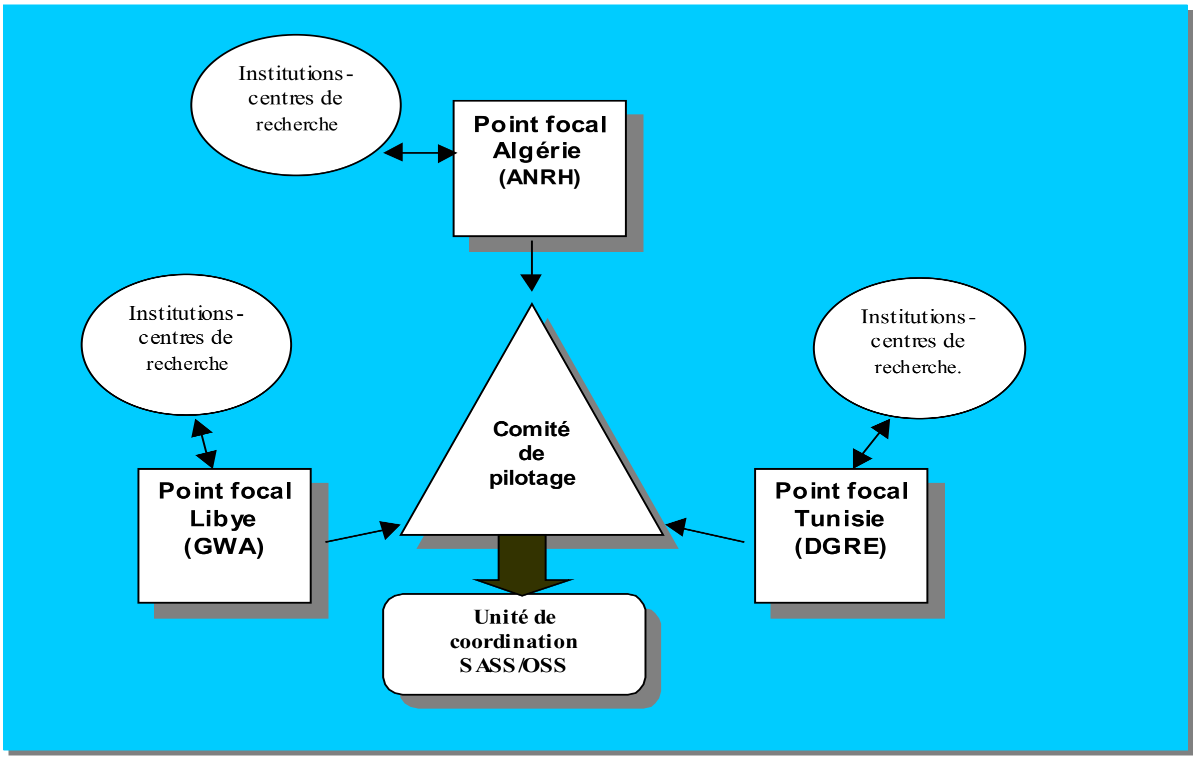
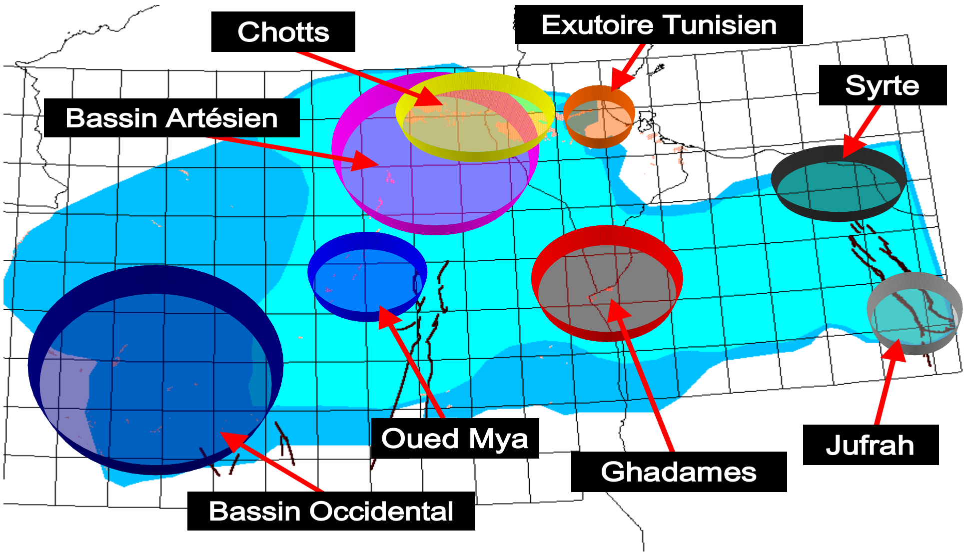


Fig. 4 : Mechanism of consultation Scheme.

This concerted management will reduce the proliferation of major risks in the strong interferences between countries, water salinization, artesianism disappearance, outlets drying up, and excessive pumping depths, as determined on the risk map (Fig. 5). Enumerated risks affect the whole extent of the aquifer and the three countries concerned. We also note:


Chotts
Exutoire Tunisien
Syrte
Bassin Artésien
Oued Mya
Ghadames
Jufrah
Bassin Occidental

Thus, a simultaneous representation of all layers was adopted (aquifers and aquitards) (Zammouri, M. (1990) , which allows to take into account the links and the hydraulic and chemical exchanges between all layers of the basin, and therefore the system behavior in medium and long term.

6.2. Exploratory simulations

The period chosen for the calibration was the historical period 1950-2000, with, as initial condition, the situation measured in 1950. A baseline scenario, called scenario zero was defined. It consists to maintain constant withdrawals made by drilling in 2000 and to calculate the evolution system corresponding to 2050.

6.3. Results of exploratory simulations

These exploratory simulations have put in evidence the nuisance and risks to which the water resource is exposed. To continue the use of the CI and CT water layers, these risks must be minimized and managed, which can be summarized as:

a) artesianism disappearance,
b) excessive pumping depths,
c) Tunisian outlets drying up,
d) excessive drawdowns interference between countries,
e) potential recharge by salt lakes.

6.4. Management

In Algeria, two scenarios:

a) A hypothesis, considered to be strong, representing an additional withdrawal of 101 m^3/s, which would bring the Algerian withdrawal to 42-143 m^3/s between 2000 and 2030;

b) A hypothesis, considered to be weak, for an additional withdrawal of 62 m^3/s, which would bring the withdrawal from 42 to 104 m^3/s.

In Tunisia: The scenario states that the savings through improving the irrigation efficiency will offset the additional demand for new irrigated areas, which corresponds to retaining the current.

In Libya: exploratory simulations concern two programs of the Great Artificial River Project [GARP]: the Ghadames-Derj pumping field, with an additional flow of 90 $Mm^3/year$, and capturing field of DJebel Hassaounah.

In terms of exploratory simulations, the principle adopted was to overcome the search of developping scenarios based solely on predictions of water demand, and to seek to build scenarios based on hydraulic, established on production capacities of SASS and minimizing the risk of identified nuisance.

7. CONCLUSION

The combined use of hydro geological knowledge and that of the model can make realistic conclusions about the ability of SASS to provide significant amounts of water while minimizing the risks on the resource. The results obtained show that it suits to jointly manage that resource. It is in order to prepare joint use that has been recommended by the OSS, from the launching of this project, to promote an awareness of the water and implement a "consultative mechanism".

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Case Study of Transboundary Aquifers in Yemen:

UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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ABSTRACT

The complex field hydro-geological researches are executed in Yemen. Some complexes of underground waters have a local distribution, and some of them are transboundary aquifers. Yemen and Saudi Arabia is located on the Arabian Peninsula and part of the groundwater flow comes to the Red Sea and Indian Ocean. At the same time penetration of the sea-water to the water-bearing strata presents certain danger to the costal water withdrawal. The executed researches have been taken as a principle mathematical models. On the basis of the executed complex hydrogeological researches by the author the estimation of natural and operational stocks of underground waters has been executed, places of creation of underground water basins are offered, ways of formation of stocks of underground waters to the largest wadi Hadramaut are studied.

Key words: arid territories, transboundary aquifers, underground reservoirs, irrigation, mathematic modeling

1. INTRODUCTON

Water resources are one of the most valuable components of the environment. Sustainable development of the countries to a greater extent depends on their state. Over 30 % of the world population lack access to a safe water supply and some do not have even basic sanitation. Every year over 50 millions of people are suffering from poor water. The United Nations General Assembly announced the beginning of the "Water for Life" Decade.

Arid territories (deserts and semi-deserts) occupy approximately 1/3 of the surface. When studying the World arid territories the scientists face various problems. The biggest one is lack of data on atmospheric precipitation, surface and sub-surface water flow (Kalinin, 1998).

2. OBJECTIVES

In presentation I would like to highlight the issue of water cycles variables in water management of transboundary aquifers wadi Hadramaunt (Saudi Arabia and Yemen). I had worked in Yemen for 3 years and tried to integrate the isolated data on water cycles and supplement it with the outputs of my own research. A series of field experiments had been carried out in the arid mountain and intermountain regions of the Yemen southern and eastern provinces. The main feature of the region was the lack of the regular scientific observation on the natural waters and absence of data about some of the regions. The data was collected on frequency and intensity of rain, specifics of flood in wadi, subsurface water levels, amplitude between rise and recession periods, quality of water (Kalinin, 1997).

The studied region is located in the Middle East. Two thirds of the population is involved in the agricultural production which is concentrated on the 5 % (percent) of the territory. The rest of the land (almost 95 %) are arid territories – deserts & semi-deserts.

In Yemen Republic a number of joint projects were implemented in specific areas by foreign and local experts during several decades. Nevertheless the projects dealt with specific issues – either – description of water supply source and recommendation of how to use it, or flood regulation issues besides drilling wells. All these projects did not allow to build up a complex view of the formation and distribution of water resources, as well as questions of water management.

For Yemen, which is located in the southern part of the Arabian Peninsula, the most significant problem is to increase the volume of the pumped-out ground waters from the artesian wells. This should be carried out due the running process of depletion of water resources.

Yemen land forms were formed under the active neotectonic movements of the earth's surface. Whole territory can be conventionally divided into coastal area, upland region and wadi Hadramaut area with intermittent riverbeds and springs. Wadi is an Arabic term used for valley with periodic surface or flood flow.

Climate in Yemen is tropical, which determines two different seasons: hot and relatively cool. Hot season coincides with the monsoon from Africa. Average daily temperature is 39 ^{0}C in the western part of the coastal zone and it reduces down to 30 ^{0}C in the eastern direction.

In hot season amount of precipitation is over 300 mm (Mukeiros and El-Dali). Air humidity in the coastal region is permanently high – over 70 %.

Relatively cool season starts in October and lasts till April. Daily temperature in the mountains is 23 ^{0}C in January, in wadi Hadramaut – 27 ^{0}C. Air humidity reaches 90 % in Aden. There are over 200 sunny days a year. Solar radiation is higher then in other parts of the world at the same latitude.

In the region there are no permanent large rivers and water reservoirs. Just one small permanent water flow exists on the surface of wadi Hajar.

Surface water is formed only due to the atmospheric precipitation – in the period of monsoon rains. The specific feature of the basin hydrology is the predominance of the mountain area of water supply over the plain area. Flood water flows on the surface to the sea more faster, then it infiltrates to the water-bearing strata. The temporary ground dams are constructed to increase the irrigated areas. Water for agriculture and to drink is located mainly underground.

Available land is limited. It constitutes around 1 % of the investigated area. Only 50 % of the population need in grains and vegetables is covered by agriculture.

Regular observations on underground water levels and its chemical content are not carried out in the provinces. Records on underground water consumption for irrigation and other needs are not stored. Indirect quantitative data on underground water consumption is being collected only in small areas and have eventual character.

3. RESULTS

The author had estimated the stock of the underground waters on the investigated area, which is used for drinking and agricultural purposes. The operational stock was estimated by analytical and mathematic methods. The map which was developed on this data might allow conducting the reconnaissance of the underground water. It was stated that a sufficient amount of underground water is located in wadi Hadramaunt as well as in the eastern part of Ramlat-es-Sabain desert (Saudi Arabia), where the estimated stock for the next 50 years would be over 10 dm^3 per km^2 in one second. Total potential stock of the underground water for 5 provinces of Yemen is estimated for the next 100 years of operation as 9,4 km^3 per year.

For the first time both the potential water resources for the mountain regions where they grow coffee as well as demand for water were estimated. A modulus map on exploited resources of underground water was build. It was estimated that potential stock of water for the coming 100 years is about 100 million m^3 per year. But for the sustainable development of the region the demand for water is around 107 million m^3 per year.

Natural resources of the underground waters are poor and do not provide future or existing demand for water.

As it was stated above the surface waters are formed mainly due to the precipitation. Floods take place once or two times a year. At the same time there are years when it rains up to 15 times or exclusively dry periods when surface waters are not formed during a couple of years. In such periods the river beds in wadi remain dry.

Rain floods of various intensity and duration are observed in monsoon periods. Depending on the place of formation the streamflows come either to the sea or to the mountain cavities. They also can be trapped in the deserts.

Permanent and temporary dams are built up to redirect the streamflows for the irrigation purposes but the construction of the dams is quite expensive, besides, evaporation leads to the high losses of water.

As one of the rational means of water consumption in the arid territories, it was suggested to create underground reservoirs. It means that, artificial mountain cavity would be used for accumulation and operation of the underground waters and streamflows. The complex hydrogeological study, which was carried out in the mountain area, pointed out 77 places for future underground reservoirs.

The estimation of the natural and operational stock of subsurface water was done for the biggest wadi of the Arabian Peninsula – Hadramaut by mathematic modeling on the base of data collected by the author.

As a result of the researches it was stated, that recharge of the water-bearing strata is replenished by atmospheric precipitation which is, however, not equal in the catchment area and unequally infiltrates to the ground water strata. If we conventionally divide total amount of precipitation into four parts it will be obvious, that one part infiltrates directly into limestone of seiwoon suite through ravine system, another, which is collected on the plateau comes first through cracks and karst cavities into limestone of Jezza suite, and, after that, infiltrates into limestone of seiwoon suite. The third part forms surface run-offs and flows into the main streamflows. It fills soil with water, recharge the alluvial strata both within inflow territories, and main valley, especially during high waters. The fourth part of precipitation which falls out in wadi Hadramaut, evaporates and infiltrates into alluvial-prolluvial sediments. If we take advantage of data on balance of surface waters during the spring, then we would notice that the first, second and fourth parts take 46 % of the water recharge, and the third part - 54 %.

Extremely important feature of water intake in the Cretaceous sandstone is the presence of a thick Paleogene limestone layer above, which accumulates significant volume of water in storm rains periods.

However as limestone and sandstone are alternated by clay soils, and water, which infiltrates into the clay soils, does not come directly to the lower sandy strata but spreads gradually. It means that limestone substitutes underground reservoirs which feed the main water-bearing strata. The value reaches its utmost in monsoon periods. It helps to keep the precipitation for water-bearing replenishment at a maximum extent in a catchment area and prevent from useless disperse of water in the form of surface run-off.

Natural stock of the underground waters is estimated in 350 km^3 in wadi Hadramaut. The main part is located in sandstones. Relatively small amount is placed in alluvial water-bearing strata – around 15

km^3. Aground 1500 wells needs to be constructed for water withdrawal with flow rate 2 000 m^3 per 24 hours each.

4. CONCLUSIONS

Some problems territories Arabian Peninsula still remain not studied. They are the following:

1. Role of precipitation condensation in the increase of the transboundary aquifers of the arid territories Arabian Peninsula.
2. Problems connected with the relic water (transboundary aquifers) which is 7 - 20 thousand years old.
3. Yemen and Saudi Arabia is located on the Arabian Peninsula and part of the groundwater flow comes to the Red Sea and Indian Ocean. At the same time penetration of the sea-water to the water-bearing strata presents certain danger to the costal water withdrawal.

Issues connected to the interaction of the sea-water and underground water in the costal areas of Yemen still needs solution.

Certain gains have been made in study of transboundary aquifers wadi Hadramaut (Saudi Arabia and Yemen). But a major effort is still required.

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Deep Transboundary Water-Bodies: Exploration & Management in the Pannonian Basin of the Republic of Croatia

UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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ABSTRACT

Oil & gas exploration and production information in north Croatia opens the way to delineation and characterization of deep water bodies of the Pannonian basin or the Danube-river basin, most of which are transboundary between Croatia and the surrounding countries.

The importance of this presentation is to improve the understanding of Croatia's deep transboundary aquifers with the information and knowledge from the countries where they are already recognized as well as to point out their existence to the countries where the process of their delineation is in development. There is need for stronger opening of discussion about deep transboundary water bodies. This can be achieved by introducing understanding of deep geology, here obtained by the process of O&G I&P, to point out strategic water reserves and water as a carrier of mineralization and geothermal energy. A more holistic approach to water is also a crucial environmental feature.

Croatia shares a number of deep transboundary aquifers with surrounding countries, and support in the implementation of world standards in the area is important. Countries that have deep transboundary aquifers should assist each other in aligning the national laws, rules and procedures and ensuring institutional capacity in fulfilling the planning, regulation, reporting and information requirements to harmonize with world standards. Multilateral collaboration of experts from abroad, meeting specific local experience and vice-versa is important in the delineation and characterization of these features, and supporting of the process with new knowledge and experience.

The most prolific water bodies are available in reservoirs of fissured massive rocks, especially karst developed carbonates, and most common and widespread are primary porous clastic rocks. According to chemical characteristics we can find potable water very deep in the Basin fill, as well as in the deep burned bedrocks. Delineation of saline and high saline water bodies is important as well as of geothermal aquifers. The results of geological, geophysical, petrophysical and geochemical information from O&G I&P process are an available base for the delineation of deepwater bodies.

Key words: exploration and management, deep transboundary aquifers, Pannonian basin, fresh, mineral & geothermal water.

1. DELINEATION OF DEEP WATER-BODIES

Exploration and management of deep water-bodies, some of which are transboundary in the Pannonian basin of the Republic of Croatia, is an important issue for the country's economy. In the beginning it is important to underline the meaning of deep water body character to distinguish them from ground water-bodies, explored and produced by hydro-geological methods and subsurface catchments. If we use criteria that thermal water temperature should be above 30°C, most of deep water-body will fall in that group. The geothermal situation in the discussed part of Pannonian basin (high geothermal gradient 5°C/100 m, mean surface temperature 11°C) suggests that we can find thermal water under 400 m of depth in tertiary basin areas. Last, but not least criteria is that they are much more isolated from surface waters influence then ground waters, but connections are possible, and here, as in all other cases, we have to bring all criteria and our understanding of certain features together to delineate deep water-body from ground water-body.

Our experience and open questions will meet the aim of the Conference, to bring together leading world experts in the fields of law and water sciences, to discuss approaches for the sound management of transboundary aquifers, in differently developed countries. Management of such aquifers is not an internal issue and has to be harmonized with the neighbors and monitored by the international society, sharing experience and resources. It is from the transboundary aquifers themselves that we have to learn most, about their natural characteristics and dispositions, and follow those in our management and policies as much as it is possible.

1.1. Geographic and geological presumption

The north part of Croatia is located in the southeast area of the Pannonian basin. This Tertiary sedimentary basin is situated between the Alps, the Carpathian and the Dinaric mountain ranges. The basin water bodies are connected with reservoir rocks developed in the Tertiary and Quaternary sediments sequence. They are mostly, sedimentary clastic and carbonate and below them are buried, in older aquifers, parts of surrounding ranges of Hercinian and Mesozoic consolidation.

1.2. Characterization and classification

The most prolific deep water-bodies are available in massive reservoirs, which are some fissured rocks formations, especially if we deal with mighty carbonates sequences, where karst features are developed. On the other hand, most common and widespread are different sandstone bodies, controlled by primary porosity.

According to chemical characteristics we can find potable water very deep in the basin fill, as well as in the rocks below the basin fill. Delineation of saline and high saline water bodies is also important. Favorable terrestrial heat flow, applied over the deep water-bodies, makes them attractive as geothermal aquifers, a favorable media to tap geothermal energy surplus.

The results of geological, geophysical, petrophysical and geochemical information, together with hydrodynamic testing and production, from oil, natural gas and geothermal water exploration and production are make a substantial base for the delineation of deep water-bodies.

In one case story, an attempt in year 2006 was undertaken, to make a more complete regional picture of a broader area of SW Pannonian basin of North Croatia and SW Hungary, or part of the Danube-river basin. It was attempted to exchange our experience in exploration and production of oil, gas and geothermal water in Croatia with international and Hungarian experience as member of the ICPDR (International Commission for the Protection of the Danube River) which takes part in the work of WFD related expert groups, since 2002, especially in the field of transboundary groundwater bodies.

Criteria for the delineation of water-bodies have been designated on the guidance according to a hierarchical approach, in harmony with the possible lateral and other changes of body characteristics:

- *type of the geological feature*s:
  - type of reservoir porosity:
    "karstic" (k) in fractured and karstic type porosity
    "porous" (p) with primary developed porous

Both of them can be in basin or outcropping position, or mixed basins and mountainous position

- *Containing water temperature above 30℃* in thermal karstic (kt) / porous (pt) water-bodies.
- *subsurface catchments* in:
  Hydro-geological units in porous / karstic aquifers,
  Water management units of mountainous region,
- *Large scale upward flow* in the water-bodies of alluvial plains, to make distinction in chemistry and in the sensitivity of groundwater dependent ecosystems.

With this approach, we understand that some deep water-bodies can have hydrodynamic connection with different ground water-bodies.

We have to be wary careful if we claim deep water-bodies to be:

thermal karstic (kt) and
thermal porous (pt)

In that starting attempt it was necessary to make regional unification, simplification and to bring together, sometimes numerous and in some criteria different features. Further on, we deal only with deep water-bodies or deep thermal karst and porous features, hydro-geological objects we left aside. To indicate possible deep water-bodies with transboundary character, we found the results quite satisfactory.

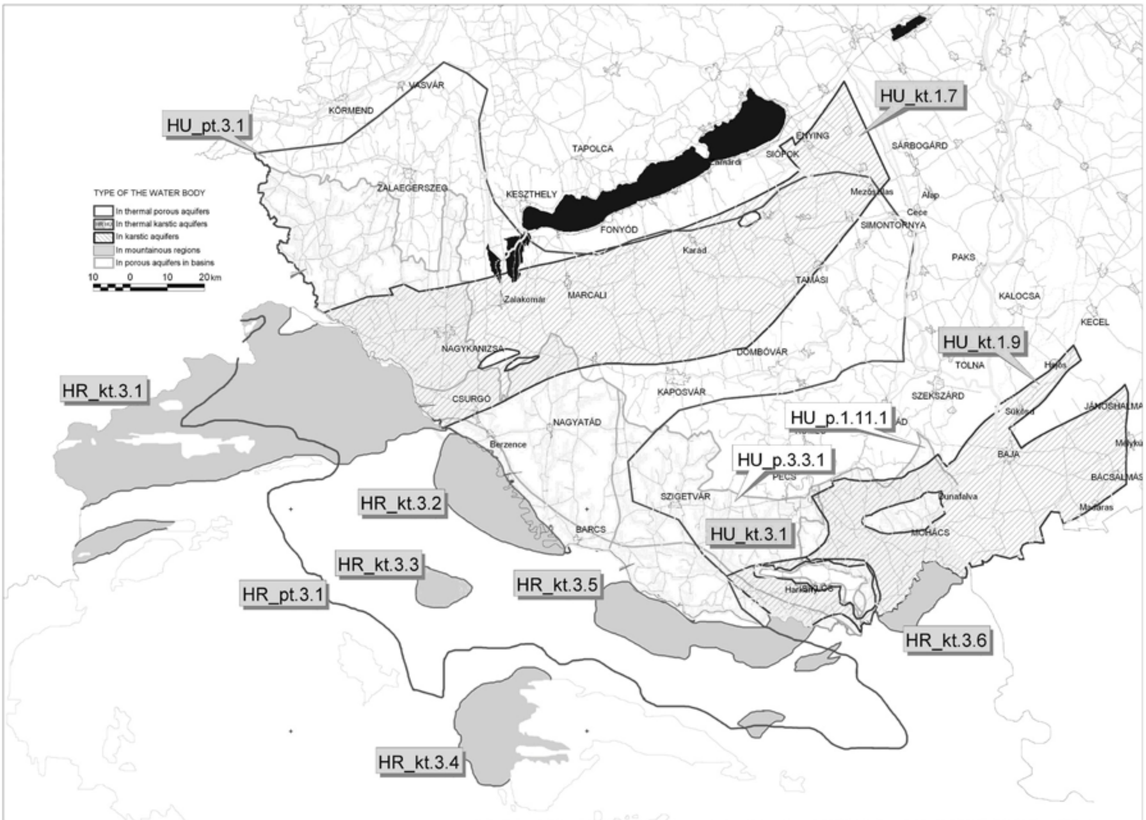

Figure 1. Presentation of important water-bodies along the Croatian – Hungarian border line. At the Croatian side only the deep water-bodies, or thermal karstic and porous aquifers are pointed out and arbitrary transboundary connections with the potentially matching ones on the Hungarian side. From the 8 delineated thermal karstic deep water-bodies 3 are possibly of transboundary character as well as 1 thermal porous deep water-body in the Tertiary Drava basin fill. Later oil and gas explorations result with gas-condensate field discovery in NW part, of the complex Mesozoic-tertiary "karst" water-body HR_kt.3.5, by its transboundary prolongation to the Hungarian side.

2. LEARNING MORE ABOUT DEAP WATER-BODIES

It its from the early sixties that experts at the O&G company INA Naftaplin and the Mining university of Zagreb (Čubrić at al., 1995; Jelić at al., 2000 &2005; Kolbah et al., 2010) have made advances in the understanding of the deep water bodies of the NW Croatia, in connection with oil, gas and thermal water production, and have been continuously reporting at the *World Geothermal Congress*. Numerous geothermal testing and production preparations about deep water –bodies was gradually performed up today (Kolbah et al., 2004, 2007, 2008 & 2009; Pravica et al., 2006; Kulenović et al., 2006; Kurevija et al., 2008 a & b).

An attempt to collect all the experience necessary for further exploration and management of that deep resources in NW Croatia is organized and in great deal produced in the modular project (Kolbah et al., 2006).

Building regional geological solutions makes the basis for understanding all important natural processes necessary to get an idea of how to apply existing abandoned deep wells and other surface infrastructures or drill new facilities and develop technologies in harmony with both deep water-bodies (DWB) and surface enviroment. Better understanding of that complex issue finally can help in rising confidence in making crossboundary arrangements.

2.1. Scanning the deep water-bodies

Massive and very expensive information left after the intense period of oil, gas and geothermal exploration and production and experienced human resources make possible to do deep structural mapping of the basin conditions, through which we can follow speeding and characteristics of important DWB. Beside their deep geometry and buildup, it help us to fulfill a puzzle of understanding thermodynamic and hydrodynamic processes, carrying together al other important chemical and physical characteristic of active fluid water in first place.

There exist thousands of kilometers of 2D seismic lines and other geophysical information, also 3D seismic shooting on hundreds of wells holds a large amount of information that can be used for our purposes.

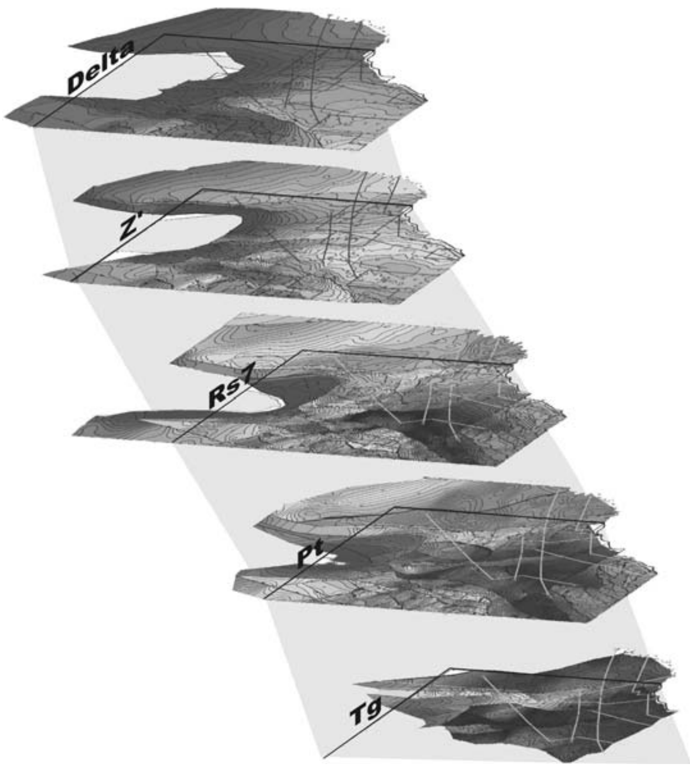

Figure 2. here we can see a mapping scan of most of the important features in the basin: Hercinian consolidated basement (Tg). Pre Tertiary rocks (Pt), mostly Mesozoic, with important carbonate bodies and geological mapping was performed to delineate them. Important sedimentary breakdown in mid Miocene (Rrs) help us to visualize that package of that basin fill, in quite irregular basis some additional important carbonate bodies and core braces formations are controlled in it, here further detailed works have to be done to delineate them. Most of the Pannonian sandstone reservoirs are controlled by thickness between top formation discordance (Z') and top mid Miocene (Rs7). Important Lower Pontian sandstones in same way are controlled by top formation marker (Delta) and top Pannonian marker (Z'). In deeper parts of Drava basins it is important to map top Upper Pontian sequence (Alfa) on which Pliocen and Quaterniar beds are spread.

2.2. Closing a circle

Geological interpretation of deep structures, we can say, starts with putting together elements on cross sections. The obtained results can be presented best on them as well, besides using maps.

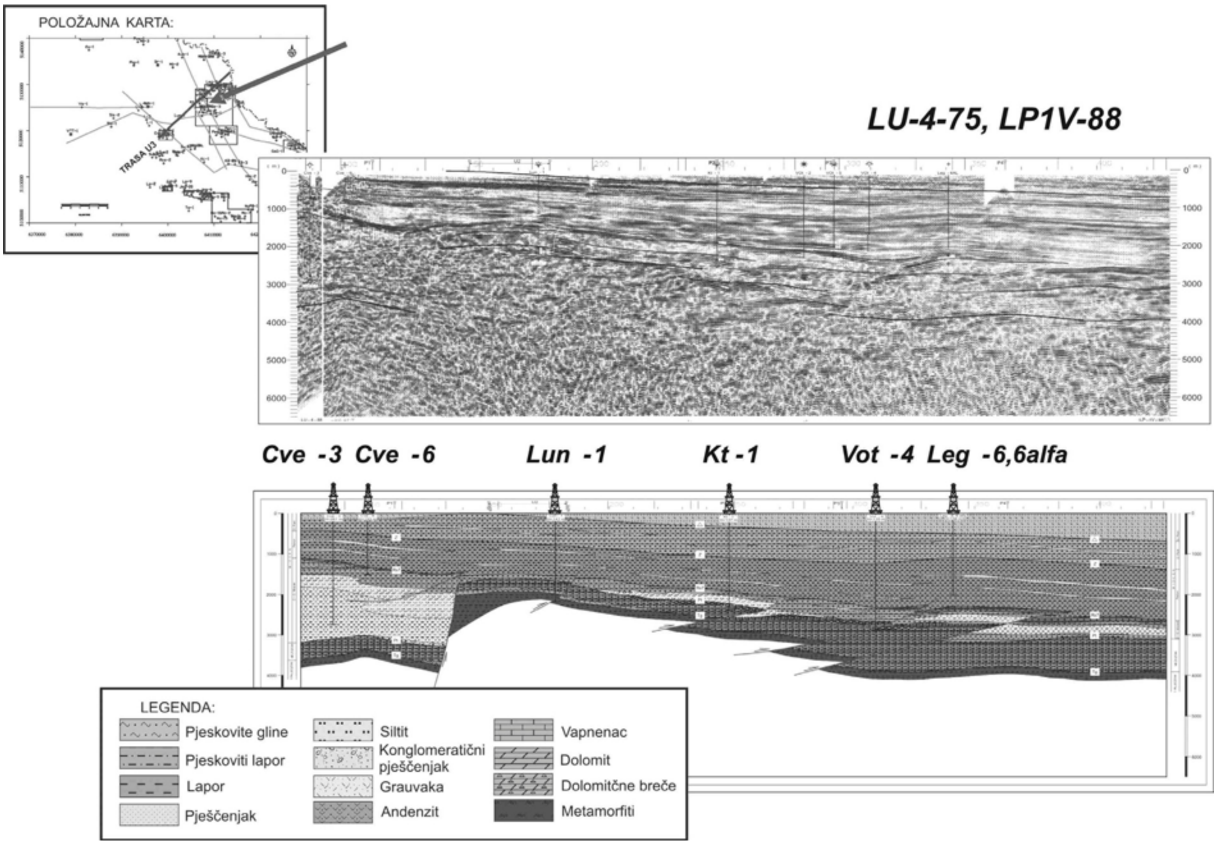

Figure 3. On cross section U2, important geothermal field Lunjkovec –Kutnjak is presented. On the NW end it shows crosboundary character of the main DWB in fractured Mezozoic carbonates, and also in the Tertiary sandstones of the area.

3. DISCUSION

Exploration & management of deep transboundary water-bodies in the Pannonian Basin of the Republic of Croatia have deep roots in Oil & gas exploration and production but its future is geothermal energy and water utilization in harmony with neighbouring countries. So far we discussed case stories from Drava River valley tertiary basin. Same experience we can apply on the border with Serbia, Bosnia and Hecegovina and Slovenia. DWB in Dinarides range of southern Croatia are not discussed here because they need different approach. There is a need for stronger opening of the discussion of deep transboundary water bodies. Transboundary agreements over the DWB can be achieved by introducing mutual understanding of the country's interest, with great help if both sides accept presented deep geological solution. Same understanding is necessary to protect crucial environmental features.

4. CONCLUSION

Croatia shares a number of deep transboundary water-bodies with surrounding countries. Using their own experience and getting international support creates a good chance to implement high world standards in the area. It is a long way to aligning the national laws, rules and procedures and ensuring institutional capacity in fulfilling the planning, regulation, reporting and information requirements to harmonize with world standards. Multilateral collaboration of experts from abroad, meeting specific local experience and vice-versa is important in the delineation and characterization of these features, and supporting of the process with new knowledge and experience.

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Global information and Knowledge Sharing on Transboundary Aquifers
- a discussion paper-

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ABSTRACT

This discussion paper is about generic benefit of transboundary aquifer assessments as carried out nowadays all over the world. The paper addresses relevance of assessed information & gained knowledge for others (than the involved aquifer states) in terms of replicability and lesson learned. Once the relevant knowledge is identified, it needs to be disseminated to the potential user in the most appropriate way. The paper discusses current practice and recommends further methodological development, harmonisation and use of contemporary information and communication technology.

Key words: transboundary aquifer assessment knowledge sharing

1. INTRODUCTION

During the last decade, with increase of general awareness about the importance of groundwater, an issue of transboundary aquifers (TBAs) has also started to receive more attention from international community. Very instrumental for this process were initiatives of UNECE (to conduct a first inventory of TBAs in Europe), of UNESCO & IAH (to set up an international program – ISARM), and of GEF (to include groundwater in its International Waters projects). In meantime, various TBA inventories and assessments have been conducted worldwide, producing valuable information and knowledge about this complex issue.

This paper addresses the following two questions:

- Which part of information & knowledge on a particular transboundary aquifer could be of practical use to others (than the involved aquifer states)?
- In which way should this specific information and knowledge be made available and accessible to potential users?

In order to discuss these questions, an overview of available TBA information is made, including among other its consistency, completeness and dissemination (the next chapter). The overview is followed by an analysis of generic TBA knowledge and its sharing (the third chapter). The article is rounded off with some conclusions and recommendations regarding TBA methodology and TBA knowledge sharing.

1. THE MAIN TBA ACTIVITIES AND THEIR GENERIC ADDED VALUE

This chapter gives a critical overview of the main TBA assessment activities conducted so far. Only the main regional and global TBA activities are included in the overview, namely: UNECE assessments, GEF TBA projects and ISARM Programme.

1.1. UNECE Inventory 1999

The first major step towards TBA assessment was made by UNECE in 1999 by organizing an inventory of transboundary groundwaters in Europe (UNECE Task Force on Monitoring & Assessment, 1999). The inventory report gives an overview of groundwater characteristics in 25 participating countries, identifying in total 89 transboundary aquifers. The questionnaire prepared for the inventory was quite comprehensive and contained mainly quantitative items, i.e. requesting numerical characterisation of aquifers (the subsequent

UNECE and ISARM questionnaires will be much more descriptive). The questionnaire forms were in most of the cases only partially filled out, showing the limited knowledge on TBAs. Moreover, the inventory team faced all the challenges of international data harmonization (language, classification, formatting, organizational and other differences). Finally, it became very clear that assessment of TBAs is much more challenging than the assessment of international surface waters. While the presence and extent of surface water is usually a given fact, in the case of (invisible) groundwater is that one of the main issues to be agreed upon between riparian countries. The same holds for all the other components of the assessment such as the status of the system, the future trends, measures to be taken, etc.

Generic added value of the 1999 inventory is its pioneering role in addressing TBAs, formulating their characteristics (the questionnaire) and providing a pan-European overview. Lesson learned, as briefly mention above, made a clear message about the importance and complexity of TBA assessment.

The UNECE inventory has lead to development of Guidelines on Monitoring and Assessment of Transboundary Groundwaters (UNECE Task Force on Monitoring & Assessment, 2000). An effort was made to generalise the findings of the inventory (and some other activities conducted at that time, namely about the use of models and indicators) in order to assist further assessment and management of TBAs in the region of elsewhere. Beside the monitoring and assessment issues, common management and institutional arrangements are briefly addressed as well. The guidelines are quite general but give a proper scope for further elaboration.

1.2. The first UNECE assessment 2007

After the 1999 TBA inventory, UNECE concentrated the TBA assessment at two following regions: South East Europe (SEE) and Caucasus and Central Asia (CACENA). The results of the assessment were presented in 'The first Assessment of Transboundary Rivers, Lakes and Groundwaters in UNECE region' (UNECE 2007). The groundwater assessment was carried out in cooperation with UNESCO, INWEB, IGRAC and other international organisations. For the SEE region, the main source of information was a TBA inventory & workshop from 2004 (INWEB, 2004) and the subsequent Thessaloniki workshop in 2007. For the CACENA region, the Almaty workshop in 2007 delivered the most of the aquifer data.

The first UNECE assessment was carried out following the structure of the "Driving Forces-Pressures-State-Impact-Responses (DPSIR) framework" adopted by the European Environmental Agency (EEA). This approach gives a quite clear regional overview of pressures (groundwater is exposed to), of current groundwater status (including the transboundary impact and management measures), and of future trends and prospects. Hence, this approach can be recommended for a regional assessment, certainly in terms of factors/characteristics to be taken in account/assessed. However, an assessment of individual aquifers asks for more elaborated methodological steps. During the first assessment, extent of aquifers is only partially delineated, and that mostly in the SEE region.

1.3. The second (on-going) UNECE assessment

The second UNECE assessment is on-going and it will be completed next year. This time, the intention in to assess surface- and groundwater in an integrated manner per catchment area. Practically, the second assessment of TBAs includes (next to SEE and CACENA) also Eastern European countries that are not a part of the European Union (EU). For the EU region, the second assessment will use the results of the EU Water Framework Directive (WFD) if those became available in meantime. Since the TBA activities in the second assessment are described in an other paper prepared (by A. Liponnen) for this conference, only a few lesson learned (so far) will be mentioned here:

- It is still difficult to implement a balanced integrated approach, especially in areas with large rivers where groundwater easily remains insufficiently addressed.
- EU WFD defines groundwater bodies (GWBs) rather than aquifers, causing the harmonisation difficulty at the borders of the EU. Moreover, the guidelines for definition (including delineation) of

GWBs are rather supple, leading to various interpretations across the Europe. Consequently, the GWBs within the EU are not harmonised yet. (It would be interesting to analyse the motivation behind various interpretations)
- The assessment remains politically very sensitive so that countries often hesitate to confirm the facts that are not completely obvious (which is often the case with invisible groundwater).
- So far, the assessment has not provided sufficient information on the role of groundwater in the changing world, regarding both anthropogenic impact and climate variability.

The second assessment is planned to be completed 2011; hence, there is still time for possible improvements.

1.4. GEF TBA Projects

In the last several years, Global Environment Facility (GEF) has initiated and co- financed several large TBA projects and encouraged inclusion of groundwater component in various surface water-related projects. The most important GEF TBA projects carried so far are:

- Groundwater and Drought Management in SADC
- Environmental Protection and Sustainable Integrated Management of the Guarani Aquifer
- Integrated Management of the Shared Nubian Aquifer
- Managing Hydrogeological Risk in the Iullemeden Aquifer System
- Protection of the North West Sahara Aquifer System (NWSAS)

These are large, long term projects, four of them located in Africa and one in South America. Also interesting for this discussion is the project 'Developing Renewable Ground Water Resources in Arid Lands: a Pilot Case - the Eastern Desert of Egypt', because of its replication objective and Protection and Sustainable use of the Dinaric Karst Aquifer System (DIKTAS), because of its hydrogeological specifics.

While the UNECE assessments provide a regional overview for dozens of TBAs and the countries, the GEF projects usually concentrate at one aquifer, allowing more in depth analysis. Besides, the GEF projects are not only about assessing but also about suggesting solutions. Each GEF International Water (IW) project comprises a Transboundary Diagnostic Analysis (TDA) and a Strategic Action Program (SAP). The TDA is actually a TBA assessment, including hydrogeological, ecological, socio-economical, organisational, legal and political facts relevant for actual or potential future disputes or conflicts. The SAP is primarily a joint suggestion for TBA management, including national ('baseline') and international ('incremental') activities. Noticeably, the GEF do not require a TDA to be conducted according to a prescribed elaborated procedure; a TDA content and the applied methodology are substantially defined by the specifics of the problem and by consensus of involved aquifer countries. GEF recommends use of experience from exemplary TDAs conducted elsewhere, which is useful (given the right selection of projects/cases) but not the most efficient way. Moreover, the aquifer countries (that are about to commence TDA) could have various opinions about experiences and recommendations made elsewhere.

At the moment, the TBA GEF projects are in various stages of execution and information about results already achieved is not equally available for all the projects. Nevertheless, some comparison and analysis of conducted TDAs can be done. It seems that hydrogeological part of TDA does not bring much novelties to be adopted elsewhere. From a hydrogeological point of view, it is certainly interesting to learn about some advanced implementation of satellite imagery or isotopes, but they are not specific for a transboundary context. Transboundary specifics can rather be found in data and information handling procedure, being not only a technical matter (differences in language, formats, references, classifications, software, etc), but also having its cultural, social-economical, organisational and political connotation. Nevertheless, experiences about transboundary data and information assessment and management could be used elsewhere, if made available in an adequate form. For instance, the Netherlands and a German state of North Rhine-Westphalia harmonised lithostratigraphical and hydrogeological classifications prior developing a common portal; that allowed on-fly semantic translation of groundwater information in the portal (Kukuric & Belien, 2006). Info on both the process and the technology should be clearly communicated if intended to be replicated elsewhere.

Replicability is often specified as one of the objectives in GEF TBA projects. 'Eastern Desert' was even not a TBA project and yet, the implementation of the in the project developed methodology to other regions and countries was one of the project objectives. Similarly, DIKTAS project addresses the assessment and management of a transboundary regional karst system and this unique experience is expected to be applied elsewhere. In order to achieve that, the relevant experience needs to be adequately described and conveyed, allowing for easy access to key information and necessary adaptation to a new situation. For instance, a standardised way of assessing/describing/presenting ecological or socio-economical impact of TBA problems would be very helpful.

Establishment of consultation and cooperation mechanisms is a part of each GEF TBA project, providing interesting approaches and solutions. These experiences could be sorted out with respect to relevant (cultural, political, organisational) conditions, allowing a better insight in their applicability elsewhere.

Suggested solutions included in the SAP (such as guidelines for community based management, training and outreach) could be very inspirational and instructive for other regions. Besides, some of the SAP solutions are already implemented or under implementation, bringing the reality check of their feasibility.

Two additional, on-going GEF project should be mentioned as well, being very relevant for improvement of TBA assessment and dissemination of results: Transboundary Water Assessment Programme (TWAP) and Enhancing the use of Science in International Waters Projects to Improve Project Results (SCIENCE). TWAP develops a methodology for a global assessment of five transboundary water systems (rivers, lakes, groundwater basins, large marine ecosystems and open ocean). The methodology will be used for assessing the changing conditions resulting from anthropogenic and natural causes. Development of the methodology is based on indicators derived from available measurements and proxy information. Hopefully, the global TWAP methodology will also bring more consistency in the assessment of individual TBAs. The GEF SCIENCE project is designed to recognize, capture, analyze and integrate the scientific findings from GEF International Waters projects and to disseminate them across the IW portfolio and beyond. The project includes activities such as documenting and understanding best practices and establishment of 'Science Learning Network'. Regardless whether the knowledge generated in TBA projects could be qualified as scientific of not, improvement of mechanisms for knowledge extraction, systematisation and dissemination is very much needed development.

1.5. ISARM

Internationally Shared Aquifer Resources Management (ISARM) initiative is UNESCO and IAH led multi-agency effort aimed at improving the understanding of transboundary aquifers. ISARM operates as an umbrella programme, (co)organising various TBA-related activities all over the world (www.isarm.net). The most of ISARM engagements in the past was at regional level, contributing to inventories and regional (initial) assessments of TBAs (similar to UNECE assessments, but than world-wide). In 2001, ISARM produced a Framework Document, identifying the main TBA aspects, namely hydrogeological, legal, socio-economical, institutional and environmental. Each of these aspects has required elaboration and methodological approach. In meantime, a substantial progress has been made in describing a legal TBA aspect. The International Law Commission produced so-called Articles on the Law of Transboundary Aquifers (Yamada, 2008), to be used as a basis for an international guideline, convention or a law. The articles are the result of excellent cooperation between layers and hydrogeologists that was necessary to properly capture hydrogeological issues in a legal form. It has been noticed that the legal clarity on basic TBA issues is already alleviating the assessment and establishment of transboundary (legal) agreements in practice.

Likewise the legal, the hydrogeological TBA aspect has also been further elaborated since the ISARM Framework is produced. A methodology for hydrogeological assessment has been suggested by IGRAC (Kukuric et al, 2008), consisting basically of three steps:

- Delineation and description
- Classification, diagnostic analysis and zoning
- Data harmonisation and information management

Although IGRAC has been involved in practically all ISARM activities, its main contribution so far has been to the hydrogeological assessment. In the last several years, the mapping activities (delineation and description) are carried in various parts of the world (Americas, Africa, Asia, Europe), yielding precious information on aquifers presence and extent (IGRAC, 2009). Yet, not all transboundary aquifers are delineated and many aquifers are delineated in an approximate manner. Even when TBA boundaries precisely match the boundaries of outcropped hydrogeological units, no further info is available on aquifer extent (depth, inclination) under the surface. Besides, aquifer countries do not always agree about delineation criteria and there is no consistency in conducted inventories and aquifer descriptions.

Aquifer delineation and description need to provide information sufficient for subsequent classification, diagnostic analysis and zoning. There are very few examples found of systematic classification and zoning, whereas DPSIR (used by UNECE) and TWAP (under development by GEF) are the examples of regional diagnostic analysis. The last step of the hydrogeological assessment (i.e. data harmonisation and information management) is addressed in next chapter.

IGRAC has also made an initial step to elaborate the remaining (socio-economical, institutional and environmental) TBA aspects (IGRAC, 2009). ISARM activities, as conducted so far, usually do not provide sufficient insight in these aspects in order to allow some methodological suggestions. On the other hand, various TBA conferences (e.g. Tripoli 2002, 2008, Ciudad Real 2006, Thessaloniki 2008) and symposia have generated relevant information that needs to be processed, together with experiences coming from GEF projects and UNECE assessments. That would lead to further methodological developments regarding economical, institutional and environmental TBA aspects.

2. GENERIC TBA KNOWLEDGE AND ITS SHARING

A number of TBAs activities conducted in the last decade is substantial. The results of these activities could be relevant elsewhere (i.e. outside of the activity region) by:
- contributing to the development of common methodology
- addressing (hydrogeological, socio-economic, etc.) specifics recognisable elsewhere

There is still no generally accepted TBA methodology; UNECE uses a rather descriptive DPSIR based framework for a regional diagnostics and GEF is currently developing indicator-based methodology for a regional/global assessment. At the aquifer level, GEF is using generally defined TDA, whereas IGRAC has elaborated the hydrogeological aspect of the ISARM framework. The necessary foundation for the legal assessment has been provided, but the same is still lacking for other (economical, institutional and environmental) TBA aspects.

Like in any other field, critical (sufficient) amount of information (produced) and experience (gained) is necessary for a mature methodological development. In that respect, international groundwater community has been making a tremendous progress during last ten-eleven years, carrying out numerous TBA activities and producing plenty of new pieces of information. Yet, since ISARM Framework Document (2001), no comprehensive guidelines have been produced addressing the complex assessment issue. Consequently, information produced is often not consistent in content and/or format, making it more difficult to comprehend, compare and accept elsewhere.

The other precondition for a methodological development and for use of experience gained elsewhere is information accessibility. The importance of conferences and symposia for exchange of experience is indispensable. In order to bridge the gaps between the face-to-face meetings, internet-based communities or fora are often introduced. A successful example is a Global Groundwater Forum, set up (by UNESCO and

IGRAC) to bridge two GEF conferences (2005 and 2007). General lack of interest to join a TBA forum could be partially explained by sensitivity of the issue, but this should not be decisive for the exchange of experience.

Although UNECE water website http://www.unece.org/env/water/ is not particularly conveniently arranged, UNECE is publishing all the information collected/generated during the assessment process, including meeting minutes, presentations, background documents, etc. This transparency is very relevant for the TBA process and the document repository alleviates the consistency of the assessment. On the other hand, only the final inventory and assessment reports provide to external user a clear insight in the implemented procedure and achieved results.

Accessibility of GEF initial project documents was always good, whether through GEF project database (http://www.gefonline.org/) of databases of GEF implementing agencies (such as World Bank and UNEP). However, the project sites needed more time to develop. Moreover, the sites contain mostly general project information and less descriptions of project results. Since the start up of IW-Learn initiative (www.iwlearn.net), visibility of GEF project activities has increased. Via the IW-Learn platform, GEF projects can use Website Toolkit, that substantially increases the consistency of published information. The toolkit contains a dynamic content management system that is rather easy to use and efficient. It also provides a possibility to generate RSS feeds and share news with other sites. The IW-Learn platform offers also templates for Experience Notes, a sort of lesson learned, nowadays a standard part of each GEF project.

The ISARM site (www.isarm.net) is a portal to information on the ISARM programme and various regional TBA activities. The portal provides a link to the IGRAC's Global Groundwater Information System (GGIS). The GGIS contains a TBA Global Overview, an interactive global map, connected with TBA indicators and related project organisations and documentation. A country-based Global overview connects to 70 attribute values (per country) and hundreds of documents and addresses. That is unfortunately not a case with TBA Global Overview (Fig.1). The main obstacle is a lack of harmonisation. Information collected through various regional ISARM enquiries needs to be harmonised prior storage in a common GGIS database. Only then the GGIS search mechanism can be employed to identify similar situation and reuse the knowledge gained elsewhere.

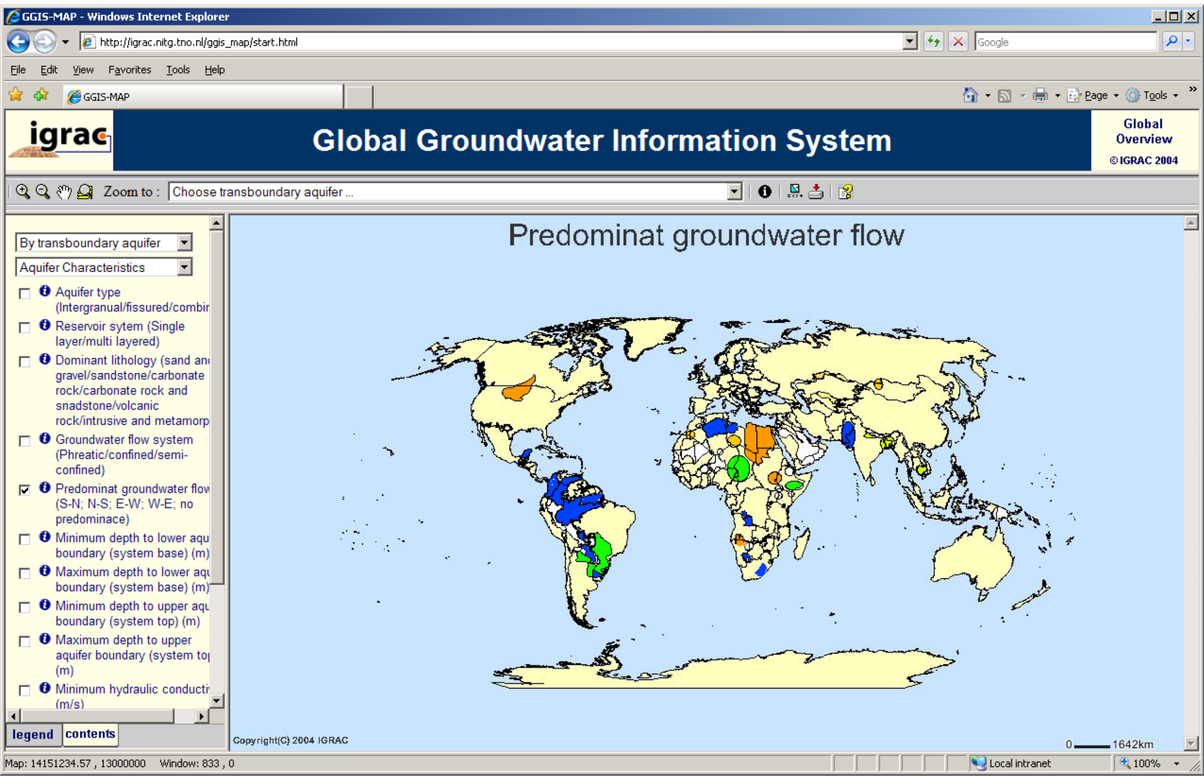

Figure 1. Transboundary Aquifer View (in GGIS - Global Groundwater Information System)

Harmonisation of TBA information is a difficult issue, not only concerning the content of collected information but also aquifer delineation. The experience of EU WFD shows that simple guidelines (EU WFD, 2003) lead to various interpretations and considerable delay in accomplishing the assessment. Consequently, WISE (Water Information System Europe) does not contain TBA information yet. ICT is not an obstacle any more and development of distributed and even real-time TBA information systems is already possible (Kukuric & Belien, 2006). The main obstacle is a lack of cooperation.

3. CONCLUSIONS

Amount of information on TBAs has been rapidly increasing during the last decade. The accessibility of information is gradually improving, also due to GEF, UNECE and ISARM activities and ICT advancements. However, TBA info if often collected, processed and disseminated in a way that do not allow easy comparison and possible reuse elsewhere.

A considerable progress has been made in shaping up a common TBA assessment methodology, especially regarding hydrogeological and legal aspect of TBAs. Yet, the other aspects (ecological, socio-economical, organisational) need to be elaborated as well. Use of common methodology would ensure higher consistency of information content and format, alleviating knowledge transfer and reuse. The ISARM core group needs to play a more active role in further methodological developments.

GEF IW-Learn initiatives such as experience notes and website toolkit (with RFF feed) also lead to better knowledge sharing. Contemporary ICT provides broad possibilities for web-based storage and processing of global TBA information that is relevant for reuse elsewhere and for policy analysis and planning. The main obstacle remains general unwillingness of aquifer countries to publish information that is not obvious or not easily confirmable (invisible groundwater). Fortunately, this is also a subject to gradual change, mostly due to unavoidable (and in this case positive) globalisation.

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Geochemical and neo-tectonic data provides a new understanding of the hydrogeology of the Great Artesian Basin

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ABSTRACT

The Great Artesian Basin (GAB) underlying 22 % of the Australian continent is one of the largest groundwater basins in the world. While of great national and societal significance and importance in its own right, the GAB is an iconic example of a continental scale artesian groundwater system. New geochemical, hydrological and neo-tectonic data suggests that existing models that involve recharge in eastern Australia, relatively simple flowpaths and discharge in springs in the western margin requires modification. New geochemical data indicate a small volume flux of deeply derived (endogenic) fluids mixing into the aquifer system at a continental scale. Hydrogeological data indicate multiple recharge sources and fault portioned sub basins. Neo-tectonic data indicates active tectonism today that provides a fluid pathway through faults for the deeply sourced endogenic fluids to discharge in GAB travertine depositing springs. Thus, new conceptual models need to include: 1) hydrogeological sub basins with varying chemistry, flowpaths and mixing implications, 2) the importance of faults as conduits and seals between subsins and that serve as sources of endogenic fluid inputs, 3) characterisation of endogenic inputs that include mantle derived helium -3, and carbon dioxide and metals that may degrade water quality.

Key words: Great Artesian Basin, environmental isotopes, hydrogeology.

1. INTRODUCTION

The Great Artesian Basin (GAB) is one of the largest groundwater basins in the world and contains Australia's largest water resources (Figure 1, adapted from Radke et al 2000). It is of international scientific importance as sustainable groundwater management is emerging as one of the great global scientific challenges of the new millennium. Groundwater flow and storage has long been considered to occur in a continuous sand sheet like aquifer that underlies slightly over one fifth of the Australia continent (Habermehl 1980). Under this scenario groundwater travels up to 2000 km flow paths from recharge areas in eastern Australia with major discharging occurring along the south west spring zone line. While this model describes the hydrogeology in broad regional terms it does not account for the complexity of the system in particular faulting providing conduits to a deep seated groundwater flow. In this paper we examine new neo-tectonic data inferred from Travertine dating using Uranium series as well as noble gas data form bores and springs in the GAB.

2. GEOCHEMISTRY DATA

Geochemistry of water and gas in mound springs provides a window into groundwater mixing in the Great Artesian Basin (GAB). Elevated $^{3}He/^{4}He$ gas values, termed "xenowhiffs", provide unequivocal evidence for small volume mantle-derived fluid sources that have been introduced into the groundwater system in the last several million years and hence document an active mantle-to-groundwater fluid linkage. Fluid and gas mixing is evaluated using multiple tracers. We estimate the external (deeply derived) CO_2 in water samples from both travertine mound springs and artesian bores using water chemistry and C isotope data. Contributions from dissolution of carbonate in the aquifer (Ccarb=Ca+Mg-SO_4) is distinguished from contributions from biological/organic sources (d13C= -28) versus mantle sources ($\delta^{13}C$= -5). Of the external C, mixing models using $CO_2/^3He$ values of 9 x 10^9 (Warberton Spring) to 2 x 10^{10} (Bubbler Spring) can be used to model contributions of CO_2 from the asthenospheric mantle (MORB end member taken as 2 x 10^9) versus lithosphere. Elevated $^{87}Sr/^{86}Sr$ values at Dalhousie Spring indicate fluid-rock interactions in granitic crust and small volume, but geochemically potent, crustal contributions to the endogenic fluids. Travertine-depositing springs are windows into active and heterogeneous groundwater mixing. Major ion chemistry suggests different and highly variable water chemistry spring to spring, different endmember endogenic fluids, and variable mixing proportions in different sub basins. For example, western GAB springs are shown to fall into two hydrochemical facies (Dalhousie Springs and the CO_2 mound springs), each distinct from waters produced by aging and slow transport of eastern Australian recharge waters. The travertine mound and platform rock record suggests the observed distinction between groundwater hydrofacies has been in place for at least about 650 ka, thus providing a link between the present paleohydrologic systems of the GAB. Hence new models for the GAB require interactions between mantle and deep crustal fluid inputs, neotectonic pathways and groundwater mixing and segmentation within this continental scale artesian basin.

3. TRAVERTINE AND NEOTECTONICS

The travertine deposits of the western Great Artesian Basin, collectively provide a record that can be used to link the present hydrologic system to paleohydrology of the GAB. The travertine deposits are associated with mound springs (many still active) and form calcium carbonate precipitates due to CO_2 degassing as the highly carbonated groundwaters emerge along faults. The travertine mound spring deposits also provide underutilized and sensitive gauges of neotectonics in Australia, one of the oldest, flattest, and least tectonically active of the continents. At a continental scale, the locus of mound spring discharge follows lithospheric zones of weakness (Tasman line and Torrens hinge zone). These were established in the Neoproterozoic but are currently being reactivated along the boundary between high velocity mantle in Western Australia and lower velocity mantle in eastern Australia, and as zones of concentrated microseismicity in the upper crust. At an intermediate scale, travertine deposits offer the potential to quantify rates and locations of neotectonic uplift/subsidence. They are located at the broad hinge region separating actively uplifting mountain ranges (Flinders and Dennison ranges) from subsiding areas (Lake Eyre).

Preliminary U-Series data provide age constraints on travertines. A age of 250 ± 4 ka from near the top of an elevated extinct travertine mound at Beresford Hill (base of travertine ~ 42 m elevation, sample ~ 53 m elevation) indicates rapid denudation rates (relative to the present ~16 m elevation of the Bulldog Shale surface) of 100-150 m/Ma likely driven by uplift. A U-Series date on the platform near Elizabeth Spring of 372 ± 14 ka (~34 m elevation relative to surrounding surface of ~14 m elevation) gives lower but still appreciable denudation rates of 54 m/Ma. Our hypothesis is that more comprehensive dating may show differential uplift depending on position relative to uplifting (west) versus subsiding (east) domains on either side of the mound springs line hinge. Collectively, the lowest elevations in the Australian continent, the mound springs lineaments, and the resulting locations of the main discharge areas of the Great Artesian Basin are seen as a product of interacting scales of active tectonism. The U-Series dates indicate persistent deposition of travertine mound springs at discrete vent sites over hundreds of thousands of years. A second testable hypothesis is that times of largest travertine accumulations (10 - 20 ka, 120 ka, and 350 - 400 ka) may have corresponded to palaeowet times. Detailed records are also obtainable from travertine; a travertine sample that was growing inwards in a vertical crack-filling in a travertine platform several meters above the modern drainage near Sulphur Spring provides a potential paleoclimate record. Ages so far are 9,324 ± 93 yrs, 10,039 ± 100 yrs, 11,993 ± 120 yrs, 20,256 ± 1,620 yrs providing a detailed record of the transition into the Holocene. Stable isotope analyses of the dated travertines reveals that spring groups have different carbon isotope averages that may reflect local hydrology, all spring groups show striking temporal variations in oxygen isotope composition (ranging over 6 permil), with synchronous variations seen in different spring groups. These results demonstrate that the extensive travertine deposits can be used to develop a climate record at both 100 ka and 1 ka time scales for comparison with other proxies - such as shore lines and speleotherms.

Understanding the relative importance of recharge and discharge rates is important when examining a large groundwater basin such as the GAB that is in a transient state. This work will provide proxy data to understand the relative magnitude and chronology of spring discharge through time, this will aid in the development of transient conceptual groundwater model of the system.

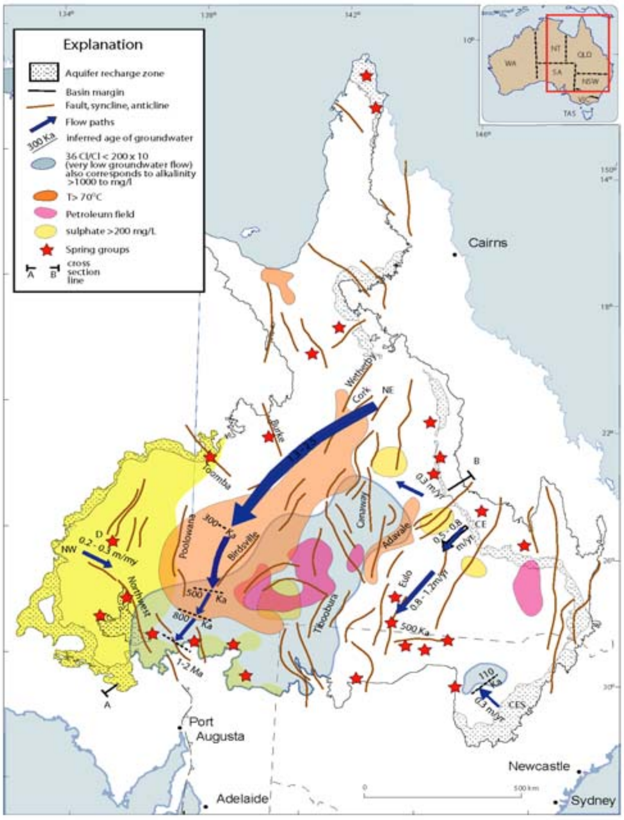

Figure 1. Hydrogeochemical features of the Great Artesian Basin

CONCLUSIONS

These data infer that new understanding of the GAB will require holistic models that merge these hydrogeological, geochemical and tectonic perspectives with detailed hydrogeological models for fault geometry. Effective management of the GAB resource will require improved cooperation between the states and the federal government understanding complex flowpaths and water quality variations for effective allocation of water and preservation of springs.

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Circum Saharan Transboundary Aquifers: Inventory and challenges for Management

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ABSTRACT

The circum-Saharan trans-boundary aquifers have a large structural configuration, with a thick sedimentation in a border of the crystalline basement cratons. These multi-layers aquifers have an extension exceeding the political boundaries of many circum-Saharan countries. They content the major water resources of the area.
During the Pliocene and early Quaternary, the paleo-climate conditions contribute to have a good recharge of these aquifers and a big reserves take place. The major part of these aquifers water resources are non renewable. Recently, the increasing of exploitation deregulates the hydrodynamic equilibrium. In many cases, are noted dropping of springs flow, reduction of flowing wells storage, degradation of water quality and reduction of irrigated soils production.
A sustainable management of these water resources aquifers needs a real consultation between the countries sharing the aquifer system, based on a good and updated evaluation of the water resources, a monitoring of the piezometry and the exploitation of the aquifers and a shared vision to the development options.
The Project of Northern west Saharan Aquifer System (NWSAS) shared by Algeria, Libya and Tunisia, gives a good example of the approach used to have updated data and to start the consultation mechanism for the shared management. This approach is applied in the circum-Saharan area, in others cases like Illumeden Aquifer system (IAS) and Nubian sand Stone Aquifer (NSAS).

Key words: circum-Saharan, multi-layers, non-renewable, management, consultation.

1 – INTRODUCTION

The circum-Saharan aquifers extend on both sides of the Sahara: in North Africa and in the Sahel. These aquifers, which are usually located in large sedimentary structures, come in the form of multi-layers systems with relatively important geological reserves extending over several countries. Under arid conditions, their recent recharge is very limited and most often they are the exclusive water resources. Their exploitation has been steadily increasing with the ever-growing water demand. The abstraction of these aquifers reflects a severe competition between users, with extensive impacts observable over the countries boundaries.

The information about the hydrodynamic functioning of the circum-Saharan aquifer systems is sketchy and focused on the abstraction areas. Only some of those aquifers are well studied over all the extension of the basin and the available data is usually scarce and insufficient for precise modeling or analysis.

This paper syntheses the state of the knowledge about the circum-Saharan aquifers and discusses the issues related to their sustainable management.

2 – MAIN CARACTERISTICS

The main trans-boundary aquifer systems of the circum-Saharan area are (*cf.* Fig. n°1):

- in North Africa: North West Saharan Aquifer System (NWAS), Nubian Sandstone Aquifer System (NSAS), Murzuk Aquifer System, Djeffara Aquifer System, Tindouft Aquifer System,
- in Sahel area: Senegalo-mauritanian Aquifer System, Illumeden aquifer system (IAS), Tanezrouft- Taoudeni Aquifer System.

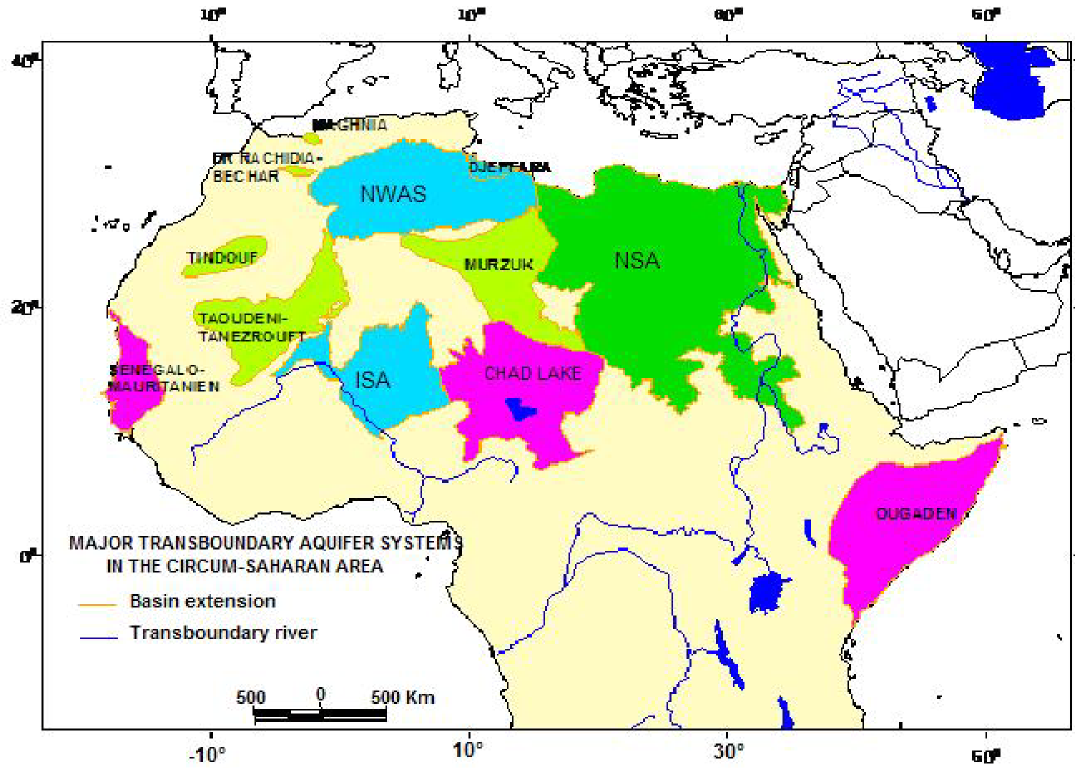

Fig. 1. : Location of the main circum-Saharan trans-boundary aquifer systems

2.1 – Geological Structure

The main aquifer systems surrounding the Sahara have a large extension (i.e., 500 000 - 2 000 000 km²) and stretch over several countries. Their geological structure comes in the form of large sedimentary basins with thick layers. Their spatial continuity has been continuously perturbed by the tectonic evolution from the Precambrian era until now.

Three main categories of structures are present in this region (ISARM/OSS, 2005):

- Complex structures with many blocs where the water resources are mainly renewable by recent recharge. The management of these resources is tightly linked to the climate conditions and to the increase of abstraction. These resources are mainly located on the substratum areas (e.g., Hoggar, Aïr and Tibesti) and do not support intensive exploitation.
- Structures focused on large rivers (e.g. Nil, Niger, Senegal and Chari) with water resources depending on the exchange between the river and the aquifer system and important geological water reserves, such as the Sahelian aquifer systems (e.g. Senegalo- mauritanian, Taoudeni-Tanezrouft,

Illumeden and Chad basin). The intensification of these aquifer systems exploitation have an appreciate security in the geological water reserves, but it generates several negative impacts

- Structures in large sedimentary basin without surface water courses, and with multiple interlinked aquifers, such as the Saharan aquifer systems in North Africa (e.g. NWAS, NAS, Murzuk and Tindouft). The intensive exploitation of these aquifer systems is clearly engaged and many negatives impacts are observed.

Generally, the circum-Saharan aquifer systems have large extension and inter-connected multi-layers. The knowledge of their geological structure is -except in the case of petroleum exploration in the area – limited. Without a precise simulation of the aquifer system structure, it is difficult to have an exact appreciation of the water reserves volume and the conditions of flux on the basin boundaries.

2.2 – Hydrodynamic functioning of the aquifer system

The recharge areas of the circum- Saharan trans-boundary aquifer systems are often located on the borders of the sedimentary basin. Most often, the recharge area is in the upstream country and the outlet is in the downstream country, with a large distance separating them. In this case, the recent recharge is weak and thus it is difficult to evaluate it, except in the areas near the outcrops of aquifer beds and in shallow aquifers (e.g. Nubian aquifer system in Sudan and Chad and Illumeden aquifer in Mali and North of Niger).

Usually, it is also difficult to identify the real boundaries conditions of the aquifer systems because of their large extension and the lack of data. However, only a precise conceptualization of the functioning system taking into account the real exploitation conditions and the entire extension of the aquifer basin, would make it possible to identify the intensive abstraction impacts.

The efficient localization of the abstraction fields depends on the opportunities to tape the deep aquifers by wells or by boreholes. These fields are established near users (e.g., agriculture, water supply and industries) in order to minimize the transfer costs. Focused in small zones, the abstraction has been growing continuously with the increasing demand, which generates negative local and extended environmental impacts (e.g., the drying of springs, the dropping of flowing wells and the degradation of the water quality).

The hydrodynamic evolution of the functioning of the big aquifer systems reflects first the continual piezometry decline and in a second stage the drop of the flowing springs and wells. The impacts of these phenomena may extend beyond the boundaries between countries. In comparison, the degradation of the water quality is a slower and a more localized phenomenon. This later reflects more the vertical interconnection (i.e. leakage) between the aquifer system's layers, than the large spatial extension of its hydrodynamic decompression.

Many similar situations of decompression or depletion are observed in the cases of North West Saharan Aquifer System (OSS, 2003), Nubian Sandstone Aquifer System (CEDARE, 2002), Senegalo -Mauritanian Aquifer System (Diagana B., 1997), Illumeden Aquifer System (OSS, 2007).

Because of their intensive exploitation, the multi-layer aquifer systems have shown a gradual decompression with increasing depletion. Their water quality degradation is an ultimate indicator of their over-exploitation. In fact, after an excessive abstraction of the shallow aquifers, confined aquifers (i.e., deep aquifers) have been tapped and intensively exploited, because of their higher water production. These deep aquifers contain mainly non-renewable water resources. Therefore, their depletion represents a crucial issue since it is difficult to find substitute alternatives.

3 – EXPLOITATION IMPACTS

The water management of the big aquifer systems, particularly their non renewable resources, is strongly linked to their hydrodynamic and the technical-economical conditions of their exploitation. This management imposes a strategic vision taking into consideration their depletion. Usually, their exploitation targets first the shallow aquifer. However the progress of the drilling and pumping technologies makes it possible to abstract a higher volume of water at a reduced cost. Axed on the springs and flowing wells storage, the exploitation of deep aquifers focuses initially on the best water quality resources until they are exhausted. Resources with lower water quality are then abstracted in order to respond to the demand. Such a strategy leads to localized and intensive exploitation of the existing deep aquifer resources. Gradually, competition conditions between partners' uses are established, which increases the aquifers exploitation costs and its negative impacts.

The intensive exploitation impacts appear through the piezometry decline, the drop of springs and flowing wells storage and the degradation of water quality. The decline of piezometry is clearly observed in confined aquifers and it indicates a general decompression. Usually, this phenomena has a large extension and stretches aver several neighboring countries and it causes deep modifications in the abstraction conditions of the groundwater (e.g., drying of springs and drop of flowing wells storage). On the other hand, the water quality degradation is started by leakage between different layers in the aquifer system or through its top or bottom, which limit the water resources use options.

In North Africa, the NWSAS has been intensively exploited for more than fifty years, which has caused a general depletion of its water reserves (OSS, 2003). The main springs have dried and the exploitation of many flowing wells requires their pumping. Near the chotts' depressions[1], in Algeria and Tunisia, the degradation of water quality can be clearly observed. Similar situations were reported in large regions of the Nubian Sandstone Aquifer System in Libya and in Egypt (Bakhbakhi M., 2006). These phenomena have been extending across the countries boundaries.

In the Sahelian zone, the intensive exploitation was started in the late eighties with a limited abstraction level. The first signs of the negative impacts of this excessive exploitation can be currently observed through the decompression of the confined aquifers and the decline of springs' flow. Let us note here, that no water quality degradation was reported yet in these areas.

In all the previously described situations, the partner countries are conscious that they have to share the negative impacts of the intensive exploitation of their common aquifer resources, even if they have not all contributed to their generation.

4 – MANAGEMENT AND CONSULTATION

[1] Chotts : Saharan salty depressions.

The management of the trans-boundary aquifer system resources incites the concerned countries to work together to attenuate the common negative impacts of the excessive aquifer abstraction. A sustainable management strategy should take into account all the risks associated with the competitive exploitation of the shared basin, which requires a precise knowledge of the aquifer system and the development policies of the different countries. Such as strategy need to be continually reviewed and adjusted in order to adapt to the aquifer system evolution.

The updated knowledge of the aquifer system requires the establishment of a monitoring system in order to control, at the regional level, the piézometry, the abstraction and the water quality variations. The instauration of such monitoring system is more easily accepted when the negative impacts are clear and shared by all the partners. Otherwise, the countries' are reticent to share their data or information.

On the other hand, the review of the national policies has to ensure that the economical interests of each country will not induce negative impacts on the other partners. Only a consultation mechanism is able to give all the partners the opportunity to be well informed about the national policies and thus to adopt adequate decisions in order to reduce the risks and ensure a sustainable development. The expression of a regional collaboration is confirmed when the partners work together to achieve the same objective. The main target of the consultation mechanism is to optimize the management of the water resources in the shared basin. Strategic options for the water management must be based on a referential appreciation of the aquifer system state. The consultation aims to reduce the negative impacts and to ensure a sustainable development through the reconciliation of the aquifer system capacities and the partners' exploitation policies ambitions. The technical data provided by the monitoring of the aquifer system offers objective criteria to the decision makers to choose the adequate policies.

Three examples of consultation Mechanism establishment are attempted for the circum-Sahara aquifer systems: NWSAS (OSS, 2008), NSAS (Alker, W., 2006) and SAI (OSS, 2008a). A log process with many stapes is necessary to have the countries agreement on the strategy to adopt and how to execute decisions. Only the case of the NWSAS has given real concrete results represented by an operational monitoring system and a steering committee.

5 – CONCLUSION

The main trans- boundary aquifer systems of the circum-Saharan region contain nonrenewable water resources. The exploitation of these resources is a major element for the development in the area. The intensification of abstraction in the concerned countries has generated risks of decompression of aquifers and degradation of their water quality. In North Africa, where this intensification is higher and older than in the Sahalian zone, these negative impacts are inciting the countries to establish a consultation framework. This consultation ensures the exchange of data and the discussion of the water management policies.

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Groundwater Flow Connections in Palestine
Shared Aquifers revisited

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ABSTRACT

The research in this paper breaks with the conventional wisdom on the hydrogeology of some of the possibly most studied and documented aquifers in the world – those that underlie Palestine (oPt) and Israel.
Rather than the three transboundary aquifers (2 Mountain, 1 Coastal) so commonly referred to, it is shown that actually all aquifer basins and aquifers in historical Palestine are shared and transboundary.
The sustainability, methodology and political implications of this research reach broadly and deep: The research calls into question the common methodology applied to describe and define the aquifers, their individual recharge and discharge mechanisms, their boundaries and flow connections to adjacent basins and aquifer stockworks. This enhanced understanding will help in addressing the lack of understanding of and in re-focussing on the crucial question of transboundary and inter-basin aquifer flow connections.
The implications for the Palestinian-Israeli water conflict, furthermore, are just as significant. The research sets the scientific foundation for a fundamental re-negotiation of the inequitable distribution reached in 1995, thus adding a hydrogeological dimension to those of justice and law claimed by a growing number of Palestinians.

Key words: transboundary aquifer, flow connection, recharge, equitable and reasonable share, oPt

1. INTRODUCTION – THE INTERNATIONAL "LAW OF TRANSBOUNDARY AQUIFERS"

Articles 2a of the draft Law of transboundary aquifers (UN-General Assembly, A/63/124) defines an "*aquifer*" as "*a permeable water bearing geological formation underlain by a less permeable layer*[1] *and the water contained in the saturated zone of the formation*". An "*aquifer system*" is a "*series of two or more aquifers that are hydraulically connected*" (2b). In other words, for the formational continuity, an aquifer has to cross a border and for a hydraulic connection, groundwater has to flow across a border. Article 2 (f) of the law defines a "*recharge zone*" as "*an aquifer that receives a non-negligible amount of contemporary water recharge*"[2]. Despite the weaknesses[3] and vagueness of the draft, this paper tries to apply both aquifer definitions[4] (Art. 2a, b) as well as the recharge definition (Art. 2f) to all aquifer basins in Historical Palestine, in line with the draft law[5]. At its centre stands the question: Which basins of Historical Palestine are shared and to what extent?

[1] The draft fails to quantify how much less permeable a layer should be to qualify as bottom of aquifer – several orders of magnitude in k-value? This becomes a problem for application when dealing with leaky aquifers, in-homogenous stratified aquifers with a series of aquitards, aquifers and perched local aquifer horizons.
[2] The draft fails to define and quantify the term 'non-negligible' any further, but the question here is: How much would be a "negligible amount" of flow? Certainly, 50% or even 30% of total flows are more than enough to qualify for a non-negligible contribution. But is a negligible portion closer to 5%, 10% or 20% of total flows?
[3] Also the principle of "*Sovereignty of aquifer States*" (Art. 3) poses a problem for the equitable and reasonable utilization of shared aquifers and breaks with the logic of the UN Convention on Surface Water courses. Applied to surface water, it would allow any upstream riparian to fully dry out a river. All basins where Palestinians are upstream (WAB, EMB) would leave Israel without access to water, if Palestinians were to exploit "sovereignty" to the fullest. Full sovereignty and sharing are mutually exclusive.
[4] Yet, the definitions can be mutually exclusive: Flow connections can exist without formation continuity.
[5] Unlike Israel, the official Palestinian line actively endorses and promotes international law. It seeks water negotiations for a "just solution based on international law" (PWA 2010; Phillips et al. 2004). Palestinians also endorse all 9 factors (a-i) *relevant to equitable and reasonable utilization*, as drafted in Article 5, as well as the *obligation not to cause significant harm* (Art.6), *to cooperate* (Art.7), *to exchange data and information* (Art.8) and to *protect, preserve and manage* the resources in a responsible and sustainable manner (Part Three).

2. THE CONVENTIONAL VIEW ON OF AQUIFERS IN HISTORICAL PALESTINE

Common literature differentiates seven basins in Historical Palestine (EXACT, 1998, SUSMAQ, 2002, HSI, 2006, Fig. 1): The Negev, the Galilee, Lake Tiberias and Mount Carmel, as well as the Coastal Aquifer and the two[6] Mountain aquifer basins. Figure 2 shows the rather confusing amount of aquifer stockworks overlaying each other according to the grouping system of the Hydrological Service of Israel (HSI): Along the coast stretches the **Coastal aquifer** (CAB) from Gaza to Mt. Carmel (pink, purple). At **Mount Carmel** (MCB) a shallow thin strip of Carmel coast aquifer is overlying the Cenomanian aquifers (rosé). Further north, the **Western Galilee** (WGB) again consists of deeper aquifers (Upper Albian-Cenomanian-Turonian Mt. Aquifer) and shallower more localized aquifers (Eocene, Neogene and Pleistocene) in light green colour. In the Northeast, **Lake Tiberias basin** (LTB) includes all aquifer stockworks from Jurassic (in the annexed Golan) to Cenomanian, Eocene and Neogene (strong blue). South of Lake Tiberias and the Western Galilee follow the Eastern Mountain Basins (EMB) (yellow colour). Regionally they consist of the West Bank aquifers (Eastern and North-Eastern Basins), shallower units like the Eocene and the alluvial Jordan Valley aquifers. North of the West Bank, this agglomerate of interconnected basins also includes the Nazareth Mountains and the Wadi Harod basins. Between the Eastern Mountains and the Coastal plain stretches the **Western Aquifer basin** (WAB) – consisting only of Upper Albian-Turonian carbonates (light blue). In the South, three stockworks of aquifers build up the series of **Negev and Araba Basins** (NAB) (strong green), with a lower system of very deep aquifers (Neocomian-Aptian), an intermediate system (Cenomanian/Turonian) and an upper system of Eocene to Quaternary series. Only some very minor units of local aquifers with a negligible total pumpage are not included in this system.

3. THE THREE SHARED AQUIFERS, ACCORDING TO THE CONVENTIONAL VIEW

According to conventional wisdom only 3 of the aquifers are transboundary or shared: The Mountain Aquifers (WAB, EMB) and the Coastal Aquifer (CAB). It is important to stress that such common mistakes frequent in the literature are due to a conceptual misunderstanding according to which these aquifers are considered discreet, independent and unconnected basins, laterally isolated from each other. Such an example is shown in figure 1 (EXACT aquifer map, 1998). The considerable vertical overlay of most basins (Fig. 2) is neglected. If only all <u>major</u> aquifer stockworks overlying each other are counted, their combined area stands at 56.390 km^2[7], about double the size of the entire country. Aquifer and basin overlay is the rule, not the exception.

It should be stressed that recently, Israel has begun to pretend that the Coastal Aquifer was an unshared basin located exclusively inside Israel (1949 borders)[8]. Only the Mountain aquifer basins, where Palestinians sit upstream, are shared transboundary flow and aquifer systems, Israel insists[9]. The <u>Western Aquifer (WAB)</u> is a classically shared aquifer with over 85% of recharge in the West Bank (upstream), but extractions almost exclusively (94%) controlled by the downstream riparian, Israel in the coastal plain. The North-Eastern Basin (part of EMB) is similarly inequitably shared, with Israel enjoying control over 113mcm/yr (80%) of outflows[10].

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[6] Many authors differentiate 3 Mountain aquifers – Western (WAB), Eastern (EAB) and North-Eastern (NEAB) Aquifer Basin, while the Hydrological Service of Israel (HSI, 2006, 2008) lumps EAB and NEAB together into a common aquifer system, called Eastern Mountain Basins (EMB). Hydrogeologically, both approaches are valid. This paper will follow the HSI-system for reasons of overview and comparable data for all basins.
[7] Aquifer sizes according to HSI, 2006 & 2008, to SUSMAQ, 2004 and Gvirtzman, 2002
[8] While older maps (Gvirtzman, 2002) include Gaza in the CAB, more recent Israeli maps (HSI, 2006, 2008) 'elegantly' let the CAB end at the doorstep of Gaza – a transparent attempt to avoid Israel's obligation to furnish Palestinians with an equitable share of this powerful aquifer. According to Vengosh et al. (2005) Gaza obtains 37mcm/yr of lateral groundwater inflow from Israel (~80% of the amount of rainfall recharge in Gaza).
[9] This is a tactical, not scientific position – only where Israel sits downstream, its wants the water shared.
[10] In both basins, Israeli military rule and wanton discrimination prevents Palestinians from developing their equitable share (World Bank, 2009; Messerschmid, 2007)

On the other hand, the Eastern Aquifer within the EMB is almost exclusively restricted to the West Bank with only *negligible* cross-border flows (Ein Gedi springs - 2.46mcm/yr and Arad cell[11] inflows <0.89mcm/yr, together 1.7% of total aquifer flows)[12]. Yet, Israel insists that the EAB be treated as a shared transboundary basin. In the Oslo-II agreements Israel's position to demand continued control and utilization of the lion share in this aquifer (155mcm/yr or 79% of all flow[13]!) is based on the alleged nature as a "*shared aquifer*", despite <2% of cross-border flows.

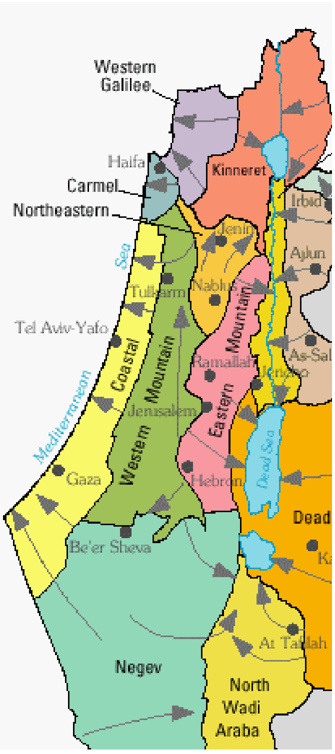

Fig. 1 Allegedly adjacent aquifers (EXACT, 1998)

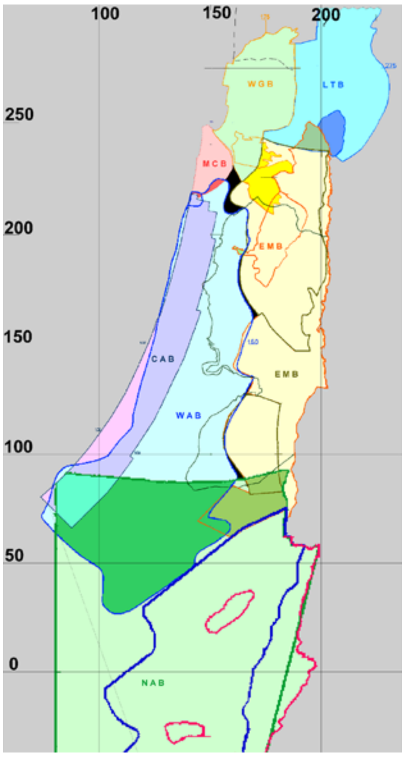

Fig. 2 All aquifers overlying each other (modified after HSI, 2008)

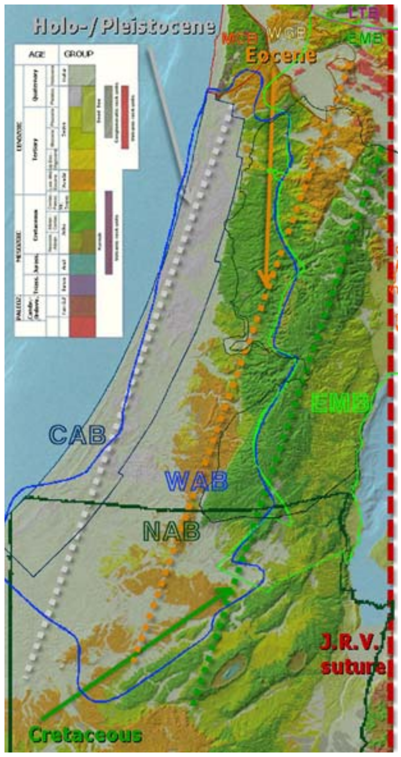

Fig. 3: Geological relief map and HSI-basins (modified after GSI, 2002)

4. THE AQUIFERS CONVENTIONALLY CONSIDERED TO BE UNSHARED

What about the other basins – NAB, MCB, WGB and LTB; which of them are shared according to the definitions of the draft, i.e. by the extent of formations (4.1) and hydraulic connections (4.2)?

4.1. Formation extent

Geographically, two of the four allegedly 'unshared' basins lap into the oPt (Fig. 2), NAB and WGB into the West Bank, NAB also into Gaza. Only MCB and LTB formations lie exclusively inside Israel. As the relief map (Fig. 3) shows, the land area of Historical Palestine can be divided into three major SSW-NNE trending aquifer stockworks, from sub-recent alluvial (grey), to shallow Eocene (orange) and deep Cretaceous (green), built up by one continuous geological realm, the Cretaceous-Tertiary sedimentary basin along the old continental hinge line – one uninterrupted outcrop (and subcrop) from the Negev up to the Galilee. Structurally it is an integral part of the Syrian Arc system. It turns out that the only mechanism that effectively inhibits any flow connections are deep graben structures, such as the Jordan Rift Valley or Wadi Fari'a (separating EAB from the so-called NE-tip).

[11] southernmost cell (No.667), no rain recharge; only inflows from EAB (North) & NAB (South); HIS (2006).
[12] If any basin in Historical Palestine has negligible transboundary flows, then the EAB, this paper tries to show.
[13] Eastern Mt. Aquifer average ('98-'07) after HSI (2008), including the powerful Dead Sea springs

4.2. Flow connections

In line with Art. 2b & f, all basins are *hydraulically connected*, exchanging transboundary groundwater flows and sharing zones with common *contemporary recharge*. They constitute common transboundary *aquifer systems*. CAB, WAB and EMB usually are seen as shared. The same will now be shown for NAB, MCB, WGB and LTB.

Negev and Araba Basins (NAB): Weinberger *et al*. (1994) report: "One of the main processes of Judea Group in the northern Negev is *continuing intrusion* into the aquifer. It appears that the Judea Group *sub-aquifers are locally interconnected.* These sub-aquifers, are juxtaposed, as a result of faulting" (Fig. 4). Deep faults enable large flow connections and groundwater exchanges between Judea group (Mt. Aquifer), deep Kurnub, Jurassic and Eocene. The Eocene in turn is connected to the Pleistocene. In North-South direction, Judea group (Mt aquifer) is one continuous aquifer reaching from the WAB into the NAB (Fig. 5) The deeper Kurnub sandstone aquifer below drains from a structural high in the North-Central Sinai in NE directions towards the Dead Sea (Vengosh, 2007).

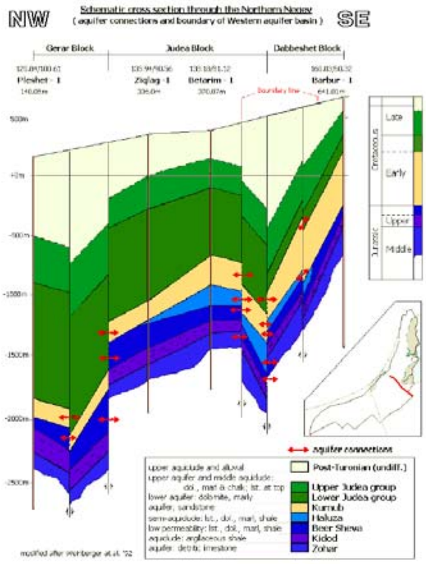

Fig. 4: Aquifer connections in the Negev *(NW-SE trending cross-section)*

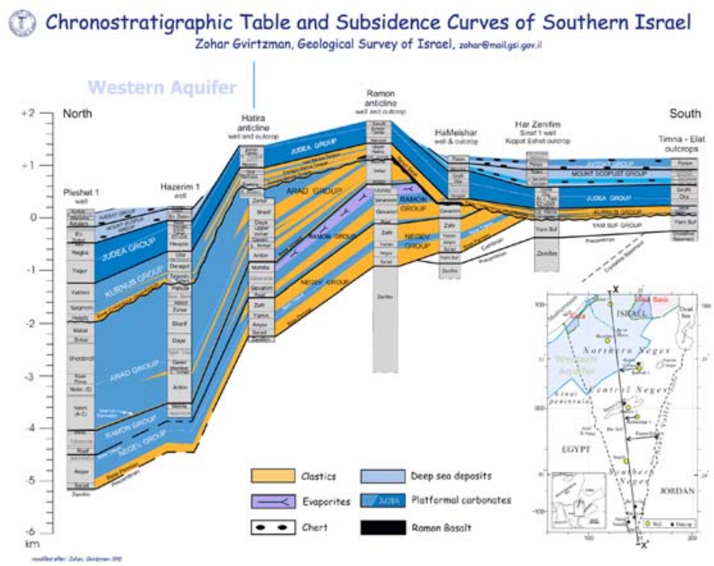

Fig. 5: Continuation of the Western Mountain Aquifer from the Coastal Plain to 'Aqaba *(N-S trending cross-section)*

The main Cenomanian aquifer is partly fed from WAB and EAB in the West Bank. All major aquifer stockworks in the NAB, from shallow to deep are hydraulically connected (Art. 2 b). The Cenomanian and deep aquifers in the South assemble to a common 'aquifer system' (Art 2 b) with 'non-negligible' amounts of flow exchange.[14].

Mt Carmel Basin (MCB) consists of a Pleistocene coastal aquifer cell (#410[15]) and 2 deep carbonate Mt. aquifer cells (# 420, 421). HSI (2008) sets the boundary between WAB and CMB at the southern foothills of Mt. Carmel, whereas Dafny *et al*. (2010) locate the boundary inside the Mt. Carmel mountain range. The boundary between MCB and WAB has to be assumed a flow boundary. The pump regime strongly affects flow amounts and directions.[16]. Dafny *et al*. (2010) indicate southern flow directions, from Mt Carmel towards the WAB plains and Taninim springs. Accordingly, the two basins act as "recharging aquifer" and "discharge zone"[17], respectively, as defined in Article 2 (*f*) and (*h*). Taninim (Timsah in Arabic) springs are the main artesian outlet of the WAB today with

[14] 5% of WAB's annual yield (20mcm) draining the Negev would equal 30% of all NAB recharge ~60mcm/yr.
[15] HSI (2008) uses a numbering system to divide the basins into aquifers, cell groups, cells and sub-cells.
[16] In half a year alone (Apr-Sep '07), water levels in the northern-most WAB dropped by 2.5m (HSI, 2008)
[17] At least under the current abstraction regime, in which Israel massively over-pumps the Western Basin, in breach of the Oslo-II agreements. Flow directions under undisturbed conditions may have been reverse.

20-58mcm/yr (historically ~70mcm/yr), certainly not a 'negligible' amount of flow[18]. Deep faults connect the Mountain Aquifer to the Pleistocene aquifers and the springs emerge from the shallow Pleistocene gravels, mostly in the MCB (cell 410), but partly also in the CAB. The rising groundwater of WAB mixes with CAB and MCB flows before the springs discharge at surface. Taninim springs constitute a common 'discharge zone' (Art. 2 h). At Taninim springs, the three basins – WAB, CAB and MCB thus constitute a common 'aquifer system' (Art. 2 b).

Western Galilee and Lake Tiberias Basins: Lithologically and structurally, the Cenomanian Mountain aquifers of the North (WGB, LTB) and the West Bank form one formation, with strong faulting[19] and frequent lateral facies changes (Rosenfeld & Hirsch, 2005). As in the Negev, this leads to flow connections between the deeper aquifer stockworks (Cenomanian, Lower Cretaceous and maybe Jurassic) but also between the Judea Mountain aquifer and the Eocene. For the Cenomanian Mountain aquifer, a flow direction from the West Bank towards the Galilee is more likely (according to water level contour maps by HSI, 2006, 2008). Conversely, the Lower Cretaceous aquifer flows N-S with recharge in the North (outcrops with rain up to 950mm/yr in Lebanon and along Israel's Northern border). The shallow Coastal Aquifers most likely are hydraulically disconnected from the deeper basins in the hinterland. They are assumed here as non-shared sub-basins. The Neogene Aquifer of the Western Galilee Basins reaches into the West Bank where it is recharged (non-negligible flows). The Eocene basins of the West Bank (Nablus syncline) and of the Western Galilee (cross-section 3-3', Fig. 6a) are *structurally* discontinuous. However, near Hayogev and near Migdal Ha-Emeq, the Eocene (T_a, yellow) is juxtaposed against the Cenomanian-Turonian (Judea group, K_j, blue). Therefore *direct flow* connections between the aquifer stockworks are enabled.

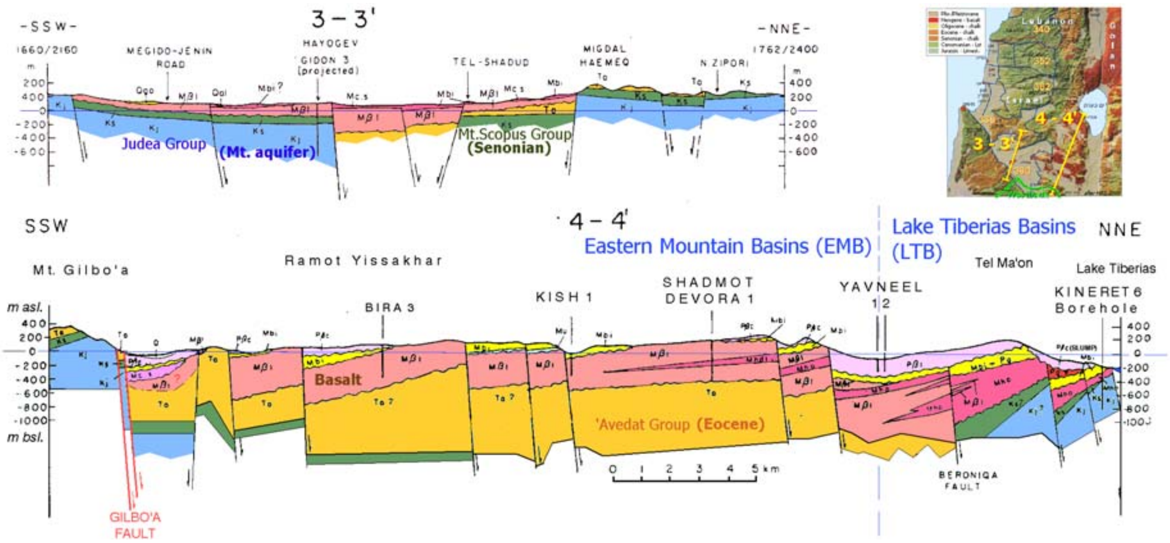

Fig. 6a, b: SSW-NNE cross-sections from EMB to WGB (4-4') and to LTB (3-3')
note: LTB and EMB Cenomanian aquifers are one uninterrupted lithostratigraphic layer...

Fig. 2 (top right) shows an almost arbitrary Upper Cenomanian boundary between EMB and LTB in Yavne'el area (Fig. 6b), 6km WSW Lake Tiberias. No surprise, the Cenomanian of the Galilee and LTB is hydraulically connected: Lake Tiberias basins receive some 125mcm/yr of groundwater flow from the Eastern Galilee (Gvirtzman, 2002; HSI, 2006). The shallow Neogene basins of EMB along the JRV overlap with LTB and reach up right to the coast of Lake Tiberias (Fig. 2). The Eocene aquifer is isolated by erosion, but with stockwork connections along deep faults (Fig. 6a).

[18] All Palestinian controlled wells and springs in the West Bank currently yield 81mcm/yr (estimates for the year 2010; unpublished correspondence with Dr. S. Attili, Head of PWA; July, 2010).
[19] Gilbo'a faults (Fig. 6b) at the N edge of the West Bank have a combined vertical throw of well over 1000m. Other faults vertically throw between 200m and 600m.

All basins (bar the shallow Galilee coastal aquifer) and aquifer stockworks of the Western Galilee are hydraulically connected to the West Bank aquifers. Due to deep faulting they are likely to form one interconnected 'transboundary aquifer system' (Art. 2 b, c). The Cenomanian (Judea Group) and Neogene aquifers of LTB are in contact – both, as formation and hydraulically, with the EMB basins emerging from the West Bank. Eocene and Cenomanian, locally, form a combined 'aquifer system'.

5. RESULTS

Both definitions of Art 2 b, c - formational, lithostratigraphic continuity (A) and hydraulic flow connections - were applied to evaluate the transboundary nature of all aquifers, particularly those commonly considered unshared.

A) Formation continuity can be evaluated by basin and by aquifer layer: By basin: Only CMB and LTB lie entirely outside the West Bank. By aquifer formation: The Cenomanian (Upper Albian – Turonian) Mountain aquifers are found in all seven major basins, except for the Coastal Aquifer. They form one almost uninterrupted formation layer throughout the country. The shallow Neogene and Pleistocene aquifers are discontinuous but occupy a relatively large area of the country (Fig. 3).

B) Flow connections can also be discriminated into flow between basins and flows between aquifer stockworks. Between basins: All allegedly unconnected basins were found connected (many with large flow) through continuous formation (*a*), strongly throwing faults (*b*) and/or inter-basin leakage (*c*) as follows (Table 1):

Table 1: Summary Aquifer connections of allegedly unconnected basins

Basin	connected through			Basin	connected through	
	ftn. (*a*) & **faults** (*b*)	**ftn.** (*b*)	**leakage** (*c*)		**ftn.** (*a*) & **faults** (*b*)	**ftn.** (*b*)
NAB	WAB, EMB		CAB	**WGB**	EMB, WAB	LTB, **WGB**
MCB	WAB, CAB	**WGB**		**LTB**	EMB	**WGB**

Connection mechanisms: (*a*) continuous formation; (*b*) strong juxtaposing faults; (*c*) inter-basin leakage

Between major aquifer layers: Lateral contacts, faulting and leakage facilitate Inter-aquifer flow. The **Pleistocene** of the CAB is connected to the leaky Eocene (NAB near Gaza) and laterally to the Carmel coast aquifer (MCB). CAB in some places directly overlies the WAB, recharging it. Hence, leakage (NAB) and lateral contact (MCB) are the main mechanisms of connections. The Pleistocene of the Jordan Valley receives considerable amounts of recharge through the main graben fault, lateral contact and indirect recharge from the Eastern Mountain Aquifer (10-20mcm/yr). Deep faults juxtapose the **Eocene** against Judea Group in NAB, WGB and LTB, enabling direct exchange of flows. The **Mountain Aquifers** of the Upper Albian, Cenomanian and Turonian are the most important groundwater resource of the country, mostly with direct rain recharge. In some areas, such as the Negev, also recharge from (and discharge to) other formations takes place, usually through connections across deep throwing faults (Negev, Taninim springs, JRV main fault and Galilee). Vertical leakage occurs between sub-aquifers (GTZ, 1999), at the bottom (Messerschmid, 2003) and sometimes at the top of the Mountain aquifer system. The **deep aquifers**, only in S-Lebanon and Syria (Golan) are recharged from rain, otherwise indirectly (leakage, faults).

6. CONCLUSION

Israel acknowledges riparian relations and shared allocations only in those basins where it sits downstream and thus displays an arbitrary and unlawful approach with respect to transboundary aquifers and groundwater, designed only to maximize its own benefits at the great expense of its co-riparians. This study approaches transboundary and shared groundwater resources in a thorough and less arbitrary manner. Scientific findings on the ground alone - not unilateral hydrostrategic advances - should determine the question which basins are shared and to what extent.

The established and all too often politically driven conventional wisdom seems to suggest a prevalence of discrete, mutually disconnected basins and the findings of this paper may come to the great surprise of many readers, but undeservedly so: Given the size and the regional geology of the country, this approach should rather be self-evident and employed unanimously. Much of the already existing research on a local scale has pointed to these local flow connections, however without breaking through the wall of a powerful, yet mistaken paradigm of unconnected aquifers and mini-basins. It is time to make the step and unify and align these findings in a bold new approach: All basins in Historical Palestine are shared. They constitute one common Aquifer system. Why should deep groundwater flows care about newly established and not even politically consolidated borders?

The simple consequence of this finding is: Palestinians and Israeli must share, utilize manage and protect ALL groundwater basins jointly and for the benefit of both sides. In final status negotiations over water, each basin should be investigated individually and case by case. All flow connections – both, in their natural state and under anthropogenic influence – should be weighed and quantified in order to define the best and sustainable fit for equitable and reasonable utilization. Upstream and downstream riparian relations should be taken into consideration in each case, as well as other factors, such as developing water demands, alternative and/or additional accessible water, economic abilities, needs and dependency, vital human needs and of course international law.

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The Silala/Siloli watershed in Bolivia/Chile:
Lessons from the most vulnerable basin in South America

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ABSTRACT

The dispute over the relatively unknown Silala, or Siloli, watershed, shared by Bolivia and Chile, demonstrates the importance of history, the role of indigenous people in the stewardship of water resources, the interplay between surface waters (naturally occurring and canalized) and groundwaters, and differences in the economic philosophies informing water resource management strategies. The waters of Silala begin as a wetland formed by groundwater springs that discharge in Bolivian territory near the Bolivian/Chilean border, approximately 300 km northeast of Antofagasta, Chile. The waters flow superficially, largely via canal, from Bolivia into Chile and are used by Chilean copper mines and to supply potable water to nearby populations. In 1908, the Prefecture of Potosí, Bolivia granted the "Antofagasta-Bolivian Railway Company" a concession to construct canals in Bolivian territory and use the waters of Silala to fill its steam engines. Geological, topographical, and historical evidence suggests that the Silala springs flowed overland from Bolivia to Chile prior to the canalization. The concession was revoked in 1997 by the Bolivian government, which observed that the waters had long been used for purposes differing from that noted in the original agreement. The two countries have since been trying to reach a new agreement over Silala, while Chile continues to use the waters. Their positions are starkly different: most of Bolivia insists that the Silala *aquifer and springs* are its national property and that Chile should pay, including a historic debt, for their use; Chile maintains that the Silala *river* is an international watercourse, subject to equitable and reasonable use by both states. Even within the individual countries, there is no consensus on the best way forward. In March, 2010, Bolivia again rejected a draft bilateral agreement on Silala despite the Chancellery and the economically impoverished community nearest the watershed pushing for its signing. How the neighbouring states reconcile their overarching differences in water policy remains to be seen.

Key words: Bolivia, Chile, international water law, international groundwater law, water dispute

INTRODUCTION

An international dispute over the rights to the waters of the Silala, or Siloli, basin has been unfolding since 1997, when the Bolivian government revoked a concession awarded to a Chilean company in 1908 to use the waters for its steam engines. A preliminary bilateral agreement drafted by the two states was rejected, and the negotiations paused, by the Bolivian government earlier this year. Resolution of the Silala dispute has been impeded by the historical context of the watershed, existing diplomatic situation between the two riparian states, and lack of agreement as to whether or not the Silala is an international watercourse (UNEP, 2007). The Silala watershed remains essentially unheard of, even among experts, outside of Bolivia and Chile despite being called the only "high risk" basin in South America and "one of the most hydropolitically vulnerable basins in the world" (UNEP, 2007). The objective of this paper is to present a brief case study, including a physical description, historical review and summary of current status, of the Silala basin and shed light on this hitherto virtually unknown watershed.

PHYSICAL DESCRIPTION

The Silala basin is shared by Bolivia (upstream) and Chile (downstream) and lies in the Atacama Desert approximately 300 km northeast of Antofagasta, Chile (Fig. 1). The waters of Silala begin as high altitude (over 4,500 masl) wetlands (called "bofedales") formed by groundwater springs that discharge in Sud Lípez, Potosí, Bolivia near the Bolivian/Chilean border. More than 70 small-volume groundwater springs have been identified in Bolivian territory, discharging from fractured ignimbrites (volcanic deposits) of Miocene age overlain by relatively impermeable andesitic lavas of Pliocene and Pleistocene age (SERGEOTECMIN, 2003). Preliminary evidence supports claims that the groundwater was principally recharged by glacial melt water, thousands of years ago (SERGEOTECMIN, 2003). The Silala Aquifer is considered a transboundary aquifer, but little is known about the underground flow component.

Most of the springs are drained by a series of small, man-made channels which direct the flow towards two central drainage channels, the north and south canals, which join to form a principal canal (Fig. 2). Each canal is clearly man-made (lined with rocks and very straight in certain stretches; Fig. 2). The south canal is nearly 3 km long and contributes about two thirds of the flow to the principal canal, whereas the north canal is less than 1 km long and contributes the remaining third of the flow. The principle canal directs the water for about 700 m before crossing the international border into the II Antofagasta Region, Chile. In Chilean territory, the principle canal flows 7 km to its confluence with the Cajón River, forming the San Pedro de Inacaliri River, a tributary of the Loa River (Fig. 1). The Loa basin is the largest in Chile and the only exorheic (allowing outflow) basin in the Antofagasta Region. Mean discharge of the principal canal near the border crossing is approximately 0.2 m^3/s (SERGEOTECMIN, 2003); however, the flow rate is significant given that the Silala basin is situated in the Atacama Desert, arguably the driest place on Earth. Mean annual precipitation and potential evaporation in the basin between 1983-1995 were 59.1 mm and 914 mm, respectively (SERGEOTECMIN, 2003).

Geological, topographical, and historical evidence suggests that the Silala springs flowed overland from Bolivia to Chile prior to the canalization. The principal canal clearly follows a natural drainage course featuring significant, natural alluvial erosion, including a relatively deep (tens of metres) canyon incised in the desert floor (SERGEOTECMIN, 2003). The general manager of the Bolivian company hired (in 2009) to evaluate Silala's hydroelectric potential concluded, based on detailed topographic studies, that the canals were constructed to make more efficient, but not to alter, the natural course of the waters, which naturally and inexorably flow to Chile (Alvarez, 2010). In the 1908 application for the concession to use the waters of Silala, a Bolivian citizen acting on behalf of the Antofagasta (Chili) & Bolivia Railway Co. Ltd. (FCAB, following the Spanish acronym), stated that "In the Province of Sud Lípez near the border, there exist springs which form the Siloli River, which flows in Chilean territory" (Martínez, 2004).

The only Bolivian users of the waters of Silala are the soldiers (numbered seven in January 2010) stationed at the Silala advanced military post. The Silala basin is strategically important to Chile because it is a significant source of process water for the Chuquicamata copper mine and potable water for nearby populations including the city of Calama. Chuquicamata, run by state-owned CODELCO, is the largest open pit in the world. CODELCO is the world's largest copper producing company and generator of about a third of the Chilean government's income (Government of Chile, 2010). Chilean copper miners consume approximately 11.5 m^3/s of water per tonne of copper produced (Reuters, 2009). The city of Calama has a population of 143,000 and receives an average annual precipitation of 5.7 mm, making it one of the driest cities in the world (DGAC, 2010).

HISTORY

To many Bolivians, Silala is symbolic of their country's loss of access to the Pacific Ocean to Chile in the War of the Pacific (1879-1883). Bolivia lost its *Departamento Litoral* (coastal region), including significant mineral deposits, to Chile as a result of the war. An additional consequence of the clash was the division of the Silala basin, which, prior to 1883, was situated entirely within Bolivian territory. The conflict is also referred to as The Saltpeter War after the nitrate-bearing mineral over which the two countries and Peru were fighting. Following the war, saltpeter, gold, silver, and, chiefly, copper mines were excavated on the newly Chilean territory.

Rail was the only reliable way to get the minerals to market and steam engines required a constant supply of water, a scarce commodity in the Atacama Desert. The then English (now part of the Chilean Antofagasta PLC investment group) FCAB identified the Silala springs as a potential source of water and requested the Prefecture of Potosí, Bolivia for permission to use the springs to power their locomotives (Martínez, 2004). In its letter of request, FCAB offered to leave a third of the volume of the Silala for "public use" but Bolivia never exploited the waters, except for possibly the occasional local llama herder and, more recently, the soldiers stationed at the nearby military base (Martínez, 2004; Berna, 2010). In 1908, the Prefecture of Potosí, Bolivia granted the company a concession, in exchange for nothing, to construct canals in Bolivian territory and use the waters of Silala (Prefecture of Potosí, 1908). This concession was revoked in 1997 by the Bolivian government, which noted that the waters had long been used for purposes differing from that noted in the original agreement (Toromoreno, 2000).

Since annulling the 1908 concession, Bolivia has taken a number of potentially provocative actions with respect to Silala. In 2000, the government of Gonzalo Sánchez de Lozada awarded the rights to Silala for 40 years to the Bolivian firm DUCTEC SRL for $46.8 million (Toromoreno, 2000). DUCTEC SRL attempted to charge CODELCO and FCAB for their use of the waters of Silala but no payments were made (Martínez, 2004). In 2006, the government of Evo Morales inaugurated a military base on the banks of Silala (Fig. 2) and publicly discussed a plan to bottle the water and sell it with the slogan "Drink Silala water for sovereignty" (Bloomberg, 2006). In 2009, the Prefecture of Potosí hired a La Paz based engineering consulting company to conduct a feasibility study for a hydroelectric plant at Silala. They reported that approximately 50 kW of electricity could be generated, enough to provide only for the nearby military base and, perhaps, a future tourist installation (Alvarez, 2010). The possibility of using Silala for agricultural purposes has been dismissed by the leader of Quetena Chico, the community nearest the Silala watershed (Berna, 2010).

On the other hand, despite a lack of official diplomatic relations, the two countries have demonstrated efforts to cooperate on the issue. In 2004, the Bolivian and Chilean Ministries of Foreign Affairs struck a working group on Silala, which would meet several times in the ensuing years. In 2008, the topic of Silala was included in the 13 point bilateral agenda adopted by Evo Morales and Michelle Bachelet on behalf of their respective states. Most notably, in July, 2009 the Chancellery of the Republic of Bolivia provided to the media a draft preliminary bilateral agreement on the use of the waters of Silala (La Razón, 2009a). The agreement establishes that Bolivia would be compensated by Chilean users of the waters of Silala and that "Bolivia is entitled, initially, to fifty percent of the total volume of water of which flows across the border... and that this percentage may be increased in Bolivia's favour, based on the results of joint studies to be carried out under the agreement" (translated from La Razón, 2009a).

CURRENT STATUS

The draft agreement remains unsigned and the Silala negotiations have yet to resolve the two states' distinct positions. The Chilean government claims simply that Silala is an international river (Toromoreno, 2000). Chile asserts its right to equitable and reasonable utilization, as described in the United Nation's 1997 *Convention on the Law of the Non-navigational Uses of International Watercourses* (1997 Watercourses Convention) (for which Chile voted in favour, Bolivia abstained, and neither country has ratified; UN-ILC, 1997). Bolivia, for the most part, denies that there exists a Silala *river,* asserting that the Silala *springs* would not flow to Chile if not for the construction of the canals over a hundred years ago (Bazoberry, 2003).

Thus Bolivia claims ownership of the waters and demand payment (estimated at $15,000 per day) from Chile for their use (La Razón, 2010a). Many Bolivians believe that the payment should include a historic debt for use of the waters not stipulated in the original concession (La Razón, 2009b). The draft agreement reflects Chile's willingness to pay, but not a historic debt and only, initially, for fifty percent of the total volume of water that flows across the border (La Razón, 2009a). Parliamentary representatives from Potosí and community activist groups alike rejected the articles implying that Chile would initially have to pay for only half of the transboundary flow, believing that Bolivia is the rightful owner to the waters of Silala in their entirety (La Razón, 2009c; 2009d).

Bolivia rejected the draft bilateral agreement despite the economically impoverished, indigenous community of Quetena Chico and the Bolivian Chancellery pushing for its signing. Quetena Chico would stand to benefit from the Chilean compensation for their use of the waters of Silala. The leader of the community previously warned that "if the pre-agreement isn't signed, those who opposed it should pay us one hundred percent of what the Chileans were prepared to compensate" (Berna, 2010). He and a representative of the Chancellery were booed at the "International forum in defence of the waters of Silala", held in December 2009 in La Paz. The forum declared Bolivia's sovereign right to one hundred percent of the flow of the Silala, calculated that Chile owes more than a billion dollars for historic use of the waters, and concluded that any negotiation with Chile should guarantee Bolivia access to the Pacific Ocean (Hora 25, 2009). The Bolivian government declared a pause in the dialogue over the 13 point bilateral agenda, including the Silala negotiations, following the election of Sebastián Piñera in Chile in March 2010 (La Razón, 2010b).

DISCUSSION

The Río Lauca is shared by Bolivia and Chile in the region north of Silala. Though there are enough differences between the Silala and Lauca watersheds to warrant cautious comparison, there are revealing similarities. Perhaps the most important of these is the Bolivian desire to link a local watershed with the War of the Pacific, in which Chile left Bolivia without access to the Pacific Ocean. Glassner (1970) noted that "the Lauca had become essentially a tool with which the Bolivian government could unite its people on the less dramatic, but much more basic, question of an outlet to the sea". Forty years later, one can substitute "Silala" for "Lauca" in Glassner's writing and have no less a fitting observation. The Río Lauca dispute prompted Bolivia to propose "Preliminary studies on the legal problems relating to the utilization and use of international rivers" to the United Nations General Assembly (UNGA) in 1959, setting in motion a process that would eventually yield the 1997 Watercourses Convention. Three years later, the dispute would provoke a break in Bolivian/Chilean diplomatic relations that continues to this day.

Further hampering the Silala negotiations is the stark contrast of philosophies influencing the management of water resources in Bolivia and Chile. On one extreme is Chile, an often cited model of privatization for its 1981 Water Code (reformed in 2005), which created water markets and established transferable water use rights (Bauer, 2004). On the other is Bolivia, whose support for water as a human right is enshrined in its new constitution, and whose "water wars" in Cochabamba and El Alto put it at the forefront of the anti-privatization movement (Olivera, 2008; Shultz, 2009). Bolivia championed the *Resolution on the Human Right to Water and Sanitation*, recently adopted by the UNGA (UNGA, 2010). Yet Bolivians, to whom water is not for sale, seem to agree that Chile should pay for its use of Silala.

It is also interesting to note the two countries' levels of inclusivity and media coverage surrounding the Silala negotiations. The Chilean position on Silala has been established by experts and has had relatively little media coverage in Chile. Bolivia's position is defined by multiple actors (Bolivia's president and vice president have even hinted at the possibility of a national referendum on the issue; La Razón 2009e, La Razón, 2009f) and national media coverage is rampant–one newspaper (La Razón) alone published nearly two articles per week on the subject in 2009.

CONCLUSIONS

The dispute over the Silala basin illustrates the importance of history and the effects of differences in national socio-economic philosophies informing water resource management in international negotiations concerning transboundary watercourses, regardless of their size. The Silala is about one million times smaller the Amazon (in terms of mean discharge) and far lesser known, yet is has been labelled the only "high risk" basin in South America, largely because of the lack of official diplomatic relations between Bolivia and Chile and the fundamental disagreement as to whether or not the Silala is an international watercourse (UNEP, 2007). Nevertheless, the two countries have made important strides towards an agreement concerning the use of the basin.

The Silala case provides an illuminating example of the overlap between surface and groundwater regimes and the range of interpretations states can uphold regarding this complex interaction. The next step in this study will be to test the applicability of, and attempt to reconcile, the 1997 Watercourses Convention and the Draft *articles on the Law of Transboundary Aquifers* in the context of the Silala basin.

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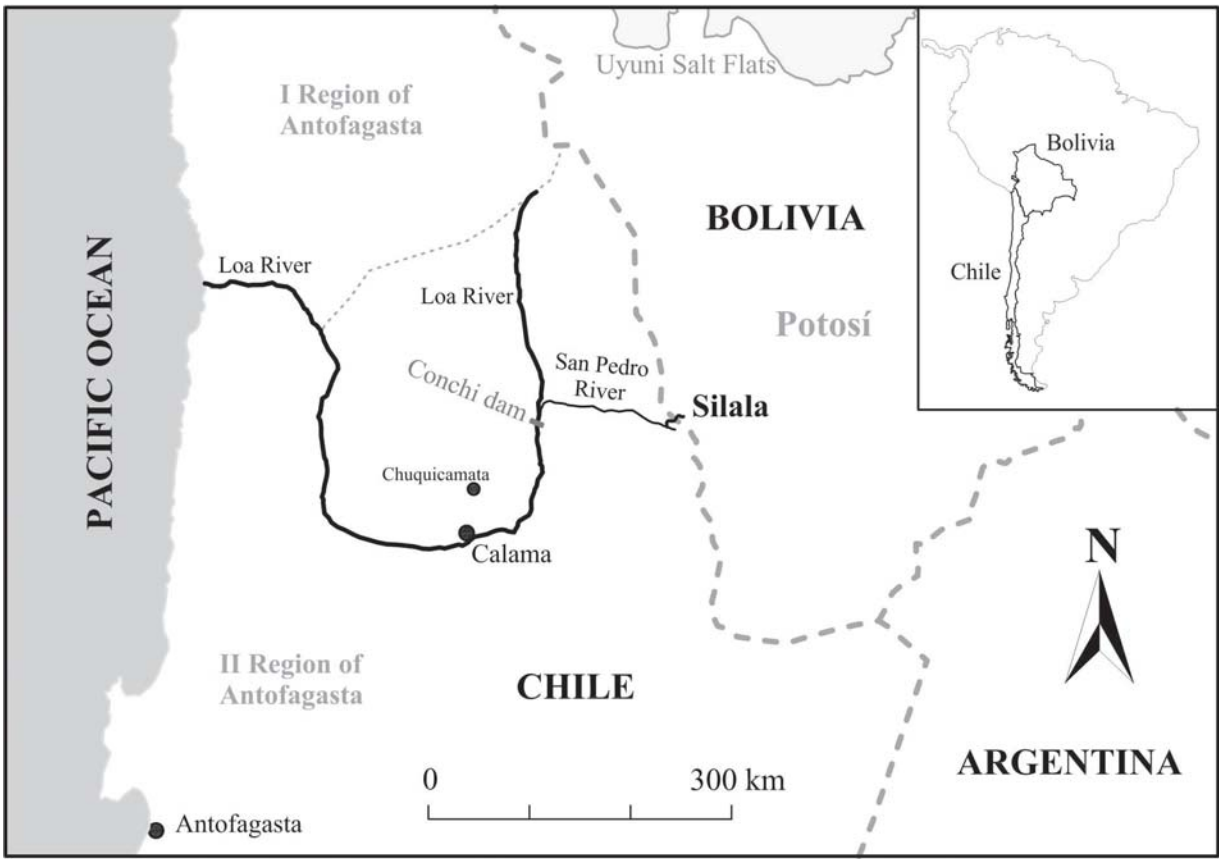

Figure 1: Location map showing Silala as a tributary of the San Pedro de Inacaliri and Loa Rivers in Chile.

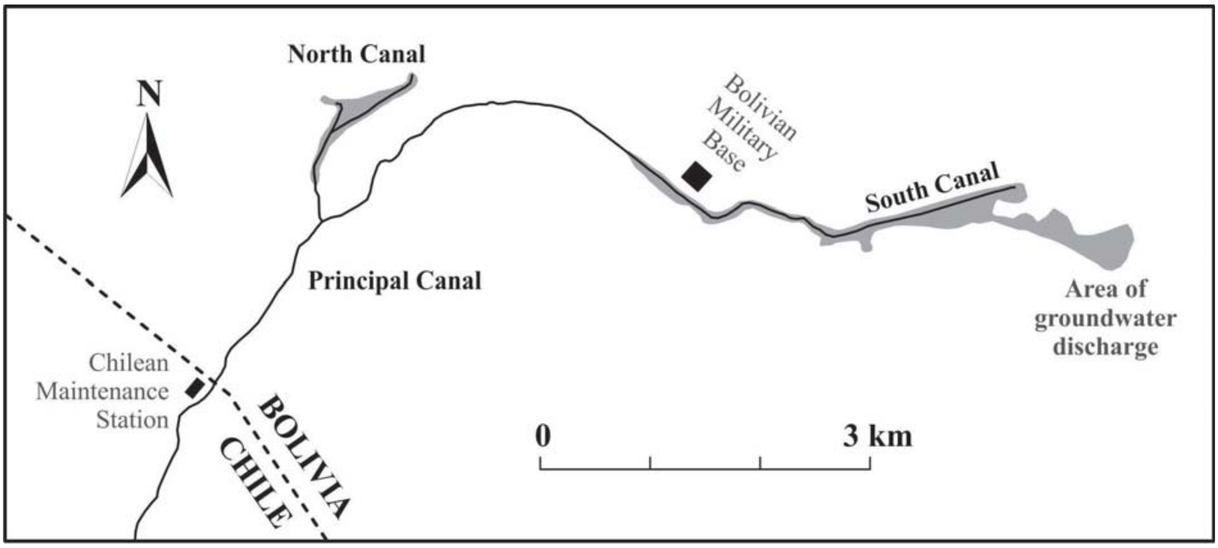

Figure 2: Detail of the source area of the Silala watercourse. Gray shading indicates the general geographic area of wetlands (“bofedales”) produced by groundwater discharge, present along both the North and South Canals.

Evaluation of groundwater recharge to the transboundary aquifer along the Maritsa River

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ABSTRACT

Transboundary aquifer along the Maritsa River is shared between Bulgaria, Greece and Turkey. Specific features of the multiannual water balance for the lower reach of the Maritsa River within Bulgarian territory are described. This is water balance *in situ* on entry into the groundwater system. Seasonality is well expressed, and the water budget elements are evaluated on monthly basis. Soil moisture variability is a weighty element of the water balance in the study area. Shallow aquifer is important in maintaining the high summer evaporation rate. The regional groundwater recharge is about 25% from the mean yearly precipitation sum, but occurs mainly during non-growing season. In general, water balance studies in the area are necessary on regular basis.

Key words: transboundary aquifer, water balance, soil moisture, shallow groundwater, the Maritsa River

1. INTRODUCTION

Transboundary issues related to water resources are important for Bulgaria. The rivers Struma, Mesta, Maritsa and Tundja are crossing the southern border of the country. Aquifers associated to these transboundary rivers in their low reaches are shared between Bulgaria and its neighbour countries – Greece and Turkey. Nowadays the International Law of Transboundary Aquifers is in preparation. Draft Articles on the law are adopted. National information on transboundary aquifers should be shared between neighbour countries to avoid conflicts and to facilitate cooperation and management of the shared groundwater resources.

Along the low reach of the Maritsa River, a transboundary aquifer shared between Bulgaria, Greece and Turkey is identified. This is alluvial aquifer EB56 (Svilegrad /Stambolo /Orestiada), according to the Transboundary Aquifers Inventory in South-Eastern Europe (Puri and Aureli, 2009). The study region located in Southeastern part of the country coincides with the area covered by the transboundary aquifer within its Bulgarian territory.

The aim of the study is to clarify specific features of the water balance within the study area. A special attention is given to evaluation of the groundwater recharge.

2. GENERAL DESCRIPTION OF THE STUDY AREA

2.1. Climate, topography and hydrology

The climate for the study area is temperate, influenced by Mediterranean climate. Rainfall sums are about 550-600 mm yearly (Koleva and Peneva, 1990). Seasonality is well expressed, and the driest season is summer. Scarce rainfalls limit the evapotranspiration value at the end of the growing seasons.

The Maritsa River is the main watercourse in the region. According to data from the river gauge at Svilengrad, it is 180-230 m wide depending on the water stage. The width of the river valley near the state boundary is about 4-5 km. The slope of the riverbed is rather low – 0.23 per mille (General Master Plans, 2000). The amplitude of variation in water stage is about 2 m. High water stages are associated to high flow rates usual for spring months. Floods occur generally in cold part of the year.

Artinian *et al.* (2008) realized a coupled hydrometeorological model of the Maritsa basin incorporating unsaturated flow reservoirs.

2.2. Geological and hydrogeological settings

According to the tectonic scheme of Bulgaria (Dabovski *et al.*, 2002), the study area is a part of the East Srednogorie unit. The Tertiary deposits comprise Eocene-Oligocene and Neogene continental to shallow marine clastics and carbonate rocks. Neogene fluvial-lacustrine sediments of the Ahmatovska Formation (ahN_{1-2}) are fine-textured and present an alternation of sandy and clayey layers. The thickness of this formation varies from 50 to 280 m (General Master Plans, 2000). Neogene deposits are widely exposed in the area. Groundwater collectors are related to layers from coarse-grained materials (gravel and sand). Quaternary deposits in the study area are represented mainly by alluvium of the Maritsa River and its tributaries (sand and gravel with thin layers of silt and clay) with thickness up to 22 m.

Groundwater in alluvial and Neogene sediments shows different chemical characteristics and total dissolved solids. Both aquifers are considered as a unique aquiferous system with high transmissivity about 1000 m^2/d, and groundwater resources of 350 l/s for the area of about 160 km^2. The TDS content in groundwater varies in the range from 0.39 to 0.89 g/l (General Master Plans, 2000).

Warmer groundwater temperature (in the range 14-15ºC) for some wells testifies to mixing of groundwater from the alluvial and Neogene aquifers. In general, mixed groundwater has a specific chemical composition.

The groundwater flow is drained by the Maritsa River and its tributaries. Water stages in the Maritsa River are of primary importance for its water exchange with the aquifer system. Low water stages (generally in late summer and early autumn) favour groundwater discharge. The low flow of the right tributaries of the Maritsa River (Biserska and Lozenska Rivers) is maintained by groundwater of the Neogene aquifer (Antonov and Danchev, 1980).

Numerous faults marked on the geological map (both proven and supposed) are expected to facilitate considerably the mixing and local drainage power of the aquifers (especially for the deeper Neogene aquifer) in the respective reach.

2.3. Soil and land use

Cinnamonic forest soils are the main bioclimatic soil type for South Bulgaria, developed usually on Pliocene and early-Quaternary relief (Koinov et al., 1998). In the study area, they are leached. Rankers are shallow soils related to silica-reach rocks under erosion, and Rankers with cinnamonic forest soils are widely developed in the area. Fluvisols are intrazonal soils that are genetically related to the alluvial deposits in the river valley. Other soil variety is Planosols.

In respect to the general climate features, the agricultural activity in the region is effective under irrigation. The sources of irrigation in the study are local reservoirs and the river.

3. OBJECTIVES, METHODS AND DATA

The objective of the study is to characterize general features of the water balance of the area with special attention to the groundwater recharge formation. The water balance is considered on monthly basis with data from the study area. A multiannual average water balance is presented.

The method of Thorntwaite was used to calculate the potential the evapotranspiration (PE). In agrometeorological practice, FAO recommends using of reference evapotranspiration ETo (Allen et al., 1998), based on daily meteorological data.

The main method used in the study is the water budget equation on monthly basis.

In general, the role of the soil moisture variability in the water balance is the most important for temperate climate, where the soil moisture varies from wilting point up to field capacity throughout the year (Lawrence et al., 2007). Heterogeneity of topography and the depth to the groundwater table control the spatial variability of the soil moisture content. The hydraulic conductivity of the unsaturated soils strongly increases with enhanced soil moisture content. As a result, wetter lands receive more groundwater recharge.

In relation to difference in the interannual rainfall distribution, two types of water balance are identified – for temperate and for Mediterranean climate (Laio *et al.*, 2002). Limited area of the country is a prerequisite for mixing of the two main types of the precipitation regime (Mateeva, 2002). Such effect was registered by Artinyan et al. (2008) who reported rather different distribution of rainfalls in two successive years, typical for different climates.

In Bulgaria, a network of agrometeorological stations is in operation, and up to now near 50-year time-series is available at the National Institute of Meteorology and Hydrology at Bulgarian Academy of Sciences (NIMH-BAS). Long-term agrometeorological observations in Bulgaria (Slavov and Georgieva, 2001) show that soil moisture varies in wide range throughout the year. Generally, by the end of each growing season the soil moisture in the topsoil is low. It increases steadily during cold season, reaching maximal values (about field capacity) in March. Since the onset of new growing season, water reserves in soil gradually decrease. The most severe reduction of the soil moisture content occurs in June and July according to high demand of plants in water. Then the soil moisture may reach the wilting point value.

The groundwater recharge is a part of the water balance of the area. The large-scale water balance equation can be written in relation to changes in the soil moisture content as (Yeh and Famiglietti, 2009):

$$\frac{dW}{dt} = P - E - R_S - R, \quad (1)$$

where W is soil moisture content, t is time, P is precipitation; E is evapotranspiration; Rs is surface runoff; and R is percolation to the water table. Deep percolation becomes recharge of the shallow groundwater. All the variables in Eq. (1) represent the regional-scale spatial averages on monthly basis.

The water balance equation for an unconfined aquifer can be written as:

$$S_y \frac{dH}{dt} = R - R_b, \quad (2)$$

where Sy is the specific yield of the unconfined aquifer; H is the groundwater level; R is groundwater recharge ; and Rb is groundwater runoff (base flow).

Data consist of precipitation sums, monthly dataset on soil moisture, and water table depth. Monthly data on precipitation are from multiannual averages for the station Svilengrad. The hydrogeological time-series refer to groundwater table for the observational well N 531A at Biser village, average values for the 1981-1988 period. The precipitation at the station Kardjali from Southern Bulgaria for this period shows monthly sums close to their norms (multiannual average). In general, both restricted data availability and the lack of free access to data impeded the work.

4. RESULTS AND DISCUSSION

The annual average precipitation at the station Svilengrad is 595 mm (Koleva and Peneva, 1990). The potential evapotranspiration is evaluated using the method of Thorntwaite based on monthly average air temperatures.

The reference evapotranspiration using the FAO Penman-Monteith method (Allen et al., 1998) was calculated for all agricultural regions of Bulgaria by Moteva et al. (2008) based on long-term (1971-2000) daily and monthly meteorological data. The obtained values refer to the potential vegetation period March-October. For the region of Svilengrad, the reference evapotranspiration is 830 mm (Moteva et al., 2008).

For in the study area, the soils moisture available for plants is assessed as 135-150 mm for all soil types except for Rankers that are shallow soils (Koinov et al., 1998). Data on the soil moisture content at the agrometeorological station Lubimets situated in the study area were used. According to data, water reserves in soil gradually decrease since the onset of new growing season. The depleted soil moisture is recovered on the account of precipitation sums during the cold season. The presented water balance studies are under natural conditions, and irrigation was not taken into account. The need of crops in water is partly due to contribution from groundwater and soil.

For the study area, average annual cycles of balance components are presented on monthly basis. Different aspects of the multiannual water balance are presented on Figures 1-3, and Table 1.

The alluvial aquifer is related to permeable layers of sand or gravel that are overlain by less permeable deposits. The specific yield of the shallow aquifer is defined as a difference between total porosity and field capacity. For most of the soil textures typical for Bulgaria, the values of specific yield ranges from 0.07 to 0.08. This analysis is made based on the parameters of Bulgarian soils, evaluated by Rousseva (2001, 2006). In the present study, the value of 0.08 was used for the specific yield of the alluvial aquifer.

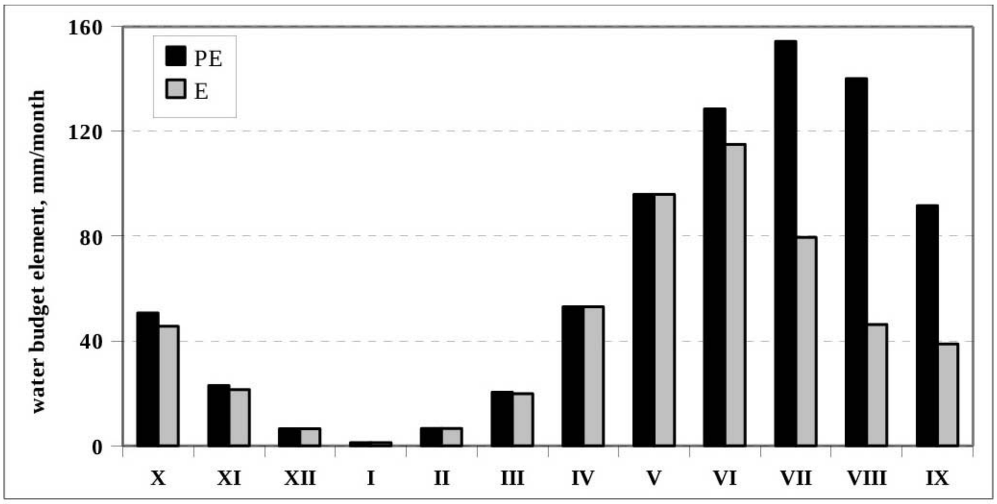

Figure 1. Multiannual average values of the potential (PE) and actual (E) evapotranspiration for the study area.

A typical feature of the water balance elements is their seasonality. The potential evapotranspiration has a maximum in July, and the actual evapotranspiration is limited by availability of water at the end of the growing season (Fig. 1).

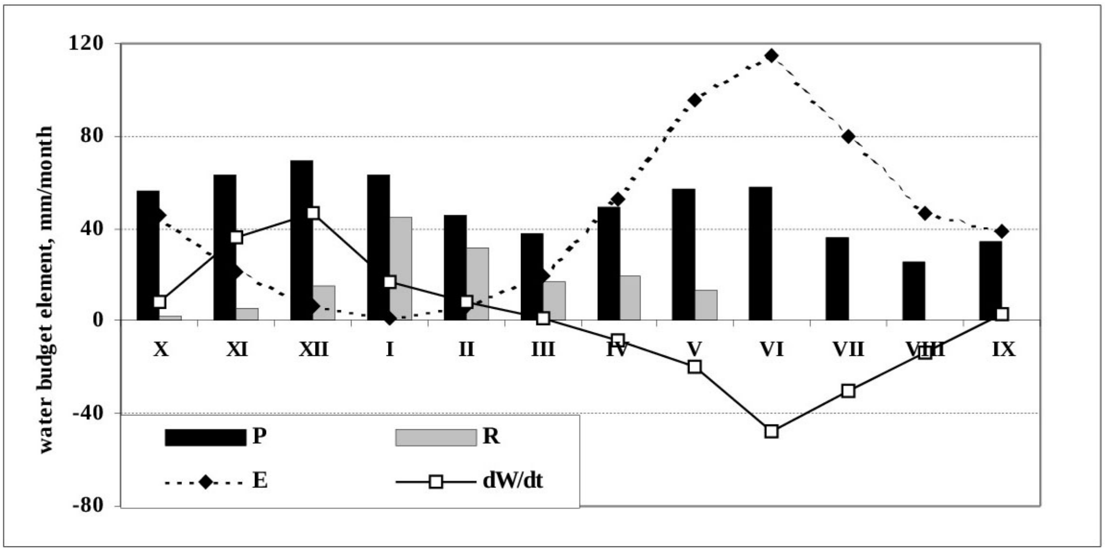

Figure 2. Interannual variability of the monthly precipitation sum (P), evapotranspiration (E), groundwater recharge (R), and soil moisture content (dW/dt).

The groundwater recharge occurs mainly during cold non-growing season. The groundwater recharge is split into storage into the shallow aquifer and the lateral outflow. The water reserves stored both in the topsoil and the shallow aquifer, are highly variable throughout the year (Fig. 2 and 3).

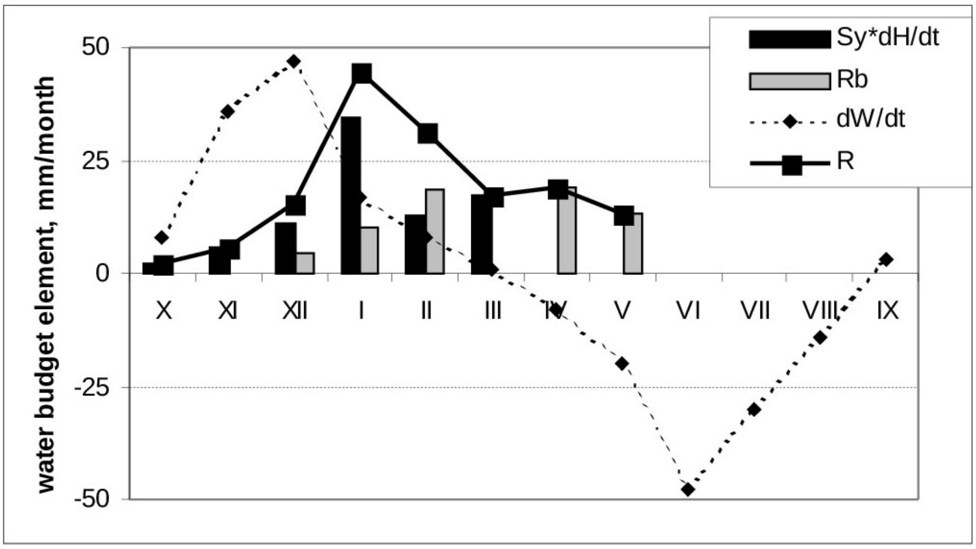

Figure 3. Interannual variability of the soil moisture content (dW/dt) and monthly groundwater recharge (R), including its components – water storage in aquifer (Sy*dH/dt) and baseflow (Rb).

The obtained value of the regional groundwater recharge (149.3 mm/an) is about 25% from the mean yearly precipitation sum (Table 1). This value is in consistence with the Groundwater Resource Map of Bulgaria (1979).

Table 1. Element of the yearly water balance in the study area

Element, index	Annual sum	Value	Sum for the period X-III
P, mm	595		335
PE, mm *	771.9		
PE / P (aridity index)		1.3	
E, mm	529.7		101.1
E / P		0.89	
Groundwater recharge R, mm	149.3		
including:			
- groundwater storage	84		
- lateral outflow (baseflow)	65.3		
R / P, %		25.1	

* - according to Thorntwaite

During summers, upward capillary flux from the shallow aquifer (exfiltration) occurs. Thus, the shallow aquifer is important in maintaining the high summer evaporation rate.

The groundwater recharge is controlled mainly by the precipitation sum during non-growing season, maximum soil water storage capacity and evaporation during the same period.

The presented water balance is typical for a multiannual period. In future, water balance studies are necessary on regular basis.

5. CONCLUSION

The transboundary aquifer along the Maritsa River is shared between Bulgaria, Greece and Turkey. General features of the terrestrial water balance in the study area are presented. This is water balance *in situ* on entry into the groundwater system, typical for multiannual period. Seasonality is well expressed. Evapotranspiration and soil moisture fluctuations are important balance elements, controlled by climate, soils and vegetation.

Regional groundwater recharge is estimated taking into account soil water balance computation. The soil moisture variability and evapotranspiration are important balance elements. The water budget elements are evaluated on monthly basis.

According to the water balance data, the groundwater is recharged mainly during non-growing season. The recharge value is about 150 mm annually, which is 25% of the yearly precipitation sum. The groundwater recharge is controlled mainly by the difference between precipitation and evaporation during the cold part of the year, and the maximum soil water storage capacity.

In general, water balance studies in the area are necessary on regular basis.

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The SADC Hydrogeological Map & Atlas:
Towards an improved understanding of groundwater regimes in Southern Africa

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ABSTRACT

The hydrogeology map of the Southern African Development Community (SADC) region is a comprehensive groundwater information system visualized by means of an interactive web- based regional hydrogeological map and atlas. The SADC hydrogeology map provides information on the extent and geometry of regional aquifer systems, and primarily serves as a base map for hydrogeologists and water resource planners. Many aquifer systems in SADC, including transboundary aquifers, have low transmissivities and are relatively low yielding. What constitutes an (transboundary) aquifer system and policy responses thus require further refinement. The SADC Hydrogeological Mapping Project has delineated 14 transboundary aquifer systems on the basis of inferred continuous and transmissive aquifers, SADC hydrolithological boundaries, and sub-basin river boundaries. Although the natural extent and hydrogeological significance of these systems will need further research and detailed field investigations, the mapping proved particularly useful for identifying data rich and data scarce areas in the SADC Region.

Key words: SADC, Southern Africa, Regional, Hydrogeological Map, Groundwater, Aquifer Systems

1. INTRODUCTION

1.1. The SADC Hydrogeological Map and Atlas

The Southern African Development Community hydrogeological map and atlas (SADC HGM) provides an overview of the groundwater resources of the SADC region by means of an interactive web-based regional map. The map is a first, but necessary, step to support groundwater resource planning at multi-national level as well as at regional trans-national scales. The preparation of a regional hydrogeological map was identified as a priority by SADC and was included as a component of the Regional Groundwater Management Programme in the Regional Strategic Action Plan for Integrated Water Resources Development and Management. The SADC hydrogeology map is a general hydrogeological map and is a valuable tool to advocate the importance of groundwater resources in the political and social development process (Struckmeier and Margat, 1995).

1.2. The SADC HGM Project

The compilation of the SADC hydrogeological map took place during the period June 2009 to March 2010 through a consultancy awarded to a consortium consisting of Sweco International (Sweden) as lead firm, Council for Geoscience (South Africa), Water Geosciences Consulting (South Africa) and Water Resources Consultants (Botswana). The project implementation agency (PIA) was the Department of Geological Survey (DGS), Botswana. The overall objective of the project was to improve the understanding of groundwater occurrence within the SADC region and to promote cooperation and better understanding of water resource planning and management.

2. COMPILATION OF THE SADC HYDROGEOLOGICAL MAP

2.1. Scale and themes

The interactive web-based hydrogeological map and atlas was produced at a scale of 1:2.500 000 and displays layers of lithology and geological structures, aquifer types and associated groundwater productivity, major transboundary aquifers, rainfall, recharge, groundwater quality, surface waters including perennial and non-perennial rivers, major river basins, and other topographical map features such as elevation, major towns and roads and international boundaries.

2.2. Groundwater information system

A major outcome was the completion of the SADC Hydrogeologic Borehole Database. The database was designed to support the hydrogeological mapping process and contains the data that was submitted by Member States. The database holds approximately 335 000 records.

2.3. Hydro-lithology base map

The hydro-lithology base map was compiled from the SADC geology map prepared by the South African Council for Geoscience (Hartzer, 2009). This was done through linking the stratigraphy to rock types. The geology map has been simplified to 12 hydro - lithological classes.

The SADC geology map contains 730 different lithological units. For the SADC hydrogeological map the units were grouped together to form different lithological units based on hydraulic characteristics. For example, siliclastic sedimentary rocks, such as sandstone and gravel, were grouped in a different unit as chemical sedimentary rocks (e.g. limestone). In the same manner, a distinction was made between sands and clays and very coarse sedimentary rocks such as tillites and diamictites and volcanic rocks were separated from intrusive rocks. Furthermore, a chronologic distinction was made to separate older metamorphosed units from younger and less deformed and metamorphosed units. The result of this process was a simplified geological base map comprising of 12 hydro-lithological units (Fig 2).

2.4. Aquifer types

Main rock types have been grouped accordingly into permeable and low permeability formations (Fig 3) based on the lithology base map and expert judgement. Permeable formations have been further grouped into *unconsolidated intergranular aquifers* (gravel, alluvium, sand, etc.), *fissured aquifers* (sandstone, basalt, etc), *karst aquifers* (limestone, dolomite, gypsum, etc) and *layered aquifers* (e.g. Kalahari formations).

2.5. Aquifer productivity

The aquifer types were grouped into eight classes according to different aquifer productivity (Table 1) following the IAH standard legend for groundwater and rocks that combines information on aquifer productivity and the type of groundwater flow regime (intergranular or fissured; Struckmeier and Margat, 1995).

The aquifer productivity of permeable areas ranges from high to moderate productive was based on local expert knowledge, and information from national representatives of member states was used to verify and update the information. The low permeability formations were grouped into locally moderate productive and low productive. A scheme was adopted to facilitate the assignment of aquifer productivity to the different aquifer types (Fig 1), taking into account flow properties (transmissivity) and sustainability of the resource (local recharge). The general productivity is mainly dependent on a combination of recharge and aquifer transmissivity.

Table 1: Hydrogeology and aquifer productivity

Productivity Class / **Aquifer Type**	1. High productivity	2. Moderate productivity	3. General low productivity but locally moderate productivity	4. Generally low productivity
A. Unconsolidated Intergranular aquifers	A1	A2	X	X
A. Fissured aquifers	B1	B2	X	X
B. Karst aquifers	C1	C2	X	X
C. Low permeability formations	X	X	D1	D2
		Denotes an extensive aquifer overlain by cover		

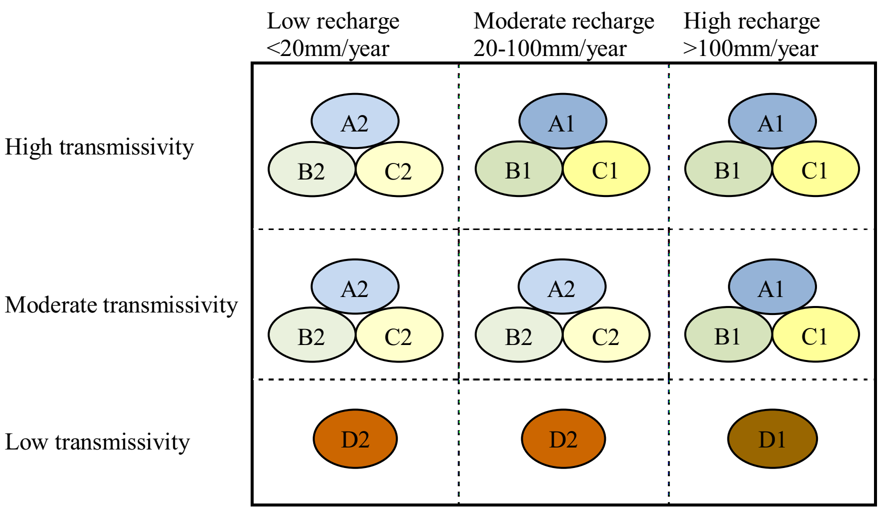

Figure 1: Scheme adopted for assigning aquifer long term productivity to hydro-lithological domains on the SADC hydrogeological map. (refer to Table 1).

The long-term aquifer productivity of hydro-lithological domains is primarily controlled by both lithology (i.e. conductive material properties) and water supply (i.e. groundwater recharge). Hydro-lithological domains can be classified by these two basic parameters. For example, moderate recharge conditions combined with a highly transmissive aquifer will be ranked as 1 (high productivity). Domains in the upper right corner of the matrix are more productive than those of the lower left corner. Hydro-lithologic domains to the left require boreholes over a larger area than the domains to the right.

2.6. Transboundary Aquifer Systems

Groundwater systems, including Transboundary Aquifer Systems, cannot be delineated by lithological domains only. Detailed information on e.g. topography, soils, depths of over burdens groundwater flow, extent of fracture systems, identification of recharge- and discharge areas is also needed, but rarely available. As a consequence, transboundary aquifers map layers on global and regional scales are commonly broadly marked as conceptual circles and ellipses.

Many aquifer systems in SADC are low yielding. Groundwater movement is controlled by the hydraulic properties of the aquifer. In the case of low-yielding aquifers, where the transmissivities are low, the concept of a transboundary aquifer requires re-consideration. Groundwater movement is either slow or occurs within local and disconnected packets (Cobbing, et al. 2008). What constitutes a transboundary aquifer or aquifer system requires further refinement in this case as the cross border impact of abstraction-, recharge-, pollution- and remediation of groundwater is difficult to assess. Following the Atlas of Transboundary Aquifers (Puri and Aureli, 2009) as a point of departure, transboundary Aquifers were delineated (Fig 3 and Table 2) using the following criteria: 1) Shared by more than one SADC country, 2) Continuous and permeable aquifers, 3) Sub-basin river boundaries, and 4) SADC HGM hydro-lithological boundaries.

Table 2: SADC HGM Transboundary Aquifers

Name	Code	States
Karoo Sandstone Aquifer	6	Tanzania, Mozambique
Tuli Karoo Sub-basin	15	Botswana, South Africa, Zimbabwe
Ramotswa Dolomite Basin	14	Botswana, South Africa
Cuvelai and Etosha Basin	20	Angola, Namibia
Coastal Sedimentary Basin 1	3	Tanzania, Mozambique
Shire Valley Aquifer	12	Malawi, Mozambique
Congo Intra-cratonic Basin	5	D R Congo , Angola
Coastal Sedimentary Basin 2	4	D R Congo , Angola
Coastal Sedimentary Basin 6	21	Mozambique, South Africa
Medium Zambezi Aquifer	11	Zambia and Zimbabwe
Dolomitic	22	D R Congo , Angola
Sands and gravel aquifer	23	Malawi, Zambia
Kalahari/Karoo Basin	13	Botswana, Namibia, South Africa
Eastern Kalahari/Karoo basin	24	Botswana and Zimbabwe

3. DISCUSSION AND CONCLUSION

The project has produced a comprehensive, interactive web-based hydrogeological map and atlas of the SADC region as well as enhanced institutional capacity in SADC member states for producing and using hydrogeological maps in water resources planning, development and management. The use and application of the SADC HGM will be crucial for the sustainability of the regional hydrogeological mapping programme. The map should be used to: Guide policy making and influence political decision-making on natural resource issues, support in transboundary groundwater planning and management, create awareness related to groundwater issues, assist in regional development planning, and to serve as a platform to update national maps.

The SADC hydrogeological map and atlas will require regular updating when relevant new information is available. Key to updating the map is the improvement of groundwater data sets and information systems in the various countries. There needs to be a concerted effort to address shortcomings. A future update of the map requires a bottom-up approach to work with countries to ensure representative datasets are obtained from the various geological domains. The ideal approach would be to move from large-scale hydrogeological mapping programmes to medium-scale and finally smaller-scale programmes.

The natural extent of SADC transboundary aquifer systems as well as their hydrogeological, social and economical significance needs to be verified by thorough research and extensive detailed field investigations.

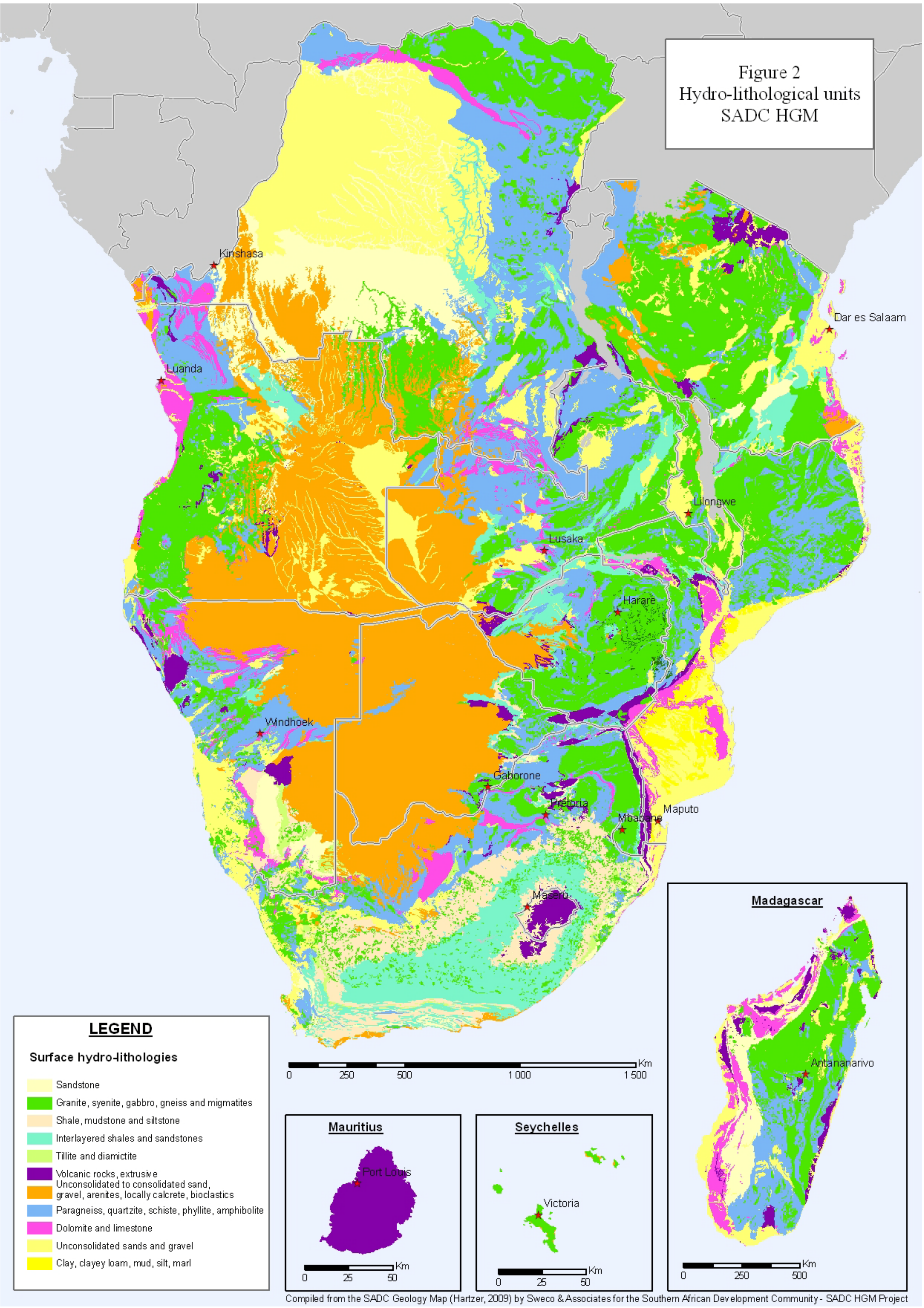
Figure 2
Hydro-lithological units
SADC HGM
Kinshasa
Dar es Salaam
Luanda
Lilongwe
Lusaka
Harare
Windhoek
Gaborone
Pretoria
Maputo
Mbabane
Maseru
LEGEND
Surface hydro-lithologies
Sandstone
Granite, syenite, gabbro, gneiss and migmatites
Shale, mudstone and siltstone
Interlayered shales and sandstones
Tillite and diamictite
Volcanic rocks, extrusive
Unconsolidated to consolidated sand, gravel, arenites, locally calcrete, bioclastics
Paragneiss, quartzite, schiste, phyllite, amphibolite
Dolomite and limestone
Unconsolidated sands and gravel
Clay, clayey loam, mud, silt, marl
0 250 500 1 000 1 500 Km
Mauritius
Port Louis
0 25 50 Km
Seychelles
Victoria
0 25 50 Km
Madagascar
Antananarivo
0 250 500 Km
Compiled from the SADC Geology Map (Hartzer, 2009) by Sweco & Associates for the Southern African Development Community - SADC HGM Project

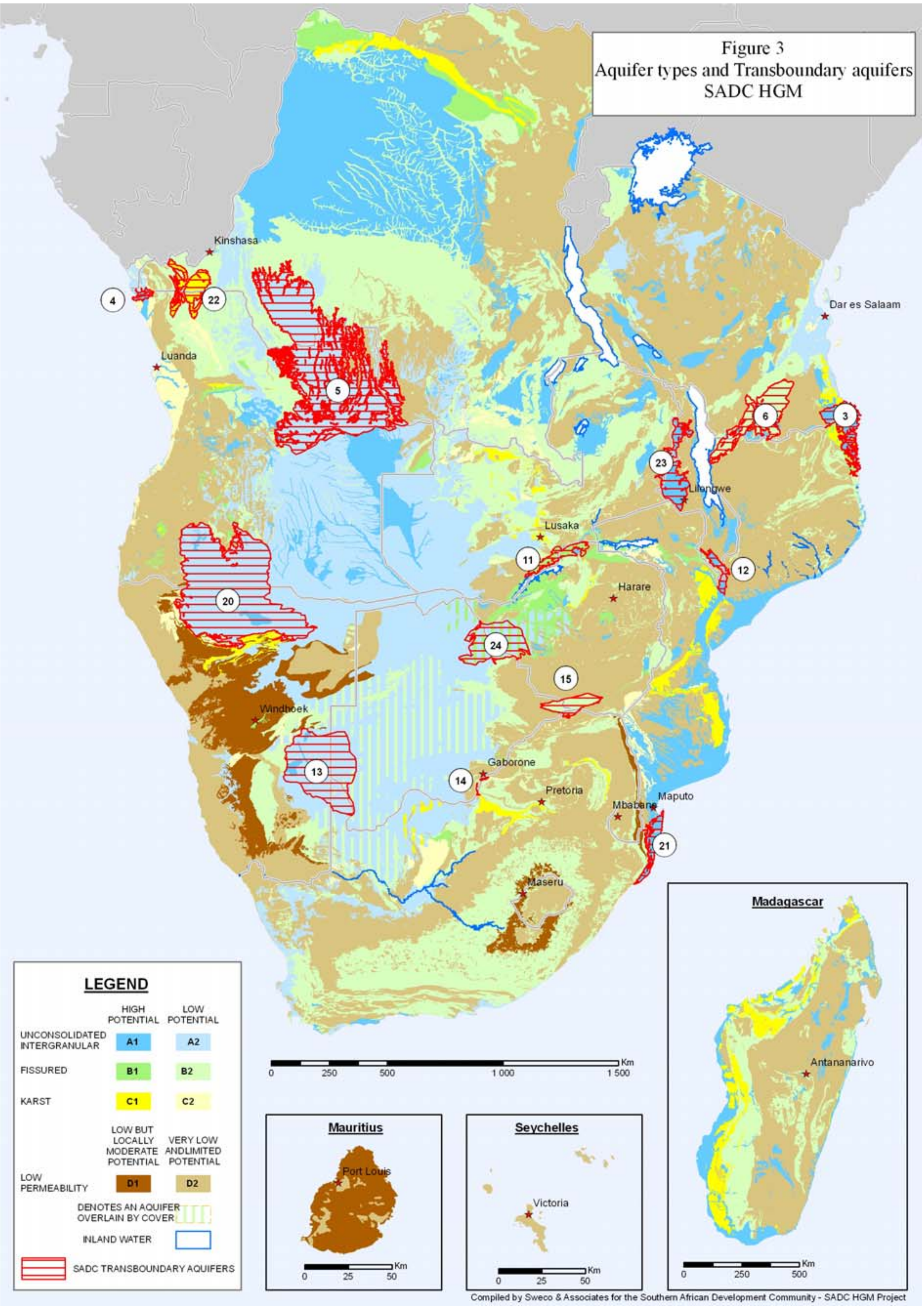
Figure 3
Aquifer types and Transboundary aquifers
SADC HGM
Kinshasa
Luanda
Dar es Salaam
Lilongwe
Lusaka
Harare
Windhoek
Gaborone
Pretoria
Mbabane
Maputo
Maseru
LEGEND
HIGH POTENTIAL
LOW POTENTIAL
UNCONSOLIDATED INTERGRANULAR
A1
A2
FISSURED
B1
B2
KARST
C1
C2
LOW BUT LOCALLY MODERATE POTENTIAL
VERY LOW ANDLIMITED POTENTIAL
LOW PERMEABILITY
D1
D2
DENOTES AN AQUIFER OVERLAIN BY COVER
INLAND WATER
SADC TRANSBOUNDARY AQUIFERS
Mauritius
Port Louis
Seychelles
Victoria
Madagascar
Antananarivo
Km
0 250 500 1 000 1 500
Compiled by Sweco & Associates for the Southern African Development Community - SADC HGM Project

Acknowledgements

The Southern African Development Community (SADC) hydrogeological map has been planned for since the early nineties. Numerous persons have been involved in the conceptualisation of the SADC hydrogeological map and their contributions to the project are gratefully acknowledged. We express our gratitude to the Water Division of the SADC Secretariat, the Project Steering Committee and other contact persons of the Member States for their input during the course of the consultancy. In particular, the project team acknowledges their time and effort in making data and information available for use in the compilation in the SADC hydrogeological map, and their active participation in workshops to edit and review the map. The staff and the Department of Geological Survey in Botswana are greatly acknowledged for hosting the project and the project team members. We are grateful to the European Union, GTZ and UK Aid for their financial support to the project.

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Cobbing, J.E., Hobbs P.J., Meyer, R., and Davies J., (2008) A critical overview of transboundary aquifers shared by South Africa. *Hydrogeology Journal* 16, 1207-1214.

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Some Problems of Monitoring, Assessment and Management of Transboundary Aquifers

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Abstract

Phase I of the ISARM program, in which we defined 15 transboundary aquifers in Kazakhstan, comes to an end. Now we are able to offer some results and define problems of monitoring, assessment and management of transboundary aquifers, which will demand scientific decision regarding:
1. Scale of research.
2. Area of transboundary aquifers.
3. Risks of ooccurrence of transboundary problems.
An important element underlying the methods of monitoring, assessment and management of resources of transboundary aquifers is a typification of such problems.
Key words: transboundary aquifers; Republic of Kazakhstan; monitoring and assessment, transboundary groundwater problems

1. TRANSBOUNDARY AQUIFERS INVENTORY IN KAZAKHSTAN

Recently, study of transboundary groundwater has been widely developed in Kazakhstan since due to recommendations provided by ISARM regarding stage I of transboundary aquifers inventory (Puri & Aureli, 2005). The common aim of works was to identify transboundary problems that require organizational intergovernmental efforts for solution thereof.

Transboundary aquifers inventory was carried out on the basis of typification of some specific features offered by ISARM that include aquifer type, reservoir system, dominant hydraulic state, predominant groundwater flow direction, and boundary conditions.

Type of aquifer depends on the type of groundwater body permeability. Aquifers may be porous, fractured, and porous-fractured. Through the analysis the types of transboundary groundwater reservoirs in Kazakhstan it was found that type of transboundary aquifer indirectly predetermines the hazard of transboundary problem exposure.

Fractured transboundary aquifers in Kazakhstan are spread out in the mountainous area. The state border crosses watersheds, river beds, and mountain rivers. Recharge area normally coincides with the spread out of aquifer area. Hydrogeological features allow using only resources of these aquifers, normally, spring runoff. Due to low population density in this territory and thus, low intensity of groundwater use, transboundary problems are not likely to occur. Exceptions are carbon-bearing geological structures with a combined type of permeability that contain their waters in fractures and karsts. However the state border of Kazakhstan does not cross such structures.

Porous transboundary aquifers are spread out in the territory where the state border normally crosses plain terrains. In these areas, the transboundary aquifers more frequently form a uniform water-bearing system consisted of aquifers and aquitards. The main risks of transboundary problems are associated with such systems.

There are phreatic (the first from of the unconfined surface), semi-confined, and confined transboundary aquifers in terms of the dominant hydraulic state. Intensity of mass exchange is crucial for confined aquifers. Deep-occurring confined waters are several thousand years old and require no pollution protection measures due to a low vulnerability thereof. It is obvious that measures are aimed at protection of recharge areas of such aquifers (the state, within the territory of which such areas are located, bears responsibility for such protection) will not influence the conditions of groundwater at near future in the area of their use.

Groundwater flow direction in relation to the state border determines referring of the recharge areas of the transboundary aquifer to the territory of this or that state, and possibility of pollution transfer by groundwater flow from a certain side.

Finally, these all taxonomic units of typification of transboundary aquifers are reflected in the schemes of boundary conditions of groundwater flows. Simplified pictures of transboundary groundwater systems from UNECE datasheet groundwater may be used as such schemes at a first approximation. They allow to visualize any possible risks of pollution and depletion of groundwater of transboundary aquifers and determine possible ways for assessment of such risks. In its turn, this allows to substantiate a type of monitoring and assessment of transboundary aquifers and define their development.

There are fifteen transboundary aquifers in Kazakhstan (Fig. 1), the land's state border of which is over 13000 km (Podolny *et al.,* 2008). Each of these transboundary aquifers has been assessed in terms of occurrence or possible occurrence of risks of transboundary interstate problems that require attention of relevant authorities aimed at mutual use and protection of groundwater resources of such aquifers. Now from this it is possible to bring some results and to define problems of monitoring, assessment and management of transboundary aquifers, which will demand scientific decision:

1. Problem of scale of researches.
2. Problem of area of transboundary aquifers.
3. Risks of occurrence of transboundary problems.

The typification of such problems is the important element underlying the basis of methods of monitoring, assessment and management of transboundary aquifers.

Fig.1. Transboundary aquifers in Kazakhstan
1 - North-Kazakhstan; 2 - Preirtysh; 3 - Zaisan; 4 - Alakol; 5 - Zharkent; 6 - Tekes, 7 - Shu; 8 - North-Talas; 9 - South-Talas; 10 - Pretashkent; 11 - Syr-Darya; 12 - Amu-Darya; 13 - Precaspian; 14 - Syrt; 15 - South-Pred-Ural.

2. PROBLEM OF SCALE OF RESEARCHES

These transboundary aquifers have been allocated with reference to scale of mapping 1:10,000,000. It is well-known that possibility of display of units of hydro-geological stratification depends on mapping scale. Fifteen transboundary aquifers which have occurred in Kazakhstan correspond to quantity of transboundary hydrogeological regions of 3-4 orders which are, in effect, basins of groundwater. Though these basins are named "transboundary aquifers" or "systems of transboundary aquifers," in the specified scale it is possible to show aquiferous supercomplex (the hydrogeological body consisting from several aquifers, complexes and zones, separated from adjacent hydrogeological subdivisions by aquitards or local confining complexes) and aquiferous group (system of aquifers, complexes, zones, supercomplexes, that are characterized by independent conditions of water exchange). Designing of a network of monitoring of transboundary aquifers, even of the very first level - monitoring of the early prevention (UNECE, 2000), demands larger scale of mapping (1:500,000 and larger). Hydrogeological stratification should be constructed according to such scale, and it should be more fractional. It will demand more detailed description of transboundary aquifers; will separate layers in which points of observation network of monitoring should be defined. The main hydrogeological subdivisions mapped in scale 1:500000 and larger, are: an aquifer, a complex, a zone, which are allocated on the basis of the accepted hydrogeological criteria of hydrogeological stratification of a geological section:

type of groundwater body permeability;

value of groundwater body permeability;

the content of gravitational water in geological bodies;

spatial variability of groundwater body permeability and waterness.

At the type of groundwater body permeability groundwater bodies are divided into two groups: with porous and fractured (including karstic and fractured-karstic) permeability. This criterion is included at ISARM' typification of transboundary aquifers.

At value of permeability the groundwater bodies are differentiated into permeable bodies (aquifers) with hydraulic conductivity more than 1 m/day, poorly permeable bodies (poorly aquifers) with hydraulic conductivity from 1×10-4 to 1 m/day, and water-proof (aquitards) with hydraulic conductivity less 1×10-4 m/day.

At the content of gravitational water the geological bodies are divided into water-bearing bodies (containing gravitational water) and waterless.

At spatial variability of water permeability the hydrogeological bodies are divided into homogeneous and heterogeneous (value of hydraulic conductivity varies within several gradation).

Thus, aquifer (weak aquifer) is the water-bearing hydrogeological body homogeneous for type and value of permeability, and aquitard - water-proof hydrogeological body.

Aquiferous complex is the water-bearing hydrogeological body with porous heterogeneous permeability in which it is not possible to allocate separate aquifers and aquitards in mapping scale 1:500,000 or larger. In case of prevalence in complex poorly aquifers it is allocated as a poorly aquiferous complex, and at prevalence of aquitards - an aquitard complex.

Aquiferous zone (fractured aquifer) is water-bearing hydrogeological body with fractured permeability.

The assessment and management also should be constructed according to such stratification.

3. PROBLEM OF AREA OF TRANSBOUNDARY AQUIFERS

There is some uncertainty about the defining the area of transboundary aquifer. Resolution of UNGA (A/RES/63/124) defines "transboundary aquifer" and "transboundary aquifer system" as an aquifer or aquifer system, part of which are situated in different States (Stephan, M.R, *editor,* 2009). Thus, transboundary aquifer is defined as area equal of its existence on either side of the border. And for the confined aquifers this condition to the full is carried out, and groundwater abstraction of one of the countries leads to occurrence of transboundary problems. A good example is the groundwater abstraction of the Preirtysh transboundary (Kazakhstan-Russia) aquifer system, which is more than

400000 км^2. The system of these transboundary aquifers consists of Paleogene, Upper Cretaceous, and Lower Cretaceous aquifers. The Preirtysh transboundary aquifer is a part of a huge artesian basin of the West Siberian plate. Today Russia intensively uses these transboundary aquifers to supply water to large cities such as Novosibirsk, Barnaul, etc. According to the monitoring research carried out by the Committee of Geology of Russia, drawdown area caused by operation of large water intake facilities reached 50000 km^2 at a maximal drawdown of 35 m and covers the territory of Kazakhstan (Fig. 2). Drawdown of a groundwater level of these aquifers is fixed in observation wells of network of the State Groundwater Monitoring of Kazakhstan (Fig. 3).

Fig. 2. Fragment of The map of a status of groundwater of territory of the Russian Federation (as of 01.01.2007), with addition (Lygin, A.M., editor, 2007)

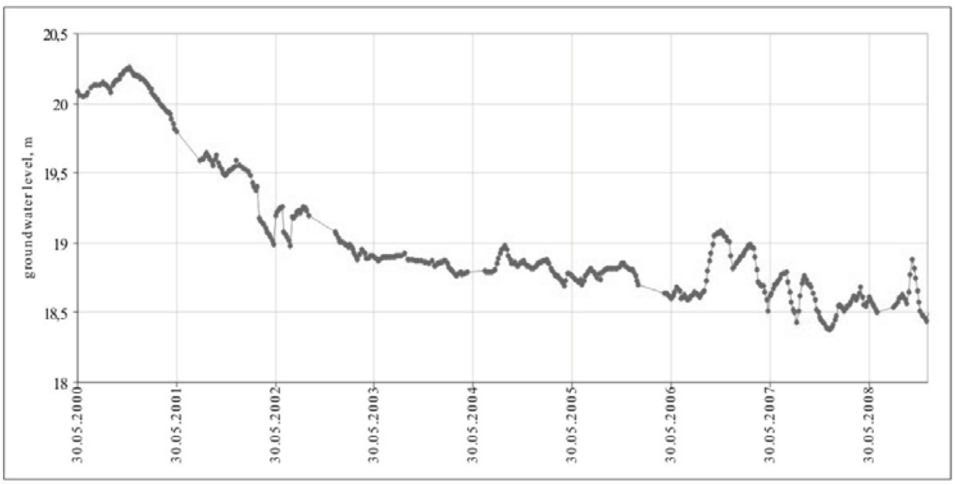

Fig. 3. Drawdown of groundwater level of Cretaceous aquifer' in the observation's well 38 in Kazakhstan

However, in the conditions of an unconfined aquifer which can have the big area and its existence area could coincide with the area of recharge, transboundary effects do not exist. For example, the aquifer of the Irtysh river valley (see fig. 2) has thickness near 50 meters and is about 600 square kilometers in Kazakhstan only. This vast aquifer lies in the system of the Priirtysh transboundary aquifer. Thus, sites of pollution of groundwater of this aquifer are not transboundary. Transboundary effects, according to calculations, can be shown on distance to several kilometers to border, and the area of possible interference does not exceed five square kilometers. It considerably reduces financial and other expenses for studying, monitoring, and assessment and, as a result, the management of such aquifers.

4. RISKS OF OCCURRENCE OF TRANSBOUNDARY PROBLEMS

The problems of exhaustion and pollution of transboundary aquifers not always are transboundary problems. First of all, all transboundary water problems related to groundwater resources may be divided into two groups. Arrangement of monitoring and assessment of transboundary groundwater and management of resources use within the groups differ dramatically.

Group 1. Transboundary river problems, associated with qualitative and quantitative condition of groundwater within the transboundary river basin.

The reason of such problems is related to the use of groundwater of aquifers fed by such a river, thus resulting in falling of river runoff, or contamination of groundwater in the catchment areas and infiltration of contaminated waters to the transboundary river thus resulting in impairment of quality of transboundary river waters delivered to the adjacent side.

We believe that such problems can be easily solved inside the state by implementing the methods of integrated water resources management into the water management system. They require close attention of relevant authorities and allocation of a certain budget for solution thereof. The major part of pollution focuses on groundwater that makes transboundary problems of river water contamination a so-called historic pollution. For example:

Waters of the Ilek River (a left feeder of the Ural River), being a transboundary river with the Russian Federation, are polluted with hexavalent chrome. This contamination of river waters is associated with entry of polluting groundwater of Quaternary alluvial transboundary aquifer that contains hexavalent chrome to the Ilek River near Aktobe city, Republic of Kazakhstan. This aquifer is unconfined. The historic focus of pollution of groundwater of this aquifer has commenced since 1957 after commissioning of Aktyubinsk chrome plant. As of 1992 the area of the pollution focus reached 14 km^2 at a content of hexavalent chrome of 0.7-3.8 g/l where MAC for drinking water is 0.05 mg/l. The flow of contaminated groundwater with a 4 km front moves towards the Ilek River. The scale of the problem of water pollution of the transboundary Ilek River with hexavalent chrome made local authorities to allocate funds to carry out research. As the result, a feasibility study of groundwater purification has been developed.

Two focuses of historic pollution of underground waters that predetermine the risks of pollution of the transboundary river are well known within the Irtysh River basin.

The first problem is the site of mercury pollution of the Quaternary alluvial transboundary aquifer of the Irtysh valley near Pavlodar. A close attention has been put to this problem. A mathematic modeling of the pollution site has been carried out methods of its elimination have been developed on international projects of UNDP and UNESCO (Tanton *et al.* 2003).

Another problem is associated with pollution of the Quaternary alluvial unconfined aquifer of the Irtysh valley near Semey by aviation kerosene. Many-years technological and accidental releases of fuel at the air base of air forces of the USSR has resulted in a catastrophic contamination of groundwater and formation of a large aviation kerosene lens occurring at the depth of 3-4 m below surface. The lens area is 0.42 km^2, liquid phase thickness – 0.5 m, estimate fuel reserves – 6500 t (as of 01.01.1992). Contaminated groundwater and floating oil products represent a threat to the water ecosystem of the Irtysh River. This lens was researched by KazHYDEC in the beginning of 1990th. Works were performed in 2000 in conjunction with HYDEC (Moscow) to prepare a feasibility study for retrieval of kerosene and elimination of pollution. However, these works have not been completed. Today the lens slowly keeps moving towards the Irtysh River.

Group 2. Transboundary groundwater problems associated with quality and quantity of groundwater.

Reduction of resources and reserves of groundwater due to water use or any other activities performed on the adjacent territory, or polluted groundwater are delivered over the state border to the adjacent territory. In this event, the methods of integrated management of groundwater resources attain a certain transboundary (interstate) specificity. And risks of occurrence of such problems are estimating already at an inventory stage of transboundary aquifers according to typification of boundary conditions of groundwater flows.

Conclusions

The troubles in substantiation of number, location, and construction of monitoring stations, substantiation of programs and carrying out monitoring of transboundary aquifers, and assessment thereof due to a big number of transboundary aquifers and large areas of such transboundary aquifers (as this concept is defined in the international legal documents (Stephan, M.R, *editor,* 2009)) need to be resolved. For this purpose it is necessary to expand the scale of research of transboundary problems; to increase mapping scale of transboundary aquifers in the international coordination of taxons of hydrogeological stratification of a geological section and parameters of their showing on a hydrogeological map; on a basis of new interstate projects to develop some guidelines for research and management of transboundary groundwater resources in interstate aspect, and others.

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Pedro Juan Caballero – Ponta Porã
A Groundwater Transboundary Situation between Paraguay and Brasil

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ABSTRACT

As one of the largest groundwater reservoirs with estimated water resources of 30.000 km^3 the Guaraní aquifer covers an area of some 1.1 million km^2 and lies underneath Argentina, Brasil, Paraguay and Uruguay. Growing industrialisation and urbanisation in the region lead to rapidly increasing groundwater production and also to increasing contamination of the resources.

Until 2009 the multinational project "Environmental Protection and Sustainable Development of the Guaraní Aquifer System" – executed by the Organisation of American States and responsible to the World Bank and GEF - supported the four countries in jointly elaborating and implementing a common institutional and technical framework for managing the Guaraní Aquifer System (SAG, Sistema Acuífero Guaraní). On behalf of the German Ministry for Economic Cooperation and Development (BMZ) the Federal Institute for Geosciences and Natural Resources (BGR) supported the SAG-GEF project through assisting Paraguay to meet the requirements in the fields of hydrogeology and groundwater resources evaluation and prognosis.

In the north-eastern edge of the oriental region of Paraguay Pedro Juan Caballero, capital of the Department of Amambay, borders the Federal State of Mato Grosso do Sul in direct neighbour ship to the Brasilian city of Ponta Porã. The twin municipalities form a bi-nationally characterised region with a good potential for future development. The investigation area involves a predominantly agricultural cropping (on the favoured lateritic soils of the basalts) and livestock-rearing area. The Brasilian part of the area is already dominated by farming at an industrial scale.

In Ponta Porã a first deep borehole has been drilled down to the SAG. As there are uncertainties about the interactive impact from the development of the Guaraní aquifer (more deep well locations are under study), this region has been identified as a real transboundary situation with the risk of conflicts. A common water policy is needed and should lead to an integrated transboundary water resources management in a regional and bi-national context on base of updated hydrogeological and socio-economic information.

Key words: Guaraní Aquifer System, Paraguay, transboundary groundwater resources, modelling

1. INTRODUCTION

1.1. The Guaraní Aquifer System

The Guaraní Aquifer consists of a sequence of (mainly weakly cemented) sandstone beds and was formed during Triassic-Jurassic age (250-145 million years BP). The aquifer is overlain by Cretaceous basalt flows (145-130 million years BP), exceeding a thickness of 1000 m in the central parts of the sedimentary basin which is affected by tectonic structures and crossed by volcanic dykes. Despite these local features the Guaraní Aquifer is considered as a continuous groundwater body across the entire region with a mean thickness of about 200 m (Gastmans et al. 2008). In homage to the indigenous population of the area the aquifer system has been named "Guaraní", generalising different regional names for the same geological formation (Botucatú in Brasil, Misiones in Paraguay, and Tacuarembó in Argentina and Uruguay).

The subtropical to tropical climate (annual rainfall of 1300 to 2000 mm) provides favourite groundwater recharge conditions for the outcrop areas along the boundary zones of the SAG and for areas of weathered and fractured basalt cover of moderate thickness. An annual groundwater recharge of 45 to 55 km^3 is considered as reasonable estimation of a mean rate. This quantity is less than 0.2 %

of the freshwater storage. The natural drainage of the SAG takes place along the boundary zones and as baseflow via rivers and probably also via swampy areas on both sides of the Parana River at the southern edge of Paraguay and in Argentina (Esteros del Iberá). At the central parts of the SAG the groundwater is highly confined and shows elevated values of mineralisation and temperature.

Both in terms of population and groundwater production Brasil has a dominating role in the SAG region: 87% of the SAG population of 92 million inhabitants live on the Brasilian territory, and about 93% of the recent groundwater production (1040 million m^3 in 2007) happens in Brasil, mainly in the federal state of São Paulo (PSAG, 2009).

Starting in 2003, the SAG-GEF project has elaborated an extensive study on hydro-geological and many other aspects of the entire Guaraní aquifer region. Detailed investigations have been carried out in four pilot areas, e.g. in Itapúa).

After the finalisation of the SAG-GEF project in 2009, international agreements have been approved to promote future SAG groundwater initiatives, including the creation of a regional groundwater institute by the Mercosur Parliament in November 2009 (INRA-Mercosur) with specific reference to the shared management of the SAG. And consequently, in August 2010 the agreement about the responsibility for a common and sustainable management (acuerdo sobre el Acuífero Guaraní) has been signed by the four SAG participating countries Argentina, Brasil, Paraguay and Uruguay.

Figure 1: General location map

1.2. The Guaraní Aquifer System in Paraguay

In close connection to the SAG-GEF project the SAG in Paraguay has been analysed and brought into a conceptual and numerical groundwater simulation model, including neighbouring zones of Argentina and Brasil (SAG-PY, Schmidt G. & al., 2009).

About 8% of the total SAG area belongs to the Paraguayan territory (87,500 km^2 in the eastern region of the country). Basically, two main groundwater flow directions are identified. In the northern part groundwater flows from Brasil into Paraguay and discharges finally into the Paraguay River in the west via a number of its tributaries which have their origin within the SAG outcrop area. The southern situation is characterised by a distinct recharge area from where the groundwater flows mainly to the east and directed to the Paraná River.

The relatively shallow movement of the groundwater is controlled by a rather fast exchange between groundwater recharge from rainfall and discharge to the drainage system of small rivers nearby. Calculated water paths in the model reflect this general flow behaviour, which is partially approved by hydrochemical and isotope studies. In total, the SAG represents a more or less "stagnant" groundwater reservoir. The Guaraní Aquifer as well as other hydrogeological units of different age, e.g. the cretaceous basalt (see also table), are included in the three-dimensional numerical model. The calibrated model results form the basis for the resource quantification and for prognostic simulations.

Referring to the Paraguayan territory, the groundwater system receives 9.12 km^3 of groundwater recharge annually, from which 6.47 km^3 (about 160 mm) infiltrate into the SAG, representing 13% of the total SAG recharge. As the second important recipient the basalt aquifer receives about 2.18 km^3 (roughly 70 mm). A vertical leakage of up to 0.24 km^3 (8 mm at a maximum) is calculated to flow from the basalt into the Guaraní Aquifer.

The groundwater budget shows that (under a regional aspect) there is almost no problem to guarantee future water supply. Following the official regulations for a complete and safe water supply (150 litres per day and consumer) 0.05 km^3 of clean groundwater from deep wells will be needed annually for all communities in the Paraguayan SAG region in future (about 1% of the recent recharge).

However, the model results show also clearly that there might be some consequences on a long term. The local concentration of production wells will create water-level depressions in the range of 2 and 10 metres. For the shallow aquifer system (Basalt) in Pedro Juan Caballero depressions of about 30 metres are to be expected.

Table: Hydraulic conductivity and groundwater recharge as results from the calibrated simulation model.

Period	Formation / Group	Hydraulic conductivity [m/d]		Recharge [mm/year]
		horizontal	vertical	
Quaternary	Fm. Chaco	8	0.001	40
Cretaceous	Fm. Acaray	2	0.0005	30
	Fm. Alto Paraná (Basalt)	1	0.0005	70
Triassic	Fm. Misiones (SAG) *shallow*	3	0.006	160
Jurassic	Fm. Misiones (SAG) *deep*	1	0.002	~ 8 (*from Basalt*)
Permian	Gr. Independencia	0.2	0.002	10
Carboniferous	Gr. Cnel. Oviedo	0.08	0.0012	2

2. TRANSBOUNDARY GROUNDWATER FLOW BETWEEN PARAGUAY AND BRASIL

Along a certain run in the south-eastern part of Paraguay the Paraná River forms the political border to Argentina and Brasil. In the hydraulic sense, this river has a dominant drainage effect on the groundwater flow in the basalt as well as in the sandstone aquifer on both sides. A transboundary groundwater flow between the countries seems to be of minor importance. A quite different situation is given in the north-eastern part of Paraguay: the groundwater passes the border of Paraguay and Brasil in a westwards direction and is under use from both sides.

2.1. Pilot area: Pedro Juan Cabllero / Ponta Porã

The Pedro Juan Caballero/Ponta Porã pilot straddles the border of Paraguay and Brasil and covers the environs of these frontier towns, which have a combined population of about 135,000 growing at over 1%/a and about 2%/a respectively. The urban 'frontier economy' is dominated by the trade and service sector, which has good potential for further development, set in a flourishing agricultural region of good soils and an annual rainfall averaging about 1,200 mm/a. On the Brasilian side, the land use and agricultural production of Mato Grosso do Sul State is already dominated by intensive soya bean - cereal rotations coupled with livestock rearing, whilst on the Paraguayan side deforestation for these purpose has come later and is still occurring.

2.2 Hydrogeological situation and water supply

Over most of the area the SAG is covered by 100 m or more of basalts (and outcrops only in the extreme west of the pilot area), and its groundwater exhibits a confined (but not artesian overflowing) condition (Figure 2) - with the frontier following the surface-water divide of the Serra/Sierra de

Amambay. The top part of the basalt is sufficiently fractured and weathered to form a semi-independent aquifer across much of the area, which provides recharge through leakage to the SAG with groundwater flow westwards from Brasil to Paraguay under hydraulic gradients of 6-7 m/km.

Groundwater from the basalts is currently the main source of urban water supply with over 100 water wells (mainly 70-120 m deep), including those of the Empresa de Servicios Sanitarios del Paraguay (ESSAP) and Servicio Nacional de Agua y Saneamiento (SENASA) around Pedro Juan Caballero and the Empresa de Saneamento de Mato Grosso do Sul (SANESUL) in Ponta Porã, which can produce a total of 1,200 m^3/hour or more. However, there is no main sewerage system in Pedro Juan Caballero/Ponta Porã, with all urban wastewater disposals to the ground via in-situ sanitation units, and the basalt aquifer is showing signs of pollution with the abandonment of some water wells.

The most satisfactory solution would be to develop a small number of soundly-constructed water wells into the semi-confined SAG and protect their wellhead areas carefully against contamination. SANE-SUL has recently completed the construction of the first deep (750 m) borehole which alone can produce an additional 260 m^3/hour, and further development is under preparation.

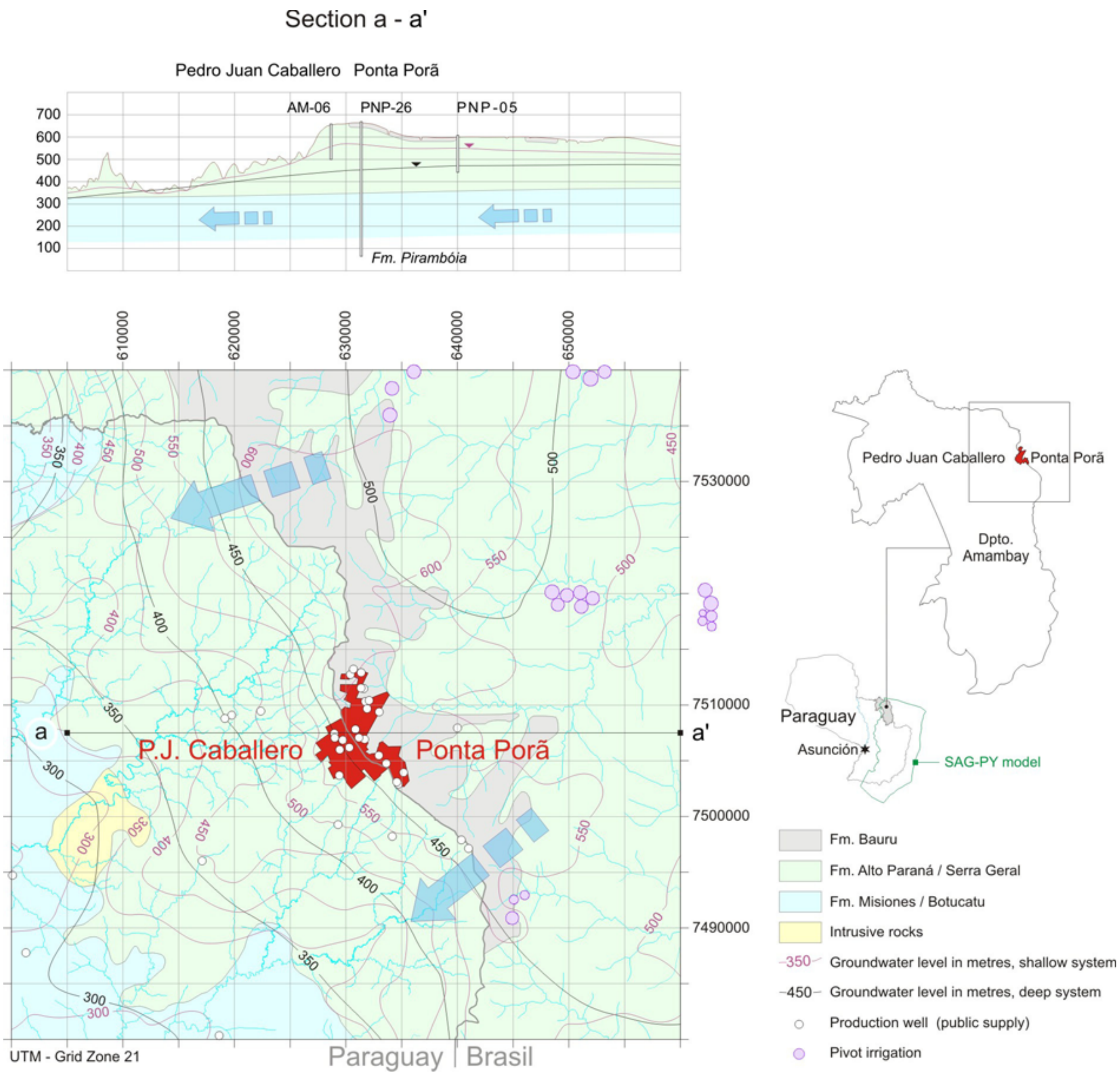

Figure 2 Locations, drainage system and hydrogeological features in the pilot area.

2.3. Preliminary simulation results

In addition to the comprehensive simulation model SAG-PY under a regional scale, selected groundwater production scenarios have been calculated at a local scale by mean of an analytical model. This well field model calculates the drawdown of groundwater pressure heads in the Guaraní aquifer during 20 years of pumping hypothetical quantities of groundwater.

Based on a uniformly spread transmissivity of 300 m^3/day and a storage coefficient of $5x10^{-3}$ (confined aquifer conditions assumed), and on a continuous groundwater abstraction of about 3 million m^3/year, the model calculates a mean drawdown of 10 metres after 20 years, whereas the well drawdown is estimated to be in the range of 50 metres. The affected area of depression below 10 metres amounts to roughly 30 km^2, and extends to 750 km^2 respectively to 1800 km^2 when the annual groundwater abstraction rate in the model increases to 9 and to 15 million m^3.

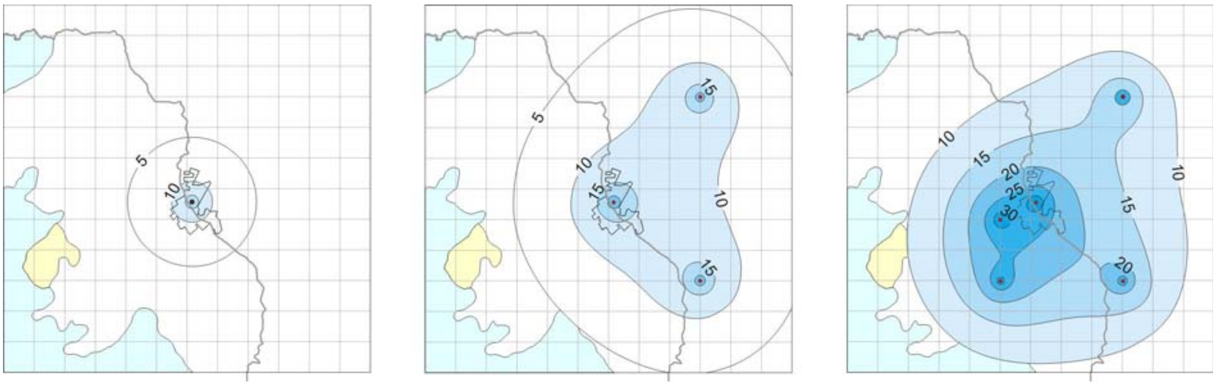

Figure 3 Simulated drawdown in metres after 20 years of continuous pumping 3, 9 and 15 million m^3/year from the SAG.

3. CONCLUSIONS and RECOMMANDATIONS

At a first glance, the estimated groundwater budgets of the entire SAG and also of the SAG part in Paraguay give the impression that the groundwater resource might be almost inexhaustible during the near future and under the recent climatic and recharge conditions. However, under local considerations the stress on the groundwater resource is already remarkable high, either by groundwater production (e.g. as in the Ribeirão Preto SAG-GEF pilot area or as in Pedro Juan Caballero / Ponta Porã) and/or by pollution hazards.

The first transboundary workshop on water and environmental management was held in February 2009 and attended by groundwater specialists and stakeholder representatives from both sides of the frontier in which it was concluded that a political mandate is needed for a bi-national transboundary commission in order to promote commonly future groundwater development.

Furthermore:

Completion of the water well inventory and hydrogeological database is required, with establishment of a conceptual and numerical model of the local SAG and an improved monitoring network for groundwater levels, quality and use.

Further development of SAG resources for public water supply will require a feasibility study and water well siting plans, and a common policy approach is needed to rationalize such development.

Measures are needed to reduce the contaminant load on the basalt aquifer, especially in those parts of the urban area where it is was likely to continue as the 'sole source' of water supply

Public information and awareness campaigns were required to gain support for stricter application of relevant existing environmental laws and regulations, and to facilitate the implementation of future groundwater protection measures.

Findings of the second workshop to be held in November 2010 in Pedro Juan Caballero/Ponta Porã and further model results from a new numerical simulation model of the pilot area are to be reported in December this year.

Acknowledgements:

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Trans-boundary Water Resources of Lebanon: Monitoring and Assessment

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ABSTRACT

Lebanon, the Middle Eastern country with an area of about 10,400 km^2, is known by a plenty water resources. It receives between 800 and 1500mm of precipitated water, snow covers around 2000km^2; hence this small land area encompasses 15 permanent watercourses (rivers) and more than 2,000 major springs, in addition, there is a number of aquiferous formations and karstic galleries, which are known to be filled with groundwater. However, there are parallel paths of increasing water stress stemming from both natural and human driving forces. Climate change, pollution, over-exploitation and the mismanagement of trans-boundary water resources are amongst the geo-environmental problems that affect these resources, the latter being the major water problem in Lebanon today. In the light of this issue, more than 74% of Lebanon's border is shared with neighboring countries, which makes the surface and subsurface water intermingle with neighboring regions, thus no volumetric measures are known. Two trans-boundary rivers between Lebanon and Syria in the north and one river with Israel to the South. Snow covers large areas of the mountain chains of Anti-Lebanon, which are shared with Syria, and Hermon chain with snow cover also shared with Israel. In addition, the three major aquifers of Lebanon extend to neighboring regions. To date, however, there is no creditable study to assess how to allocate these resources. Consequently, geo-political conflicts frequently exist due to the obscure nature of the hydrologic conditions. This study aims to introduce first hand information on the assessment and monitoring approaches to identify the principal hydrologic aspects of trans-boundary water resources of Lebanon, including quantitive measures and spatial delineations. This could be obtained through a systematic analysis of the shared hydrologic and hydrogeologic elements, thus conventional and recent tools and techniques.

Key words: shared rivers, trans-boundary, geo-political, Lebanon.

1. INTRODUCTION

Lebanon is located in the middle part of the eastern coast of the Mediterranean Sea. It is divided into three major physiographic units. These are the ranges of Mount Lebanon and Anti-Lebanon, which are separated by the Bekaa plain. The two mountain ranges are originally uplifted blocks. The three units are trending NNE-SSW (Fig. 1). The eastern Mediterranean constitutes a part of the unstable shelf of the Middle East region, which is affected by plate tectonic movements of the Dead Sea Rift system (Beydoun, 1988).

The exposed stratigraphic succession in Lebanon, starts from the Middle Jurassic age and exhibits sedimentation in a marine environment until the Middle Eocene, with carbonate rocks (mainly limestone) building up the largest part of the stratigraphic column, which is separated by continental sands and clastics at the base of the Cretaceous (Nubian facies) and some intercalated volcanic rocks up to the Pliocene. The exposed succession totals a thickness of about 5650 m (Beydoun, 1977).

The existence of elevated mountain chains, especially those facing the Mediterranean, created a climatic barrier that receives the cold air masses from west, thus resulting a high precipitation rate reaches up to 1500mm/yr. for this reason, Lebanon is known by tremendous water resources, and then described as the "*Water Tower*" of the Middle East. It is the unique region in the Middle East where thick accumulation of snow cover remains for more than four months on mountain crests and occupying coverage of about 2000km^2. As well as, there are more than 2000 major springs, with discharge exceeding 10*l*/sec, and also some 60 major submarine springs issuing off-shore (Shaban, 2003). Additionally, Lebanon is well known by the karstic cavities, which constitute a major source for groundwater.

Lebanon is considered as a country under water stress, notably in the view of climatic variability and population growth. Therefore, the available water resources are witnessing an obvious volumetric decrease since the last few decades that estimated as 40% in average (Shaban, 2009).

Even though, Lebanon has a small land area (~10,400 km^2), yet the large part of its water resources is shared with the neighboring countries. Hence, out of the 882km perimeter of Lebanon area, there are approximately 559 km (63%) is bounded with Syria in the north and utmost in the east, and 98km (11%) with Israel in the south and some parts to the east. While, the rest 225 km are facing the Mediterranean Sea (Fig. 1). Moreover, the geographic land marks (e.g., mountain tops, valleys, watercourses, etc) are often found to be coincided with the political borders between the three countries.

The lack of comprehensive hydrologic measures; however, resulted incomplete assessment to allocate shared water resources with the adjacent countries, thus geo-political conflicts frequently exist due to the obscure nature of the hydrologic conditions. This study aims to introduce first hand information on the assessment and monitoring approaches on Lebanese shared water resources. Thus, it highlights on: 1) the actual length of shared rivers and their tributaries, 2) surface water divides, i.e., catchment areas, 3) the percentage of snow cover extent in each region and 4) the extent of trans-boundary aquiferous rocks between them. This was achieved utilizing a variety of conventional and advanced tools and techniques to identify and measure the fundamental elements of shared water resources of Lebanon.

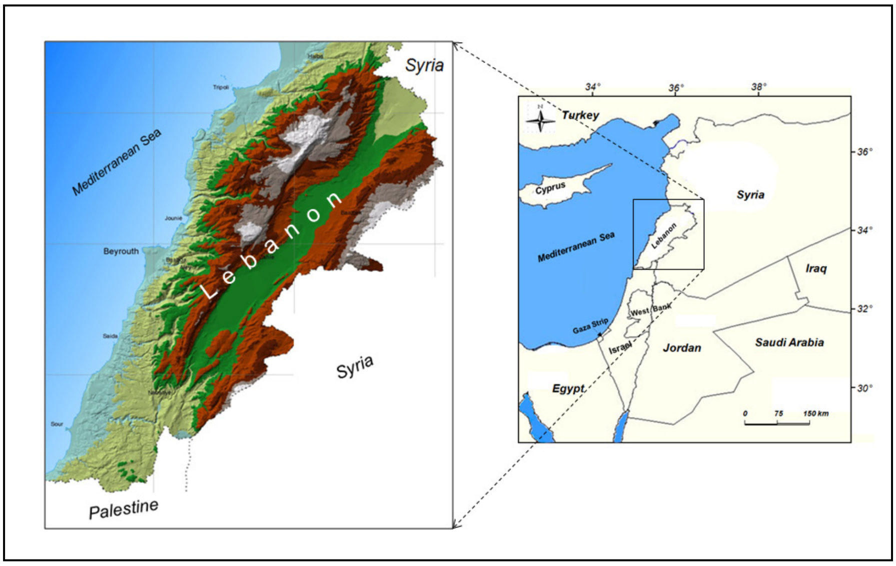

Figure 1. Regional location map of Lebanon.

2. ASPECTS OF SHARED WATER RESOURCES

There are about 215 international rivers and 300 groundwater basins that shared by two or more countries (ADB, 2008). However, trans-boundary water resources take a number of aspects either on surface or in subsurface. Some of them occur in a large-scale. Whilst, other aspects of trans-boundary water resources appear in a relatively small-scale extent.

Normally, aquifers and rivers are the only hydrologic components that considered as shared water resources. However, other components (streams, springs, etc) are also important; especially they are in direct relation with the hydrologic cycle.

Aspects of trans-boundary water must include perennial and temporary resources of different scales (Shaban and Douglas, 2008). They can be summarized as follows:

1. Groundwater reservoirs (aquifers): where groundwater is stored in rock formations that extend for large areal extent (e.g. several hundreds of kilometers) and owing considerable thickness of several hundreds of meters.

2. Rivers: as permanent watercourses usually run along slopping topography and then transect different countries.
3. Springs: which are usually considered as essential source of water. There are several springs located near political borders and issue water from one country and outlet in another.
4. Streams: which is similar to rivers, and are also transecting different topographic regions, but they usually run surface water for limited time duration after rainfall.

3. METHOD OF IDENTIFICATION

Usually, the ued tools to identify and assess shared water resources often include: topographic and cadastre maps. The combination of these two maps in conjunction with geological and hydrological data can help adjoining countries to diagnose their shared waters. However, erroneous delineation and readings of these maps usually create conflict between these countries.

In this study, the used method followed a number of approaches and a miscellany of tools was utilized (Fig.2). Also developed and recent techniques were utilized either in computerizing the available maps, or in their analysis through different software types. Thus, the applied steps can be summarized as follows:

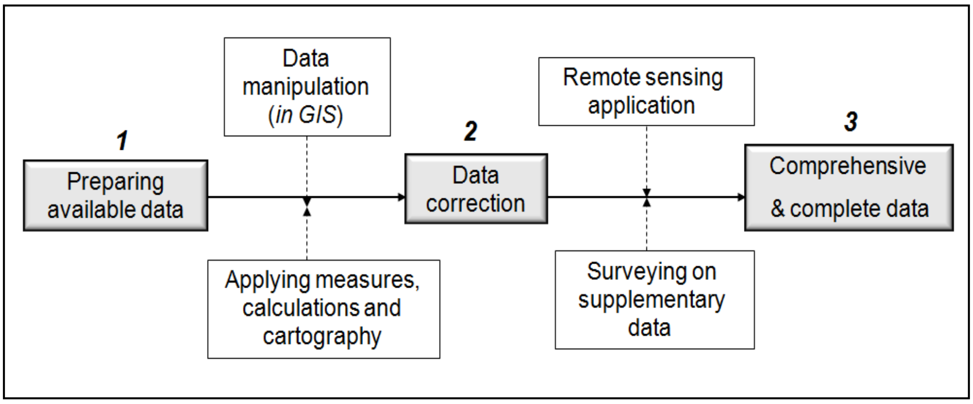

Figure 2. Schematic presentation of the followed method in this study.

1. Preparing the available maps (topography, geology and cadastre) in digital forms, including the adjacent regions between Lebanon and the neighboring countries.
2. Manipulating these maps and their supplementary data in attributed tables among the Geographic Information System (*GIS*) in order to be able to modify, measure, calculate and draw needed information.
3. Correcting the shared spatial data, including: rivers, streams, geological boundaries, location of springs, etc.
4. Using remotely sensed data; especially in monitoring the snow cover extent. For this purpose, MODIS-Terra satellite images were analyzed. In some cases, high resolution images were processed (e.g. IKONOS, Aster and Landsat).
5. Carrying out a filed survey (whenever applicable) to induce the names, ownership, and other related data on shared water resources at the border area.
6.

4. RESULTS

Following the previous mentioned approach for shred water identification by using the appropriate tools, thus surface and subsurface water resources of Lebanon shared with neighboring regions could be identified as follows.

4.1 Groundwater

Shared groundwater in aquiferous rock formations between Lebanon and the neighboring regions is composed largely of carbonates rocks and basalt with an approximate ration of 92%, where 87% shared with Syrian and the rest 13% with Israel. These rock formations are almost of carbonate rocks with high fracture and karstic systems.

Figure 3 represents a map showing the distribution of these rock formations. The major fractures systems (i.e. faults) in these rock formations were identified from satellite images. Therefore, 185 major faults were identified. These faults work as hydrologic channels and transporting groundwater from/ and to Lebanon.

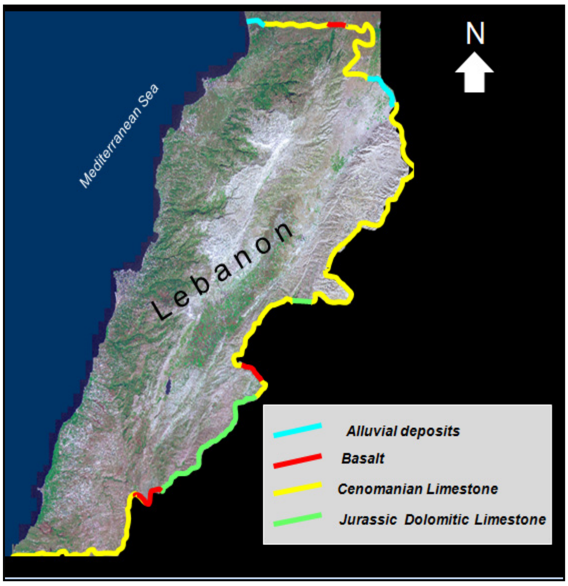

Figure 3. Shared aquiferous rock formations of Lebanon.

4.2 Rivers

There are three shared rivers between Lebanon the neighboring countries. Two with Syria and one with Israel. These are Al-Kabir River (150MCM) along the northern border of Lebanon with Syria, El-Assi (500) originated from Lebanon and extends to Syria to the north and then to Turkey, and El-Wazzani (220 MCM) from Lebanon southward to the occupied territories in Israel. Table 1 shows the fundamental characterizations of these rivers.

Table 1. Fundamental characterizations of Lebanese shared rivers.

River	Length *(in Lebanon)*	Catchment area *(in Lebanon)*	Origin	To	Major exploitation
Al-Kabir	60 km	295 km^2	Shared	Mediterranean	65% Syria
El-Assi	65 km	1900 km^2	Lebanon	Syria, Turkey	Syria, Turkey
El-Wazzani	75 km	625 km^2		Israel	Israel

4.3 Springs

Yet, springs origin in Lebanon is identified, but their actual runoff routes are almost unidentified, notably when they run toward the neighboring regions. They constitute an essential source of water in Lebanon and receive their recharge mainly from snowmelt. There are 77 major shared springs in Lebanon as resulted from the obtained survey from the topographic maps (Table 2).

Table 2. Major shared springs in Lebanese.

Topographic sheet *(1:20000)*	**Major springs***	**Sharing regions**
Wadi El Qaren	3	With Syria
Deir El Ashayer	2	
Zemrani	1	
Hourete	1	
Assal El-Wared	1	
Anjar	5	
Tfail	1	
Amshiki	5	
Ait El Foukhar	40	
Hermon	1	
Kfer Kouk	5	
Raite	5	
El Khyam	4	With Israel
Kfer Shouba	3	

**Unnamed springs with discharge exceeding 50l/sec.*

4.4 Streams

Normally streams do not accounted during the assessment of shared water resources because they do not issue water permanently. However, they appear as a geo-political issue when dams are built along these streams and running water became restricted to the upstream country and not to the downstream one. In the study, major shared streams were identified among their catchment areas, as shown in Table 3.

Table 3. Major shared streams in Lebanese.

Catchment	**Shared with**	**Orientation**	**Feeding river**	**Surface water flow**	
Al-Kabir	Syria	E-W	Al-Kabir	Lebanon & Syria	
Ouadi Khaled		SW-NE	Int St*, Ouadi Al Atshan	Lebanon	Syria
El-Assi		SW-NE	El-Assi	Lebanon	Syria
Asaal El Wared		W-E,NE-SW	Ouadi El Ouazze, Emjer El Asaaal	Syria	Syria
Barada and El Aawja		NW-SE	Barada and El Aawja	Syria	Syria
Hasbani	Israel	NE-SW	Hasbani-Wazzani	Lebanon	Israel
Marjayoun		NW-SE	Ouadi Deir Mimess	Lebanon	Israel
Naquora		NE-SW	Ouadi Naqouran- Alma Eshaab	Lebanon	Israel

**Intermittent streams*

5. CONCLUSION

Likewise many regions worldwide, Lebanon has given recently a great concern to its water resources, which became threatened in the light of the changing climatic regime and the dramatic increase in population size. However, comprehensive studies on this respect are still rare enough to make a detailed assessment for Lebanese shared water resources. This study is extends a brief discussion on the major elements of the Lebanese water resources and the approach of assessment and monitoring.

It is obvious that the existing water resources in Lebanon are almost shared with the neighboring regions. This is attributed mainly to the geomorphic and geologic setting of Lebanon. In addition, it clearly appears that most shared water resources are originated from Lebanon, which indicates their availability. However, no specific hydrologic measures have been known yet to articulate the current status of shared water resources in Lebanon. Thus, it is recommended to apply a detailed assessment to allocate the volumetric measures of shared water resources. This will help composing an integral part of the water budget for Lebanon. In addition, identifying the hydrologic characteristics of water resources will add a valuable contribution to the future agreements and protocols.

This study also shows the importance of using new techniques to identify spatial terrain signatures, and more certainly to recognize water resources and their routes and areal extent. They can be a helpful tool in applying in-depth regional studies on shared water resources.

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Ajloun and Golan – a transboundary groundwater resource?

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Abstract

The conjoined application of major and trace elements and isotopic methods yield a deep insight into the development and flow paths of groundwater in the Golan Heights and Ajoun within the border triangle of Israel, Jordan and Syria. Despite location, salinity or temperature of spring or well waters, stable isotopes showed, that the main areas of recharge are the elevated Hermon-Massif and the plain area of southwestern Syria and northern Jordan, with high to medium annually precipitation amounts. Although not connected to the Golan Heights, Jordan may be involved in a comon system as the same Cretaceous aquifer is exploited. Derived flow paths of infiltrated groundwaters strongly indicates partial occurring lateral flow across boundaries from Syria to Jordan and Israel.
By means of the investigated groundwaters we could show, that the combined hydrochemical and isotopic approaches reveal complex and large-scale groundwater infiltration- and flow-systems much better than a focused view on a specific band of elements and changes somehow coomon knowledge on the observed resources. That may have implications on further use.

Key words: REY, stable isotopes, inter-aquifer flow

INTRODUCTION

Within the Western Levant, the climate gradient from semi-arid to arid is important for the generation of modern groundwater. Large groundwater aquifers occur all over Israel, Palestine and Jordan, although the entire region suffers from over-utilization of that freshwater resources. Because of decreasing precipitation southwards, resources in the north of Israel and Jordan are the most productive. Particularly, the Golan Heights (Israel and Syria) and the Ajloun (Jordan) rank as major extraction areas of groundwater of good quality and quantity. Both are separated by the tectonically forced gorge of the Yarmouk river, which is the international border between Israel and Jordan and further eastwards between Syria and Jordan. The gorge is assumed to be a hydraulic barrier.

Within the BMBF-funded projects GIJP (German-Israeli-Jordanian-Palestinian Joint Research Program for the Sustainable Utilisation of Aquifer Systems), and the multilateral IWRM project SMART (www.iwrm-smart.org; www.ufz.de/smart), hundreds of water samples were taken from all over the Jordan-Dead Sea rift-system to understand groundwater flow-systems and salinisation of resources. The following study was carried out to investigate the highly exploited freshwater resource in a relative humid Wadi Al Arab and assumable connections to the groundwater system in the Golan Heights. For that purpose, each sample was analysed for major and minor ions, rare earth elements including yttrium (REE+Y), stable isotopes of water ($\delta^{18}O$, $\delta^{2}H$) and tritium as radioisotope.

The interaction of recharged precipitation with soils and permeable rocks in the catchment and along the flow path of the resulting groundwater defines its chemical composition. If the passed lithology is predominantly homogeneous, the water parcel receives a unique chemical signal, determined primarily by the particular major and minor mineralogy along the flow path. However, if the lithology varies along that path (e.g. inter-aquifer flow), the solute inventory is altered by the varying water/rock interactions.

Contrasting the major elements, REY behave differently: their saturation in groundwater is achieved immediately and their low concentrations (pmol/l) result from adsorption onto mineral surfaces and coprecipitation. The first water-rock interaction during infiltration establishs REY distribution in groundwater and during passage of pores, dissolved REY undergo ion exchange with and adsorb to mineral surfaces. However, after geological time spans, aquifer surfaces are in static equilibrium with the REY-content of the through-flowing water. Consequently, REY abundance in groundwaters reflects the leachable components of sediments and rocks of the recharge areas even if inter-aquifer flow occurs.

Stable isotopes of water δ^2H and $\delta^{18}O$ are less controlled by water-rock interaction than by climatic and geomorphological factors (temperature, elevation, distance from sea, etc.) at the time of replenishment. Applying the REY signature as a grouping criterion of groundwaters, δ18O vs. δ2H plots yield a new dimension in interpreting isotope data.

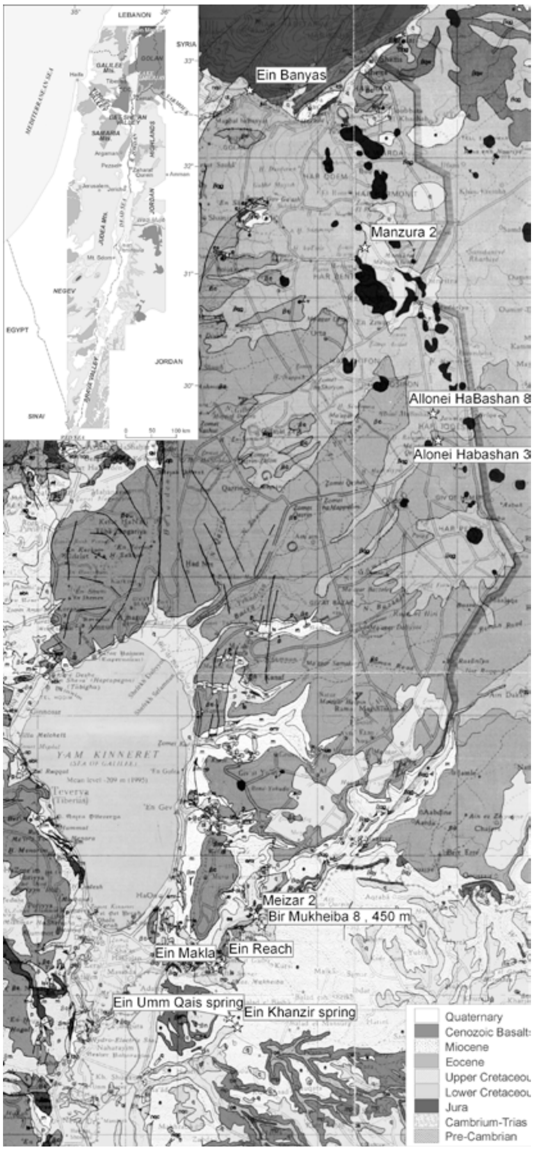

Fig. 1: geological map of the study area, situated in the north of Israel and Jordan, locations are indicated by stars.

STUDY AREA

Jordans northwesternmost corner, Wadi Al Arab and Yarmouk gorge as part of the Ajloun, is dominated by alternating strata of limestone, dolomite, chert, marl and phosphorites which are uplifted and dip towards the Jordan Valley and Yarmouk as a result of tectonical movements accompanying the Dead Sea Rift. The major hydrogeological units are the Coniac-Campanian A7/B2 aquifer (<400 m thick) and the Eocene B4 aquifer (<300 m thick) which are seperated by the marly B3 aquitard.

Along the fault driven lower Yarmouk Gorge (the border to Israel), B3 dives into the subsurface. Above, about 600 m Eocene to Oligocene Avedat Group (chalks, cherts and limestones) are followed by the up to 800 m thick sequence of Miocene to Pliocene sand-, lime- and mudstones and conglomerates (Kefar Gil'adi Group). Northwards, Golan is delimited by faults from the 2800 m (msl) high anticlinal structure of Mt. Hermon Massif. It consists of partly karstified lime- and dolostones of Jurassic and Cenoman-Turonian age and forms a typical transboundary groundwater basin between Israel, Lebanon and Syria.

The Golan Heights are predominantly covered by up to 600 m thick Pliocene-Qaternary alkali-olivine basalts, while only small deposits occur on (a) the northwesternmost nose of Wadi Al Arab, and (b) ne' of Irbid, being not thicker than some tens of meter and covering Eocene limestones (B4). Within the Yarmouk gorge, basalt flows are rarely observable at the rims. The basalt in Golan Heights is continued eastwards, where it covers vast areas of southwest Syria.

The average annual precipitation exceeds 1100 mm in the Hermon Massiv and declines to 300-500 mm in the Yarmouk gorge and in the Ajloun area (Margane *et al.*, 2002), leading to strong springs on the foot of Mt. Hermon. Springs emerge also on the Golan; along the margins of the Yarmouk gorge and within deep incised Wadis such as Al Arab, leading either to surface runoff (e.g. Jordan, Meshushim, Daliyyot) or large pools as in Hammat Gader.

SAMPLING

During field campaigns in 2001, 2004 and 2007/2008, water samples were collected at 44 locations in Wadi Al Arab and its surroundings, in the Golan and in the Yarmouk gorge to cope with the general aim of the project. Out of that, 11 locations show indications concerning the question, whether Yarmouk gorge is permeable for groundwater or not. In addition and in order to determine the easily leachable fraction of REY for various aquifer rocks, predominant rocks were sampled and leached. Sampling and lab prcedure for rocks is described in detail in Möller & Giese (1997), for water samples in Siebert (2006).

RESULTS

REY in rocks and corresponding leachates

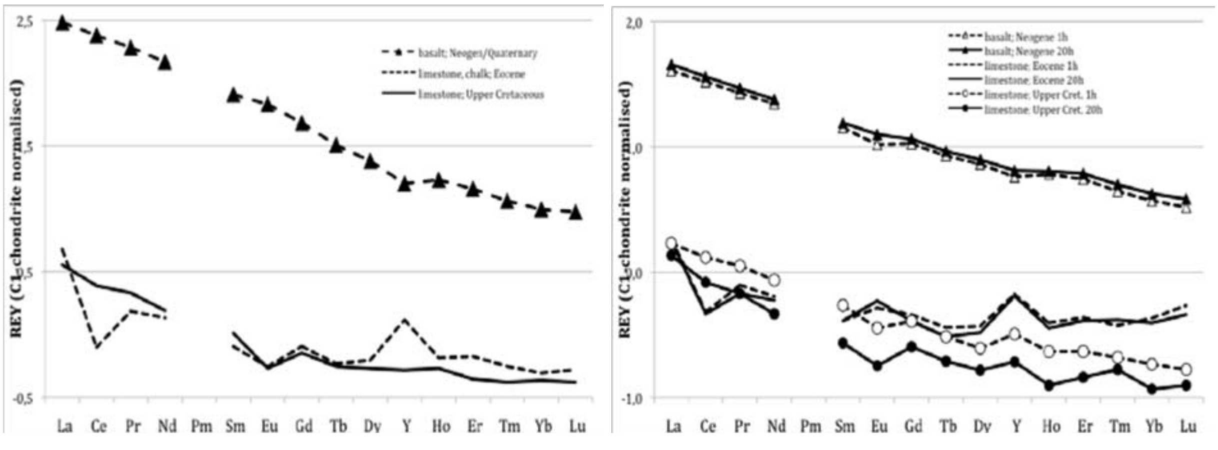

Fig. 2: C1-chondrite normalised REY patterns of (a) selected rocks and (b) their corresponding 1 hour (h) and 20 h leachates.

Eocene limestone and chalk show strong negative Ce-, and positive Y-anomalies, typical for marine and clay poor limestones (Dulski *et al.*, 1977), not observable in Upper Cretaceous rocks, pointing on higher abundance of clay minerals, i.e. marls.

The leachates of Upper Cretaceous and Eocene limestones, as predominant water conducting strata, are similar to their rocks because of dissolution of calcite (Fig. 2). Consequently, abundance of Y and medium to heavy REY (Eu-Lu) in Eocene rock leachates is higher than in the analysed Upper Cretaceous ones (Fig. 2b). Hence, Cretaceous limestone patterns decrease stepwise, while Eocene patterns are relatively horizontal. The normalised basalt pattern and their corresponding leachates show a continuous decrease from La to Lu. In magmatic rocks Y behaves as Ho (Bau and Dulski, 1995), resulting in a small step. According to Irber (1996) the similarity between REY patterns of basalt and its leachates indicates, that the glassy matrix has already reacted with groundwater.

Although REY are expected to be not as leachable under natural conditions (pH=6 to 9) as in lab experiments (pH=3), their leachte patterns give hints for the processes occuring under water/rock interaction and affecting REY fractionation.

REY IN SELECTED GROUNWATERS

Groundwaters in Figure 3a show REY patterns decreasing from La to Lu, with variable Ce-, negative Eu-, positive Y- and Gd-anomalies, resembling those of limestones. The water of Ein Banyas spring, discharging from the karstic Mt. Hermon massiv, is dominated by a remarkable negative Ce-anomaly which is much smaller in waters from Manzura 2 and Alonei HaBashan 3. These anomalies point either on clay poor limestones or oxygen-rich conditions (Bau, 1999) as expected in karstic systems. Actually, the described waters show Eh-values of +228 mV up to +445 mV (standart hydrogen electrode).

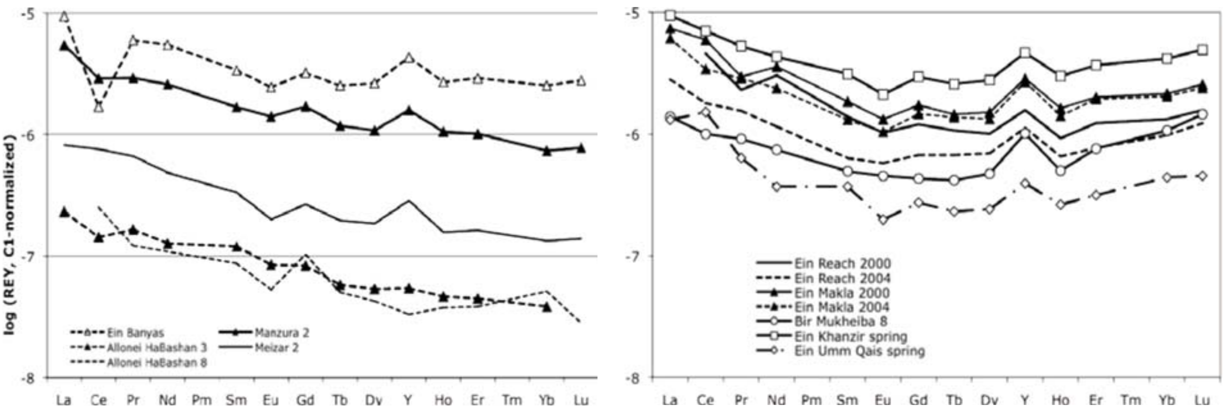

Fig. 2: REY pattern of groundwater from Golan Heights, Yarmouk gorge and Wadi Al Arab (Ajloun), referring to specific aquifers and/or recharge areas of (a) calcareous and (b) basaltic composition.

Similar but with no Ce-anomalies refer waters from Meizar 2 and Alonei HaBashan 8 to either lost of oxygen because of reducing conditions (Eh=-105 mV in Meizar 2) and hence repulping of former precipitated (Fe, Mn)OOH complexes, usually scavenging REY and preferential Ce or marly limestones.

Groundwaters with variable anomalies of Ce and Y but a minimum abundance of C1-normalised medium REY (Fig. 3b) are typical for basaltic aquifers (Paces *et al.,* 2001). These soup-bowl like pattern are dissimilar to the leachates of basalts, because water/rock interaction depends on various factors. Oxidizing sulfides cause free H_2SO_4 which improves weathering of minerals. Albitisation of plagioklas releases Ca which precipitates as calcite on porewalls, observable in basalts of Golan Heights (Siebert, 2006). The easiest weatherable mineral within the basalts is olivine, releasing Fe which precipitates as (Fe,Mn)OOH. Both processes intensely evoke coprecipitation of REY and hence distinct fractionation, developing more or less that soup-bowl shape.

Since REY in groundwaters resemble the lithology of their respective recharge areas, in principle two types of infiltration areas are definable: (a) limy and (b) basaltic.

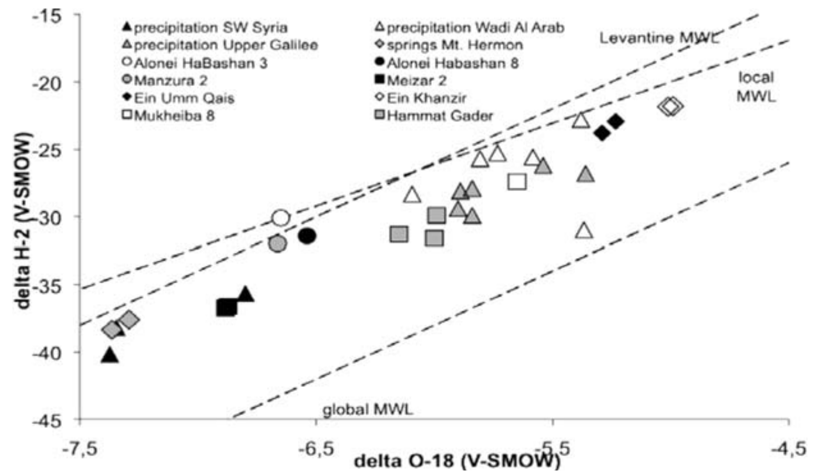

Fig. 4: shows stable isotopes of water (18O and 2H) standardised to Vienna Standart Mean Ocean Water (V-SMOW). Dashed lines indicate Levantine, local and global meteoric water lines (MWL), respectively.

Symbols in Figure 4 indicate the stable isotope composition of the sampled waters and show, all groundwater and precipitation samples are located between the levantine and global MWL. Only Alonei HaBashan 3 catches the local MWL. That common behaviour points to strong evaporation immidiately after rainfall and before precipitation finally leaves the atmospheric affected unsaturated zone and becomes groundwater. Evaporation leads mainly to enriched δ^{18}O and fewer entriched δ^{2}H signatures in the water, pictured by a positive shift along the axes.

Springs in Wadi Al Arab (Ein Umm Qais and Ein Khanzir) show heaviest isotopic composition, even heavier than the respective precipitation in the area. On the other side, Ein Banyas, recharged in the high elevated Mt. Hermon Massif, represents the lightes water (Fig. 4), as result of the temperature and elevation effect. Investigated groundwaters from Golan Heights and Yarmouk Gorge are distributed in between. However, they show unusually light signatures compared to precipitation falling in their recharge areas (in Fig. 4: “precipitation Upper Galilee”, representing average precipitation on Golan Heights) (Siebert et al., 2009).

Relatively similar signatures to the Hermon Massif are observable in precipitation over the SW corner of Syria, which is due to the continental effect.

CONCLUSIONS

By combination of information, gathered from stable isotopes and REY analyses, most of the groundwater in the region show distinct inconsistencies concerning common knowledge and hydrochemical results.

Alonei HaBashan 3; 8 and Manzura 2 are drilled into the basaltic cover of the Golan Heights. However, REY signatures refer clearly to a limy and in Alonei HaBashan 3 and Manzura 2 wells to karstified lithology in their recharge area. The isotopic compositions of Alonei and Manzura wells are much lighter than recharge in the Golan Heights pointing to recharge in the elevated Hermon Massif, later percolation into the basalts and flow southwards.

The water in Meizar 2 is obtained from Upper Cretaceous limestones. Because (1) groundwater in that strata flows southwards, (2) REY indicate limestone catchment and (3) the entire Golan Heights are covered by basalts, its water was originally replenished in the Hermon region too. That hypothesis is supported by the very light isotopic signatures of the water.

On the other hand, springs in Hammat Gader (Ein Reach and Ein Makla) and in Wadi Al Arab (Ein Umm Qais; Ein Khanzir) emerge from Eocene B4 aquifer, although their REY signatures clearly show a basaltic area of replenishment. Ein Umm Qais and Ein Khanzir closely emerge on a limestone ridge, of whats west is covered by basalts. Although their assumed catchments would be further eastwards, both springs are mainly recharged by the basaltic area, fitting to outcomes of Rödiger *et.al.* (in prep.).

Groundwater in Hammat Gader, situated on the southern flank of the Golan obviously infiltrate into the basalts above and percolate towards B4 aquifer. At the same time, stable isotopes show that the area of infiltration must be situated in the higher elevated Golan Heights or in the Syrian Golan. The first assumption is not possible, because in that case, flow paths of groundwater within the Israelian Golan Heights would cross each other.

Well Mukheib 8, situated on the southern rim of the Yarmouk Gorge and drilled into A7/B2 aquifer shows REY signatures clearly referring to a basaltic infiltration area and its isotopic compositions is similar to precipitation over Wadi Al Arab. However, the entire Ajloun neither bears volcanic rocks over outcrops of the A7/B2 formation nor in necessary amounts anywhere else. Consequently, Mukheiba 8 must receive water from the areas north of the Yarmouk, where the vast basalt covers exist. Although it would be the nearest possibility, Israeli Golan does not feed the Mukheiba area but the basalt areas in SW Syria do. That assumption is supported by the investigations of Salameh (2004). Groundwater flow from Israeli Golan Heights cannot occur because groundwater flow within the Ajloun part of the A7/B2 is directed northwestwards. The relatively enriched isotopic composition of Mukheiba 8 can be argued as result of strong evaporation during infiltration process into the basalts of Jebel Druse Volcan field.

As a result of that study, the Yarmouk gorge and the international borders of Jordan, Syria and Israel are not a compulsory boundary for groundwater, flowing according to natural conditions.

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Complex Hydrogeological Study of a Hungarian – Ukrainian Transboundary Aquifer

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ABSTRACT

In the framework of an EEA Norway grants project involving industrial and scientific partners, complex hydrogeological investigation and groundwater modeling of a regional transboundary aquifer between Hungary and Ukraine were carried out in 2009. This challenging cooperation work was completed by an EU country (Hungary) and a non-EU country (Ukraine). This pilot project demonstrated how the EU Water Framework Directive can be applied for a regional scale transboundary aquifer between Hungary and Ukraine. The transboundary aquifers play significant role in Hungary because the country land is mainly located in a deep and closed basin called Carpathian. 40 from the total 185 groundwater bodies are classified as transboundary in Hungary. The authors of this work were lucky to participate in an earlier NATO Science for Peace Project (Lenart et al. 2003), which investigated a transboundary aquifer between Hungary and Romania some years ago. The experience gained in that project (Dassargues et al. 2004) was utilized by the researchers to conduct the present complex hydrogeological study in a well-organized and efficient way.

In order to achieve the sustainable water management of the investigated internationally shared aquifer (Lenart et al. 2003), the main tasks of the present international project were: a) development of a common hydrogeological data-base; b) additional field measurements; c) interpretation of the geology for a common conceptual hydrogeological approach; d) creating the conceptual flow model of the investigated transboundary aquifer; e) regional scale groundwater modeling; f) model simulation of different scenarios for groundwater management purposes; g) review of the main results obtained from the transboundary approach in the view of the European Water Framework Directive. As one of the main output, a common regional groundwater flow numerical model has been built and calibrated on historical measured field data. It is already and will be in the future very useful for a possible joint management of groundwater resources between Hungary and Ukraine. The derived results allow a better evaluation of groundwater resources and a sustainable management of these resources.

Key words: modeling, transboundary aquifer, water management, hydrogeology

REGIONAL SCALE GROUNDWATER MODELING

The targeted aquifer, which extends on both sides of the Ukrainian-Hungarian border on 550 km^2 area (see Fig. 1.), supplies drinking water to a population of about 100000 inhabitants in Ukraine and in Hungary. The project focused on improving the previous understanding of the groundwater conditions including flow and pollutant transport across many scales, using data acquisition techniques and computer simulation models. On the basis of analysis of the available data (Gogu et al. 2001), new campaigns of field measurements were carried out focusing on the following aspects: piezometric levels or hydraulic heads; pumping tests for hydrodynamic parameters. The priority was given to measurements in areas with low density of observation wells, in order to prepare ideally all the needed data allowing a reliable groundwater modeling.

One of the most important steps in the mathematical modeling was the choice of the conceptual model of the aquifer. By keeping the essential features of the system, a reasonable compromise between the complexity of the multi-layered aquifer and the available reliable data concerning the actual structure and hydrogeological parameters was proposed. The Hungarian and Ukrainian experts agreed on a conceptual model consisting of three Pleistocene aquifer layers. The groundwater flow simulations were carried out with the Processing MOFFLOW Pro program package. As a first step, a steady-state flow model reflecting average conditions were created and calibrated. The calibration results and the simulated heads (see Fig. 2.) confirmed the reliability of the conceptual model and the accuracy of the applied regional scale flow model (Szucs et al. 2006).

Figure 1. The area of the investigated transboundary aquifer between Hungary and Ukraine.

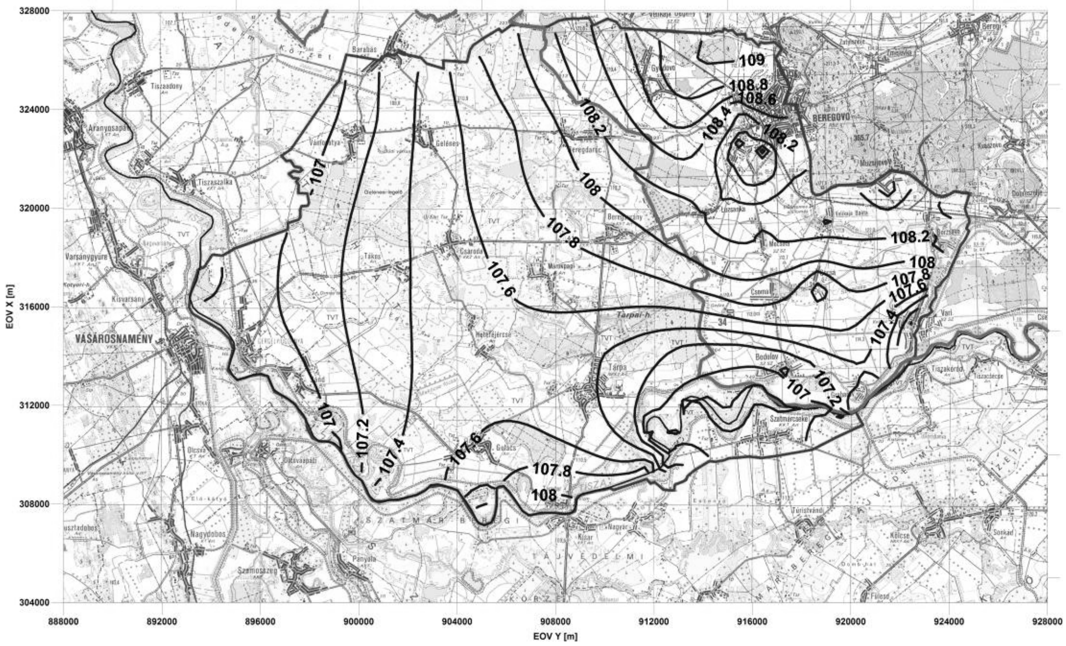

Figure 2. The calibrated hydraulic head map for the transboundary aquifer in case of the steady-state regional groundwater model.

The thickness of the Pleistocene transboundary aquifer is increasing from the Ukraine to Hungary (see Fig. 3.). The total thickness of the targeted aquifer can exceed 130 m. A MODFLOW grid system was generated to simulate the hydrodynamic behavior of the groundwater flow systems. Then the boundary conditions were determined for the modeling activity using mainly natural geological and rivers conditions (see Fig. 4.). The calibration results of the regional scale flow model were satisfactory. The RMSE value was 0.32 meter. As a next step, different future production scenarios were investigated. The expected future Ukrainian groundwater production increase is much more significant than the Hungarian one. As a result, groundwater level depressions are expected larger on Ukrainian side. Fig. 5. demonstrates that in some places the simulated shallow groundwater level decrease can exceed significantly the 0.5 meter. That means that harmful effects concerning the ecosystems can occur in those areas if the given production scenario is realized. In order to avoid the harmful consequences, some future common measures between Hungary and Ukraine should be introduced.

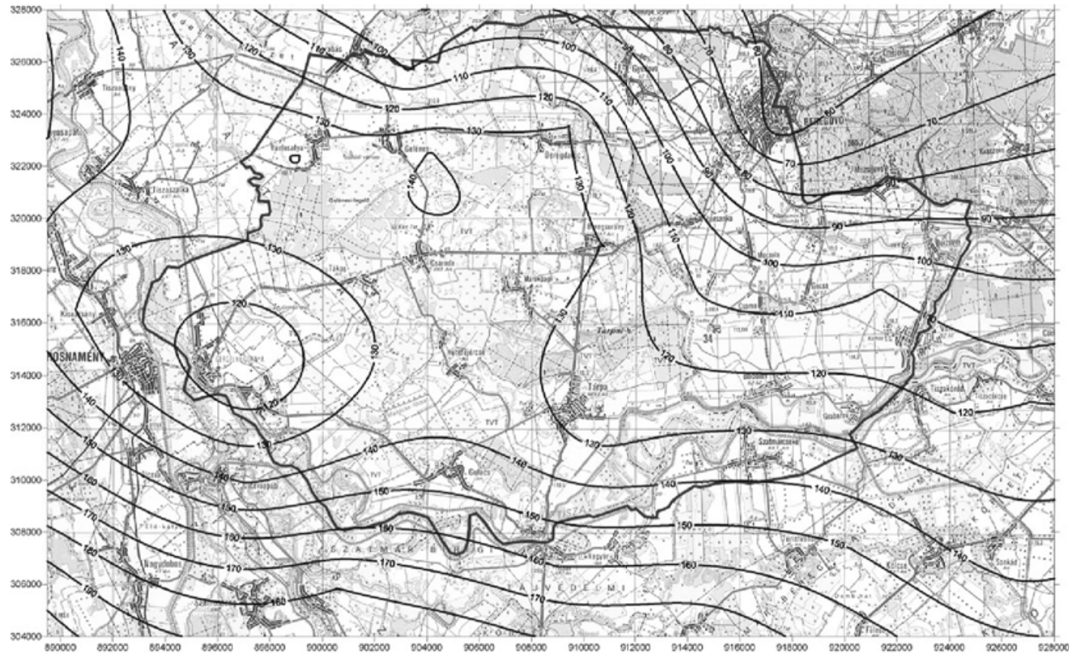

Figure 3. The thickness of the investigated Pleistocene aquifer between Hungary and Ukraine.

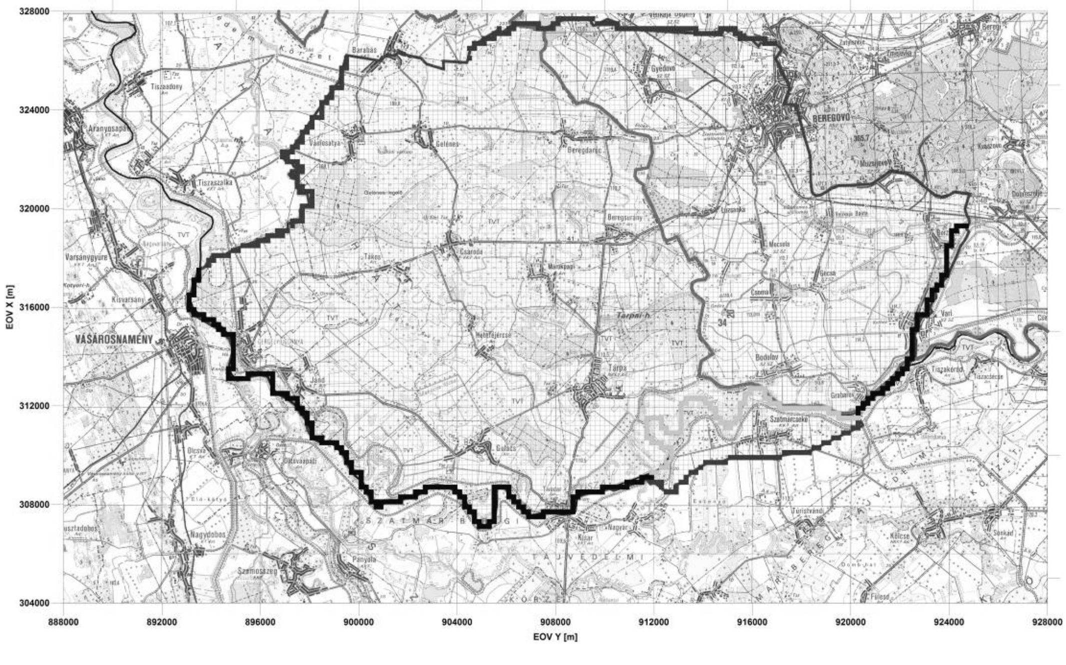

Figure 4. The grid system and the boundary conditions in the MODFLOW based flow model.

The collaboration between the Hungarian and Ukrainian experts was outstanding. Some of the obtained results have already been involved into the water management policy of this transboundary region. The monitoring activity (see Fig. 6.), the data exchange, and modeling activity will be continued in the future to get more detailed knowledge of the targeted internationally shared aquifer.

The key numbers of the water balance for this internationally shared aquifer have been also determined for water management activity.

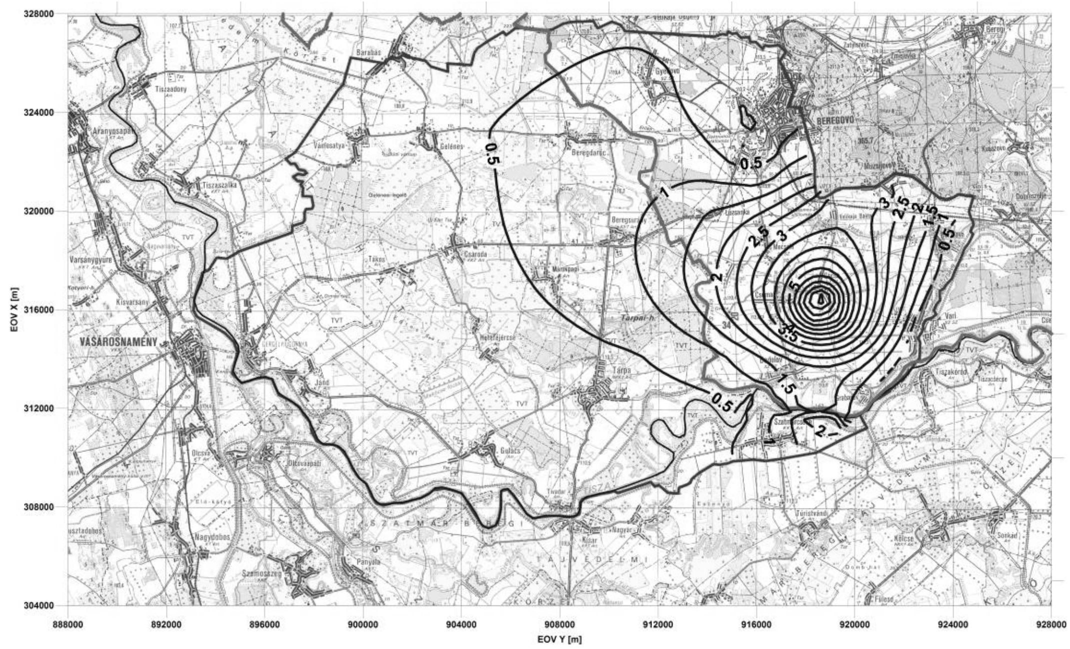

Figure 5. The expected shallow groundwater level decrease in case of a future production scenario.

Figure 6. Field measurement will be continued in the future in the framework of the common monitoring activity.

As an assessment of the quantitative status, water balance tests were carried out for the investigated, internationally shared aquifer. We tried to assess the annual average abstraction against the available groundwater resource. Based on the field measurement, it is reasonable to assume that the groundwater body is of good status. The tests for groundwater dependent terrestrial ecosystems showed that 0.5 m depression in the shallow groundwater can be tolerable. It was also a great asset that the mineral water and thermal water resources (M. Toth et al. 2007) were also reviewed and estimated in the region between Hungary and Ukraine (see Fig. 7.).

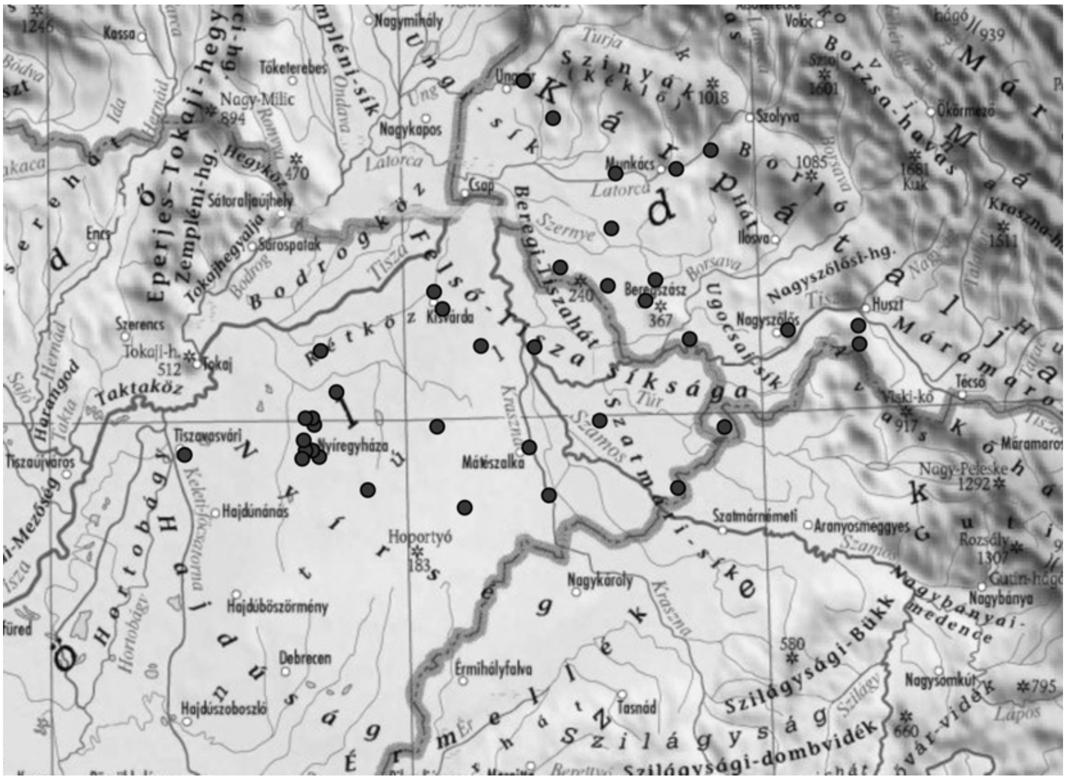

Figure 7. The main mineral and thermal water wells in the transboundary region between Hungary and Ukraine.

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Austrian-German Cooperation in Modelling and Managing a Transboundary Deep Groundwater Body.

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Key words: Groundwater Modelling, Groundwater Management, Geothermal Groundwater use

ABSTRACT

The thermal groundwater of the Malmkarst (Upper Jurassic) in the "Lower Bavarian and Upper Austrian Molasse Basin" is of transboundary importance and the only important deep groundwater body in Lower Bavaria and Upper Austria in terms of the WFD.

To avoid an overexploitation and to guarantee a sustainable use of the thermal water detailed research work has been done. It had become necessary because of the increasing economical importance of thermal –water use in the affected area on both sides of the German-Austrian border. Especially the thermal-water use for spa and for hydrogeothermal purposes are of immediate importance.

From 1995 to 1998 a model for the thermal-water aquifer was developed in a German –Austrian cooperation. First a hydrogeological model was developed to describe the hydrogeological, geothermal and water management facts. Based on these facts the conceptual model has been adapted and processed by a mathematical groundwater model.

The mathematical model of the groundwater flow for an extremely heterogeneous karstic aquifer caused by fractures and karst-tubes was done by a two-dimensional steady flow mathematical groundwater model. For the mathematical modelling a 2D-Version software was used.

In order to deal with these questions a 3D- hydraulic-thermal combined groundwater model was developed in German – Austrian cooperation from 2005 to 2007. The main aim of this research work was to gain knowledge and a better understanding of the thermal- hydraulic system and the given relations between the major processes, and furthermore to elaborate common management strategies.

In order to be able to manage the thermal water resources in a sustainable way and according to be best available state of technology the ad hoc expert group was asked to elaborate joint protection and utilisation strategies and to lay down the results in guidelines.

PURPOSE OF THE STUDIES

To avoid an over-exploitation and to guarantee a sustainable use of the thermal water detailed research work has been carried out. It has become necessary because of the increasing economic importance of thermal water use in the affected area on both sides of the German-Austrian border. Especially the thermal-water use for spa and for hydrogeothermal purposes are of immediate importance.

GROUNDWATER BODY

The groundwater body extends from Regensburg in the north to Linz in the south. Its eastern border follows the river Danube on a long distance. With a total area of 5.900 km² the length is 150 km and the width is 55 km. The top of the Malm reaches a depht of about 2000m beow sea level. The thickness of the Upper (karstic) Malm is about 300 m.

HYDROGEOLOGICAL MODEL (CONCEPTUAL MODEL)

First a hydrogeological model was developed to describe, the existing knowledge about geological, structural, hydrogeological, hydrochemical, isotopical, geothermal and water management facts.

MATHEMATICAL GROUNDWATER MODEL

The 2D-mathematical model of the groundwater flow for an extremely heterogeneous karstic aquifer - caused by fractures and karst-tubes - mathematical groundwater model. It combines a continuous approach with a discontinuous model and is able to simulate the influence of fractured zones and of karstic tubes on the permeability and thus on the groundwater flow system.

The various calculations show that temporarily changing production rates and the influence of geohydraulic tests and re-injection tests on neighbouring thermal water utilisations can only be calculated by a nonsteady flow groundwater model. For this reason a nonsteady flow model was used in order to simulate the thermal water withdrawals taking into consideration the temporal decrease of pressure of the highly confined deep thermal water.

This mathematical (hydraulic) model is the relevant instrument for authorities on both sides of the border for evaluating the required water extractions, the potential yield and the implications on other existing wells on a reliable basis.

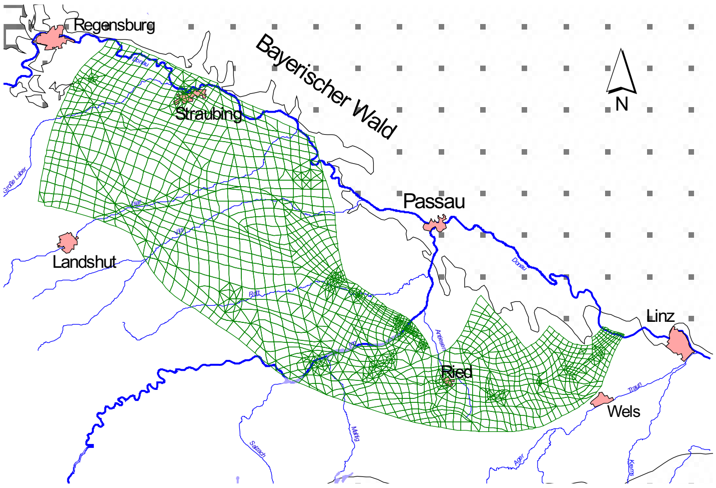

Figure 1. Survey of the water-balance area.

FURTHER PROBLEMS -INTERNATIONAL WORKSHOP MUNICH 2002

The increasing number of sites which re-inject geothermically used water creates a large number of questions which cannot be answered by using only a hydraulic model. Within the framework of an international workshop held in Munich in 2002 those questions which would have to be clarified from the point of view of water management were formulated in order to ensure a sustainable geothermal use of thermal water.

The following questions have to be answered:

Is there a relation between the reduction of the temperature in the deep thermal aquifer and the existing pressure condition?
Is there a relation between temperature and the relevant hydraulic parameters as permeability and storage coefficient?
How can the quality of those parameters be influenced, if the temperature in the deep aquifer is decreasing?
Is there a relation between the extraction of thermal water and the quantity of water (yield) which can be collected from the deep groundwater body?
Other questions concern the way in witch the temperature of the re-injected water, the location of and the distance between the boreholes for extraction and re-injection and the operational mode can influence the thermal conditions such as the temporal and spatial distribution of temperature in the deep thermal groundwater body.

HYDRAULIC-THERMAL COMBINED GROUNDWATER MODEL

In order to deal with these questions a 3D- hydraulic-thermal combined groundwater model on the basis of the results of the model from 1998 was developed in German – Austrian cooperation from 2005 to 2007. The detailed studies were carried out by a German-Austrian-Swiss consortium of engineers, the ARGE TAT. This model is based on the regional geological and hydro-geological situation in the "Lower Bavarian and Upper Austrian Molasse Basin".

The main aim of this research work was to gain knowledge and a better understanding of the thermal-hydraulic system and the given relations between the major processes, and furthermore to elaborate common management strategies.

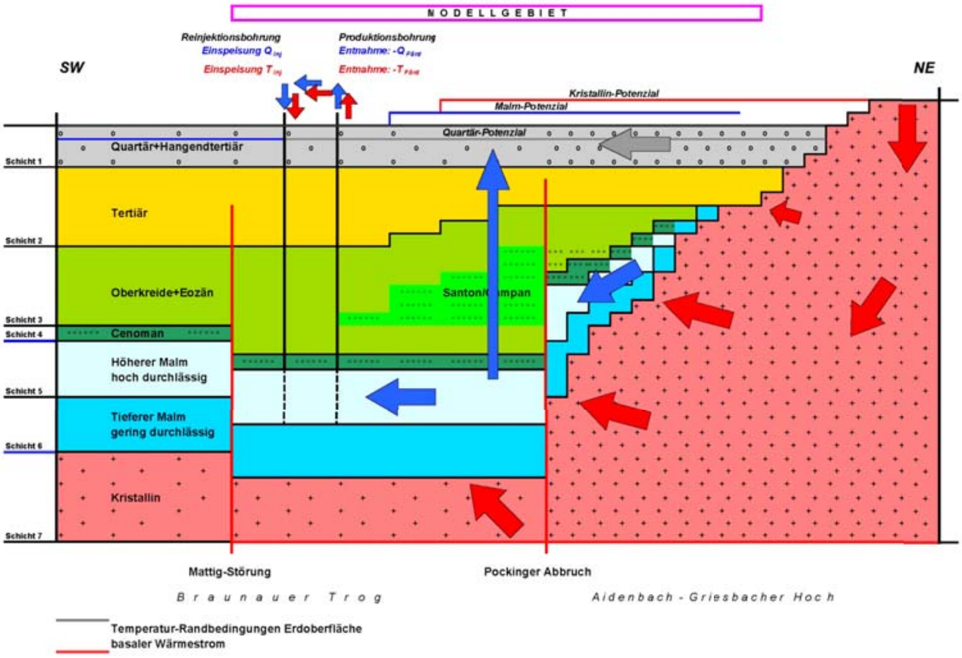

Figure 2. Schematic representation of the hydrostratigraphic units

Figure 2 shows a schematic representation of the hydrostratigraphic units lying above the crystalline taken into consideration in the 3D hydraulic thermal combined groundwater model and the relevant energy flows.

APPLICATION OF THE 3D-HYDRAULIC-THERMAL COMBINED GROUNDWATER MODEL

On the basis of this model detailed studies were carried out for a representative part of the overall system in order to gain a better understanding of the system.

A total of 39 load cases were calculated. Within the framework of these works the effects on the pressure and temperature behaviour on the one hand in the case of a certain configuration of production and re-injection wells and of changing operational modes (varying extraction quantities and re-injection temperatures), and on the other hand of a certain operational mode and changed configurations of production and re-injection wells.
Moreover it is examined how sensitively the pressure and temperature behaviour of the Malm aquifer reacts on changed system parameters.

In general the calculations were made on the basis of a nonsteady flow model for an operational period of 50 years (presently assumed technical lifetime of a geothermal doublet). One forecasting case simulated an operational period of 2000 years, two forecasting cases operational periods of 300 years.

Within the framework of sensitivity analysis system relevant parameters, such as thermal conductivity, rock porosity, permeability contrast faults / matrix and permeability in the higher Malm were varied. The range of variations of the parameters examined has been oriented according to the available measuring results and literature values. Synergetic effects of system and process parameters were initially not being investigated.

Three position configurations (case A, B and C) were examined according to the following scheme:

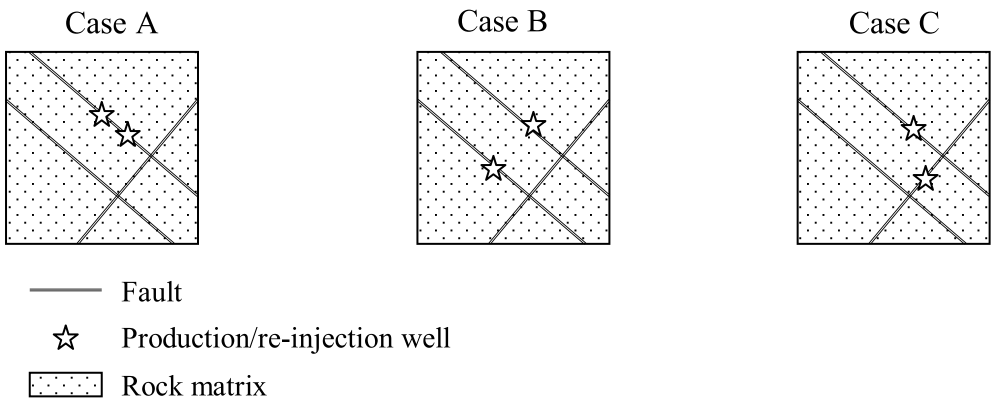

Figure 3: Position configurations for doublets

The following position configurations were taken into consideration with borehole distances of 1 and 3 km in the local models.

Case A: Production and re-injection wells on an identical fault zone.
Case B: Production and re-injection wells on parallel fault zones
Case C: Production and re-injection wells on crossover fault zones

RESULTS:
The model results were evaluated with respect to the following system and process factors.

- Volume flow rate (production and re-injection quantities per time unit)
- Temperature of re-injected water
- Operational mode (annual constant or seasonal withdrawal)
- Location of the fault in relation to the production and re-injection wells
- Distance between the production and re-injection wells
- Difference between the permeability of stone matrix and fault zones
- Heat conductivity of the rock matrix
- Porosity
- Hydraulic conductivity of the rock matrix
- Groundwater re-injection upstream of the production well.

The influence of the individual system and process parameters on the pressure and temperature behaviour in the production and re-injection wells as well as on the dimension of the cone of depression in the section examined are represented in diagrams.

The extent of the effect was evaluated as follows:

LOW: The change of a certain parameter shows no or only minor influence on temperature and/or pressure behaviour
MEDIUM: The change of a certain parameter shows an already noticeable influence on temperature and/or pressure behaviour.
HIGH: The change of a certain parameter shows a substantial influence on the temperature and/or pressure behaviour

The following diagrams show the hydraulic and the thermal impact on the production and on the re-injection well under the input parameters and boundary conditions on which the modelling is based.

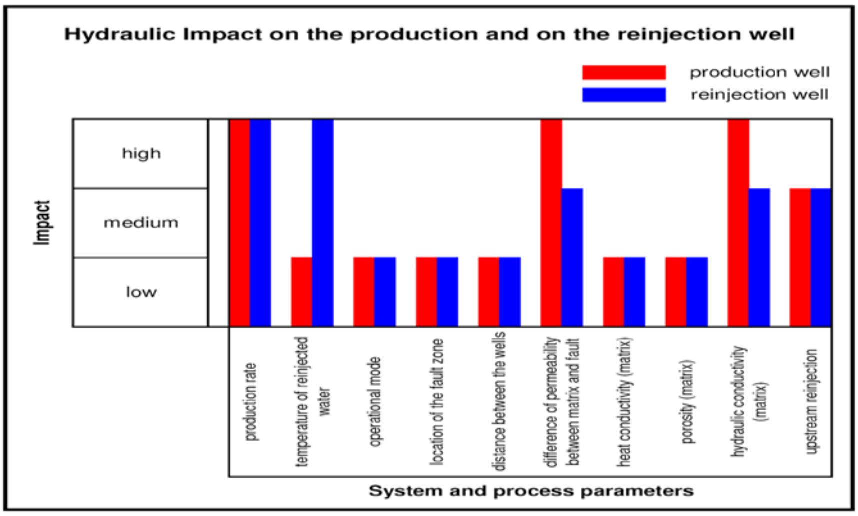

Figure 4.
Hydraulic impact on the production and on the re-injection well

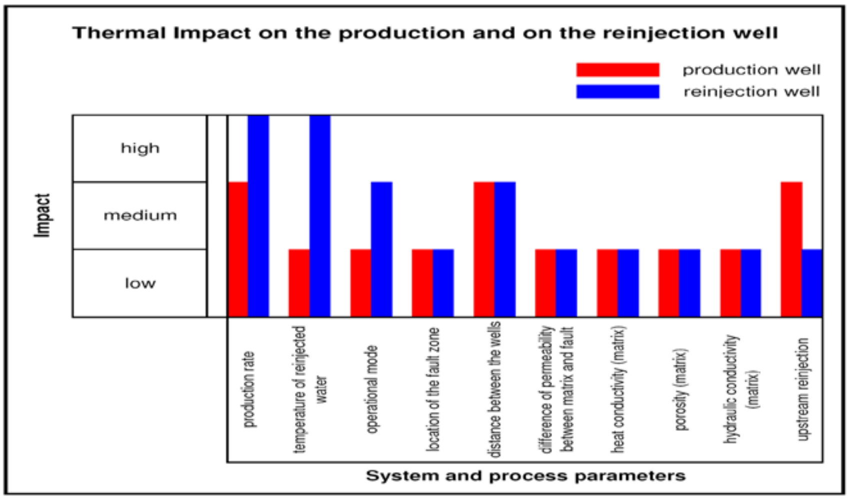

Figure 5.
Thermal impact on the production and on the re-injection well

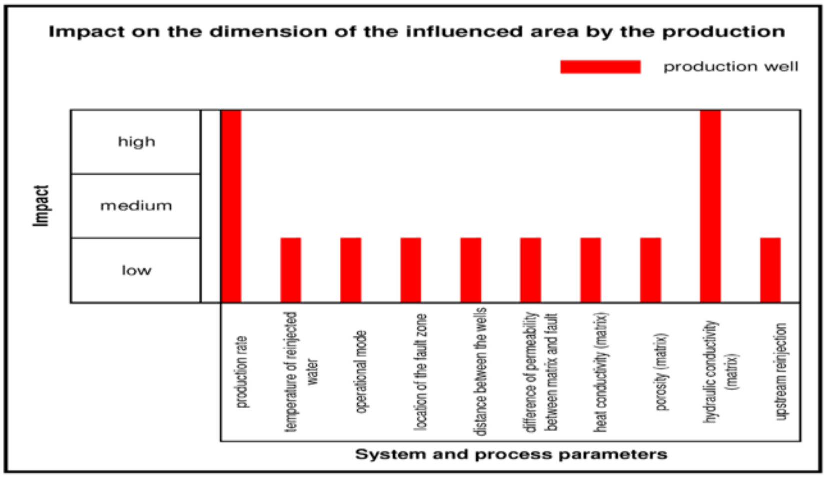

Figure 6.
Impact on the dimension of the cone of depression

Proceeding on the assumption on which the model calculations are based the following conclusions can be drawn for the representative part of the groundwater system:

- The production rate exerts high influence on the pressure behaviour in the production and in the re-injection well.
- The re-injection temperature exerts high influence on the pressure and temperature behaviour in the re-injection well.

- The difference between the permeability of rock matrix and fault as well as the hydraulic conductivity have high influence on the pressure potential in the production and re-injection well.
- The volume flow and the hydraulic conductivity have a high influence on the extension of the area affected by the withdrawal.
- A re-injection of groundwater upstream of the production well has medium influence on the pressure behaviour in the re-injection well.
- Other system and process parameters have basically low influence on the pressure and temperature behaviour in the production and re-injection wells.

GUIDELINES

In order to be able to manage the thermal water resources in a sustainable way and according to be best available state of technology the ad hoc expert group was asked to elaborate joint protection and utilisation strategies and to lay down the results in guidelines.

So far, guidelines are available on the following issues:

- Management principles
- Dimensioning of plants for the thermal water use
- Application, maintenance and further development of the mathematical groundwater model
- Required application documents
- Catalogue of requirements
- Exchange of relevant information and data

SUMMARY:

From the point of view of water management:

A better systemic understanding of the thermal-hydraulic interrelations in the model area could be gained.
The influence of the operational mode on the pressure and temperature behaviour can be better assessed in the model area.
It will only be possible to estimate the dimensions of individual parameters determining the hydraulic and thermal behaviour also in future.
In spite of a better understanding of the system forecasts of the effects of geothermal utilisations on the thermal balance still entail great uncertainties.

The parameter which has a much more restrictive effect on the utilisation of geothermal energy is the utilizable thermal water quantity.
The geothermal doublets will operate over decades without significant changes of temperature and pressure.
A statement on whether the results of the study can be transferred to other bodies of water is currently not possible, further and intensive investigations will be necessary in the future.
Basically one can proceed on the assumption of the extraction of the available energy, even though, taking into consideration the available energy sources, this will be possible over a very long period.
The results have shown that after about 1000 years, thus a relatively very long period, there will be an impact on the temperature in the production well as a consequence of the re-injection of cooled water. Even though this influence is very low compared to the original temperature it is rather doubtful whether the utilisation of geothermal energy can be called sustainable strictly speaking.

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Transboundary Aquifers in Great Mekong River Basin

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ABSTRACT

The Great Mekong River basins are located in the south-east part of Asia. There are four Transboundary aquifers among the countries, including China, Myanmar, Laos, Thailand, Cambodia and Vietnam. The groundwater resources in the basin are distributing in the plains, basins, plateaus and mountains. Development and utilization of underground water has a long history. At drought, groundwater is mainly used for irrigation and drinking residents' inland areas. In major cities, such as: Phnom Penh and some cities in Vietnam, the exploitation of groundwater is for urban water supply. Countries in the region should strengthen cooperation and exchange and research those transboundary aquifers, for coordination and joint management of groundwater resources in order to provide the scientific basis to achieve sustainable use of water resource. The DPSIR framework indicators are for the four trans-international boundary Aquifers in great Mekong River basin. Those aquifers could be scaled in to four grades on intrinsic value, Sensitive and Harmonious.

Key words: Great Mekong River, Transboundary aquifers, Environmental issues, Indicators

1. INTRODUCTION

The Great Mekong River is located in the northern part of Asia. It is an international river and through countries including China, Myanmar, Laos, Thailand, Cambodia, and Vietnam. The upstream is also named as Lancang River in China. The basin area of Great Mekong River is about 810 000 square km, the total distance from sources to the mouth is about 4880 km. Water resources in the Lancang River-Mekong River basin are abundance, but the surface water distribution is uneven in the time and space. The groundwater resources in the basin can are distributing in the plains, basins, plateaus and mountains. The development and utilization of shared water resources of international groundwater resources better meet the basin's water resources needs. The maintenance of international basin ecosystem balance is not only a regional theme of international cooperation, but also international organizations, research institutions and many non-governmental organizations. Water experts call for effectively improve the water-saving awareness, protect groundwater resources and the common shared aquifer resources, and establish water-saving society. Countries in the region should strengthen cooperation on transboundary aquifers, for coordination and joint management of groundwater resources in order to provide the scientific basis to achieve sustainable use.

2. TRANSBOUDARY AQUIFERS

Groundwater resource is an important fresh water resources and the transboundary aquifer is an important component of the groundwater system among the countries. There are four Transboundary aquifers in great Mekong River basin.

1.1 The aquifer in downstream of Lancang River

It is an aquifer shared by China and Myanmar, located at the juncture of Yunnan and Myanmar, and belongs to clastic rock fissure water. The area of the aquifer is 39509km^2, and the part in China is 31168km^2, accounting for 78% of the area of aquifer. The annual rainfall is 1000 ~ 1500mm.The supply conditions are good and natural supply module is between $10\times 10^4 m^3/km^2.a$ and $30 \times$

$10^4 m^3/km^2$.a. The chemical types of the groundwater are mainly for HCO_3-Ca.Mg and the TDS is 0.15 ~ 0.4g /l. The main lithology of the strata in the area is acidic intrusive granite rocks of Triassic, shale folder clay limestone of Jurassic, calcareous shale and sandstone folder mudstone, conglomerate mudstone folder siltstone and fine sandstone of Cretaceous. The intrusive rocks mainly distribute in the vicinity of Lincang and Jinghong and many fissures have developed. The large fault is the South Lancang fault zone and Wuliang Mountain fault zone. The north of the South Lancang fault is the Lancang River Valley on the west of Lanping, and it is south by Yongping, the north of Yunxian, through Jinghong extends into the territory of Myanmar from southwest and is a deep fault. The north of the Wuliang Mountain fault zone is Lanping; it is south by the east and west through Jinghong, the west of Zhenyuan to the southwest of Simao. Due to the impact of the fault zone, the tectonic fissures are rich; the contact position of acidic intrusive rocks and the surrounding rock is better rich in groundwater and is the large concentration water supply sources. The metamorphic rocks distribute from the east of the Lancang River to Zhenyuan - Simao area. The calcareous shale and argillaceous limestone of Jurassic is band spread. Most of the rock is with dense structure, less development cracks, poor tensional, strong capabilities resisting weathering, less developed weathering fissures. So the infiltration capacity is relatively low, and the storage groundwater is little.

1.2 The aquifer in midstream of Mekong River

The aquifer is a transboundary aquifer through Thailand, Myanmar and Viet Nam, and it belongs to fissure pore water in the plain and mountain basins. The area of aquifer is $106816 km^2$, which in Myanmar is $77955.75 km^2$,accounting for 73% of the total area, the part in Thailand accounts for 21% and the part in Vietnam accounts for only 6% of the total area. The annual rainfall in the region is between 900mm and 1600mm, Because the structure of the aquifer is complex and the supply conditions in different regions are relatively different, the difference between the amount of groundwater are also relatively large. The natural supply module is between $5 \times 10^4 m^3/km^2$.a and $40 \times 10^4 m^3/km^2$.a. The aquifer is mainly affected by leaching and mixing and groundwater belongs to the bicarbonate and sulphuric acid type. The strata's of the aquifer expose continental classic sedimentary rocks of Jurassic, sandy conglomerate of middle and upper Cretaceous and the alluvial layer of Holocene. The continental clastic sedimentary rocks of Jurassic are scattered in the surrounding areas of Udon in Thailand, while a large number distribute in the surrounding of Phupan Mountains. The main lithologies are purple mudstone, calcareous mudstone folder sandstone. Fractures develop few, the permeability is poor water and it forms a relative aquifuge. The red or brown gravel and sandstone of Cretaceous are widely distributed in the aquifer, with the thickness of 60m ~ 300m and the average thickness of 125m or so. The fissure water is mostly in the form of layered, and the water abundance of the coarse particles rocks are generally better, the flow path is not long with characteristics of in suit recharge and in suit discharge. The groundwater quality is local fresh water underlying brackish water. The alluvial material of Holocene concentrated on both sides of the Mekong River is main alluvium, and the lithologies are sandy gravel layer, silt loam layer, salty sand and gravel bedded. The rocks are composed of the slate, siltstone, sandstone, and the rounding is good. The thickness of sediments changes relatively large and it is between 100m and 500m.The surface water and rainfall are relatively rich and the recharge rate is abundant. The natural supply module in this area is up to $40 \times 10^4 m^3/km^2$.a, the water abundance of groundwater is good and the water content is rich.

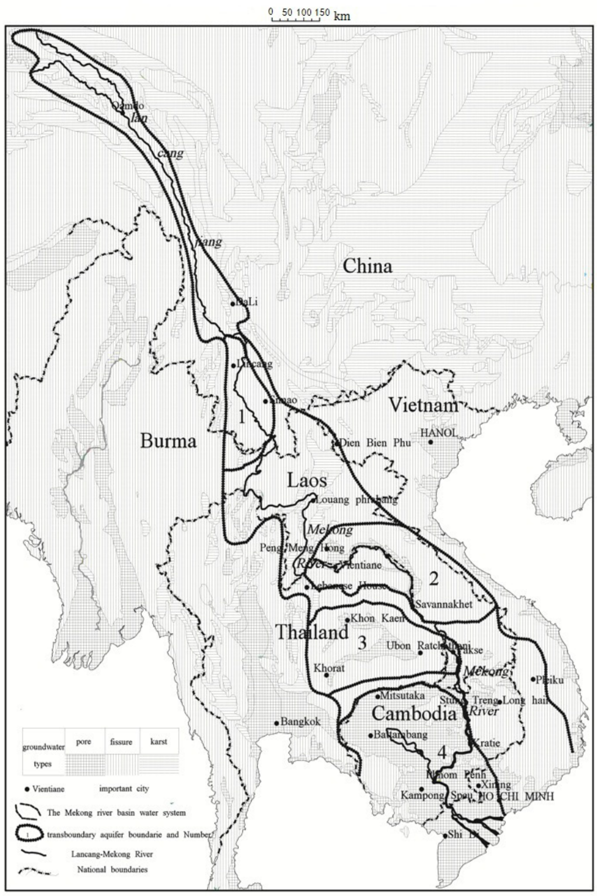
1.3 The aquifer in Kele plateau

The aquifer, shared by Thailand and Laos, is pore and fissure aquifer. The whole area is $95511 km^2$. The area of Thailand is $90837.50 km^2$, accounting for the most part, and Laos accounting for a little part in the northeast. The mean annual precipitation in this region is about 1000mm. The natural recharge modulus in most of the region reaches as high as $50\times10^4 m^3/km^2$.a, and the local modulus is $50\times10^4 m^3/km^2$.a along the bank of Meng River and Xi River. The groundwater is salt water and brackish water. The sulphate and chloride type are the main chemical type. The strata are consisted mainly of Cretacic limestone, rhyolite, silexite and Holocene loose sediment. The loose sediment of river and lake phrase distributes along the banks of XI River (Tributary River of Mekong

River) and Meng River, with gravel and clay as the main lithology. The main recharge sources are atmospheric precipitation and river, the secondary is the lateral recharge from monotonic bedrock water. The natural recharge modulus is 30-50×$10^4$$m^3$/$km^2$.a for the wide recharge sources and good infiltration conditions. The strata in other areas are Cretacic stratum, consisting of red, purple and gray sandstone, siltstone, and shale, sand limestone, calcareous Siltstone. The aquifer is bedrock fracture water with undeveloped fissures. The natural recharge modulus is 5~10×$10^4$$m^3$/$km^2$.a. The east of the aquifer is Chang Shan mountain, with the elevation 2000~3000m. The lithology is mixed rock, gneiss and slate. Quaternary basic basalt spreads around Ba se in Laos, with developed weathering fissures. The natural recharge modulus is 20×$10^4$$m^3$/$km^2$.a.

Table 1 and Fig. 1 Transboundary aquifers in Great Mekong River basin

No	Aquifer	countries shared
1	The aquifer in downstream of The Lancang River	China, Burma
2	The aquifer in the mid of Mekong river	Thailand, Laos
3	The aquifer in Kele plateau	Thailand, Laos
4	The aquifer in Mekong river delta	Cambodia, Vietnam



1.4 Aquifer in Mekong river delta

The aquifer is shared by Cambodia and Vietnam. It is a typical flood alluvial basin, of which the east is Changshan Mountain in Vietnam, the west is Oula Mountain, and the north is Biandan Mountain. The whole area of the aquifer is 223423km^2, with Cambodia 141338 km^2, accounting for 63.3% of all. The length of Mekong river in Cambodia is about 1000km. Tonle Sap Lake water system affluxes Mekong river' downstream. As the largest lake in Cambodia and also IndoChina Peninsula, Tonle Sap Lake is a natural regulating reservoir of Mekong River. The annual precipitation in this region is between 1200mm and 2400mm, with Mekong river delta the biggest. The aquifer consists of Quaternary sediment, with 100-1000m in thickness. Biandan Mountain accented intensely and the delta plain sunk relatively in tectonic movement, thus very thick loose sediments were accumulated in mountain front, forming splendid water-bearing media. The natural recharge modulus is 30~50×$10^4$$m^3$/$km^2$.a. The groundwater environment transits from brackish water to salt water. The chemical type transits from bicarbonate, sulphate to chloride, for the process transits from leaching, mix to condensing and salting from north to south. The main recharge sources are precipitation, surface water, and bedrock fissure water around. Meanwhile, there are lots of rivers in Mekong river delta, such as Tonle Sap Lake, Deep River, Saigon River, Hell River and some tributaries of Mekong River. Boulders and gravels expose from the top to the middle of alluvial fan, good for vertical intake from atmospheric precipitation. The natural recharge modulus is $30\times10^4 m^3/km^2.a\sim50\times10^4 m^3/km^2.a$. The lower delta has a good water storage capacity, as well as been a positive paretic zone. The most important fresh water aquifer is confined aquifer. Thin Holocene sediments formed not very thick phreatic aquifer generally. Extensive mid Pleistocene aquifer from coarse to fine sand spread in the north and south of the delta, with mineralization <1g/l commonly. The bottom Pleistocene aquifer which contains boulder, gravel and sand, is confined aquifer, with good groundwater quality, supplying 60% fresh water for the lower delta.

3. CHARACTERISTIC AND MAJOR ENVIRONMENTAL ISSUES

Upper Lancang River over the alpine region of Qinghai-Tibet Plateau is a sub-humid area, where there are critic weathering layer and thick layer, Strong infiltration, and snow are more melt water infiltrated into the ground and then flow to the rivers. Between Qamdo and Gongguo Bridge is the cross-sectional area mountain alpine valleys, river runoff is the type of rain - groundwater recharge mixed. Since then the following, before moving on to the low-lying Mekong, essentially the main supply belongs to rainwater supplying. Lowland of Mekong is a hilly mountain area of tropical moist, groundwater recharge to river prominent regulatory function, to Phnom Penh. Rivers accept the gradual increase of groundwater recharge. Tonle Sap Lake is a huge reservoir of natural regulation, when the downstream flow is more than $1500m^3/s$, it began to store flood water from the Delta, the flood inhaled up to 46 billion m^3. The groundwater resources in the basin can be divided to: in the plains and basins, in plateaus and mountains, in mountains and hills, and in freezing and thawing areas.

Development and utilization of groundwater has a long history. At inland areas drought, groundwater is mainly used for irrigation and drinking residents. In major cities, such as: Phnom Penh and some cities in Vietnam, the exploitation of groundwater is for urban water supply. According to the statistics of 41 major cities in South part of the basin, 20% of them rely on groundwater 39 % mainly surface water and groundwater as a supplement 41% only surface water In Vietnam, groundwater is the indispensable for urban water supply. At most areas, shallow groundwater is for drinking water. But in the main city, it had to increase the depth of the groundwater. In some cities because extraction groundwater is much larger than the natural recharge rate, the decline of groundwater levels begin to appear. The impact on the environmental aroused by groundwater development manifested in several issues. The negative impact of excessive exploitation of underground water cause the regional ground water level continued to drop; Land subsidence. If shallow groundwater levels can be control reasonable, groundwater generally can return to the critical depth of salt, making large areas of saline-alkali soil treatment. Exploitation groundwater along the riverside, it can increase recharge of groundwater. Source of groundwater pollution are included: point sources, surface sources and the proliferation sources. Point sources is refers to municipal solid waste landfill, accident of oil leakage and septic tank leakage. Surface sources refer to pollution of groundwater because of surface seepage. Irrigation water containing pesticides and fertilizers, unorganized rural towel waste water and other wastewater percolate through the soil. For excessive use chemical fertilizers and pesticides for farmland, so a large number of nitrogen and phosphorus nutrients and toxic chemicals, together with the leaching of water infiltrate into groundwater, which caused underground water pollution. We should give full consideration to the characteristics of the distribution of water, the rational use of surface water and groundwater resources.

4. CLASSIFY THE TBAS IN MEKONG RIVER BASIN WITH DPSIR INDICATORS

There are an attempt with DPSIR framework for Driving forces, Pressures, State Impact and Responses for classifications the transboundary aquifers in Mekong River basin. UNESCO-led expert group has proffered a precept on indicators for possible application of transboundary aquifers. The proposed methodology is relying on the assumption that the performance indicators will be used to interventions among the TBAs. The potential benefits to be achieved in the case of TBAs depend on three sets of variables: Transboundary aquifers intrinsic value and functions, socio-economic and legal indicators. The Global Benefit Indexes (GBI) is probe into sub-indexes. TBAs indicators are measure of the potential of generate global environmental benefits; address more urgent and vulnerable situation.We used the identification and formulation for the four transboubdary aquifers A1, A2, A3 and A4 in Mekong River.

The weighting factors ω_i (0-1) assigned to the sub-indices have considerable influence on the outcome of the calculation and prioritization of TBAs.

4.1 Intrinsic value and functions indicators

Sub-Index	Indicator	A1	A2	A3	A4
1-1 Intrinsic Value and functions of groundwater	Mean annual rate of current groundwater recharge	3	3	2	3
	Aquifer storage capacity	1	2	2	3
	Groundwater natural quality	2	3	1	1
	Aquifer vulnerability	2	2	2	1
Scoring	$I_{IV} = (x_1 + x_2 + x_3 + x_4)/4$	2	2.5	1.75	2
1-2 Human environmental dependency groundwater	Human dependency on groundwater for drinking	3	2	1	3
	Dependency on groundwater for agriculture	2	2	1	2
	Ecosystem dependency on groundwater	2	2	2	2
Scoring	$I_{HE} = (x_1 + x_2 + x_3)/3$	2.33	2	1.33	2.33
1-3 Groundwater vulnerability to stress	Groundwater vulnerability to diffuse pollution	1	3	2	1
	Groundwater vulnerability to depletion	2	3	1	3
	Aquifer vulnerability to climate change	2	3	2	3
Scoring	$I_{VS} = (x_1 + x_2 + x_3)/3$	1.67	3	1.67	2.33
Global Benefit Indexes	$GBI = \sum_{i=1}^{3} \omega_i I_i \quad (\sum_{i=1}^{3} \omega_i = 1)$	2.23	2.82	1.71	2.28

4.2 socio-economic and governance indicators

Sub-Index	Indicator	A1	A2	A3	A4
2-1 Socio-economic drivers, TB reform consistent with macro- socio - economic drivers	Sustainable socio-economic development for growth (GDP)	1	1	1	3
	Structural change: Sectored adjustment	2	1	1	2
	Sustainable national institutions	3	1	2	2
	National and regional security	2	2	2	3
	intensification for rural development food security	3	3	3	3
Scoring	$I_{SD} = (x_1 + x_2 + x_3 + x_4 + x_5)/5$	2.2	1.6	1.8	2.6
2-2 Economic instruments	Changing use costs Direct/indirect pricing	1	1	1	2
	Economic incentives	2	1	1	1
Scoring	$I_{EI} = (x_1 + x_2)/\ 2$	1.5	1	1	1.5
2-3 Economic governance Transboundary allocation	International resource/ trade/markets, quotas etc.	1	2	2	2
	Alternative economic governance structures	2	2	1	3
	Scope of associations successively expanded	3	1	2	2
	Successive spin-off for additional associations	3	2	3	3
Scoring	$I_{EG} = (x_1 + x_2 + x_3 + x_4)/4$	2.25	1.75	2	2.25
Global Benefit Indexes	$GBI = \sum_{i=1}^{3} \omega_i I_i \quad (\sum_{i=1}^{3} \omega_i = 1)$	2.19	1.65	1.9	2.41

4.3 Legal and institutional indicators

Sub-Index	Indicator	A1	A2	A3	A4
3-1 Cooperation	Existence of agreement on TBA among riparian countries	2	2	1	2
	Agreement on other water bodies	3	2	2	3
	Ratification of international or regional framework convention on international / transboundary waters	2	1	2	2
	Participation to a process or project on TBAs	1	1	1	1
Scoring	$I_c = (x_1 + x_2 + x_3 + x_4)/4$	2	1.5	1.5	2
3-2 Legal and institutional framework	Water law	2	2	2	1
	Provisions on Groundwater or regulation on Groundwater	3	2	2	1
	Absence of legal framework on water resources	3	1	1	1
	Institutions: Dealing with water	2	2	2	2
Scoring	$I_L = (x_1 + x_2 + x_3 + x_4)/4$	2.5	1.75	1.75	1.25
Global Benefit Indexes	$GBI = \sum_{i=1}^{2} \omega_i I_i \quad (\sum_{i=1}^{2} \omega_i = 1)$	2.21	1.68	1.65	1.85

According to the indicators, the trans-international boundary Aquifers could be scaled in to four grades. The GBI is (1-1.5), (1.5-2), (2-2.5) and (2.5-3) respectively. With the Intrinsic value and functions indicators, the aquifers could be scaled into Low, Medium-low, Medium-high and High. With the socio-economic and governance indicators, the aquifers could be scaled into: Most Sensitive, More Sensitive, sensitive and insensitive. With the Legal and institutional indicators, the aquifers could be scaled into: Inconsistent, Lesser Harmonious, Harmonious and more Harmonious.

5. CONCLUSIONS

Countries in Lancang - Mekong River Basin should strengthen cooperation on the four transboundary aquifers, for coordination and joint management of groundwater resources in order to provide the scientific basis to achieve sustainable use of water resource. According to the classification with DPSIR framework, the aquifer in downstream of Lancang River is a Medium-high, Sensitive and Harmonious aquifer. The aquifer in midstream of Mekong River is a High, More Sensitive and Lesser Harmonious aquifer. The aquifer in Kele plateau is a Medium-low, More Sensitive and Lesser Harmonious aquifer. The aquifer in Mekong river delta is a Medium-high, Sensitive and Lesser Harmonious aquifer.

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Investigation of transboundary aquifers in Russia: modern state and main tasks

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ABSTRACT

Transboundary problems of groundwater development are rather acute for Russia as it has land boundaries with 13 countries. The main research line concerning this problem is to develop principles and criteria of acceptable groundwater withdrawal by neighboring countries with compliance of environmental limitations. This includes groundwater protection from depletion and contamination, development of constant groundwater deposit models spread in border regions of neighboring countries in order to determine groundwater balance elements of certain hydrodynamic flows, their internal interaction and interaction with surface water. Estimation of potential groundwater shared use based on large scaled assessment and mapping of its sustained yield with regard to groundwater protection from contamination is of importance either.

Determination of prospects for groundwater use and withdrawal management is always connected with the problems of exploitation restrictions in accordance with different criteria. The latter may be both of inside and outside types. Among inside criteria are limitations of hydrogeological and hydrodynamical operation conditions, such as groundwater recharge rate, tolerance dynamic level lowering throughout estimated period, risk of non-standard groundwater drawing up to a water intake, and others. The outside criteria that can restrict the groundwater use are related to possible impacts of a planned water extraction upon different environmental components including river runoff, suppression or death of vegetation due to excessive lowering of shallow groundwater level in the upper unconfined aquifer; activization of karst and suffusion processes; earth surface subsidence, etc.

The main tasks of hydrogeological investigations are the following:

- Determination of admissible limits of groundwater extraction in each of boundary countries in order to prevent water reserves depletion in neighboring countries.
- Regional evaluation of natural groundwater resources of an exploited aquifer.
- Assessment of a groundwater pollution hazard in trans-boundary aquifers and development of joint recommendations preventing such pollution.

Specific examples of transboundary groundwater use perspective assessment in particular adjacent zone regions of Russia are presented.

Key words: transboundary aquifers, groundwater discharge, natural resources, vulnerability, core of depression.

1. INTRODUCTION

In recent years the problem of transboundary waters use has become rather actual in many countries. It concerns not only the interstate boundaries where the use of marginal or transboundary rivers (rivers that cross boundaries) in many cases is regulated by special international agreements. Also the problem of transboundary water use regulation is rather acute inside some countries (e.g. USA, Australia, Russia, India and others), where particular administrative regions (states, regions, federal divisions) have a constitutional independence and solve many problems of natural resources use independently, coordinating basic legislative acts only with neighboring countries or federal organs.

In Russia the principle of the superiority of international right to the state right in the field of the environmental protection and natural resources use is legislated by the Federal Law (Zektser, 2000)

The basic principles of international agreements in the field of natural resources use and environmental protection include sovereignty of a country over the natural resources of its territory;

impossibility of reaching safe environmental situation in one country while the environment of another country is being damaged; and settling of environmental and legal disputes by peaceful means, etc.

Without mentioning the legal and juridical problems of natural resources use in boundary regions, we would like to note that presently the cost of liquidation of adverse consequences from human activity's impacts on the environment (for example, pollution of water resources) is known to considerably exceed the cost of predictive and warning measures.

It should be noted that the problem of assessment of possible and perspective groundwater use in transboundary areas is of great importance for many countries in the world. Moreover, this problem is one of the most weakly studied in hydrology and hydrogeology. The specialists have to answer several important questions, such as: what is the mutual hydrodynamic influence of existed water intakes on groundwater; how much water can be withdrawn from transboundary aquifer by each country without depletion of groundwater resources; is there a danger of aquifer contamination; what are the perspectives of groundwater use in boundary areas of each country and etc. The careful analysis of hydrogeologic and hydrodynamic conditions in boundary zone by specialists from both sides is necessary for solving these problems.

2. OBJECTIVES

Basic problems concerning transboundary aquifers study and use are often tightly connected with each other. These problems are the following (Zektser, 2007):

(1) Quantitative assessment of natural and exploitable groundwater resources of boundary and transboundary aquifers. The method of such regional estimation is developed well enough. It is based chiefly on hydrodynamic calculations, including regional models of groundwater discharges and possible productivity of aquifers and large groundwater well fields;

(2) Determination of chemical, biological and radionuclide compositions of groundwater and an allowable level of its changes;

(3) Estimation of fresh groundwater vulnerability in transboundary aquifers to anthropogenic contamination penetrating from the earth's surface;

(4) Scientific and methodical substantiation of inter-country agreements on allowable limits of groundwater use from transboundary aquifers, including, geoenvironmental aspects, allowable levels of groundwater extraction, a risk of aquifer contamination and depletion;

(5) Development of joint interstate monitoring of transboundary aquifers groundwater use and its protection.

At present the main problem of hydrogeologic investigations in Russia is to develop scientific bases of rational use and forecasting of groundwater resources from transboundary aquifers. The main tasks concerning these problems are the following: to analyze the peculiarities of fresh groundwater formation and distribution in boundary regions of Russia; to develop methodologies for forecasting the rational use of groundwater from transboundary aquifers; to develop principles and criteria of permissible joint groundwater withdrawal from transboundary aquifers considering groundwater protection from contamination and depletion; to develop constant-working mathematical models of groundwater deposits distributed in boundary areas of neighboring states, which aim to determine conditions and values of hydrodynamic flows recharge and discharge; to approbate the models on specific examples in boundary areas between Russia and neighboring countries of the former USSR.

The main tasks of hydrogeological investigations are the following:

- Determination of admissible limits of groundwater extraction in each of boundary countries in order to prevent water resources depletion in neighboring countries.
- Regional estimation of natural groundwater resources of an exploited aquifer.
- Assessment of a groundwater pollution hazard in transboundary aquifers and development of joint recommendations preventing such pollution.

Below the basic tasks of hydrogeological investigations in boundary regions are briefly considered.

3. RESULTS AND DISSCUSSION

3.1. Determination of admissible limits of groundwater extraction in each of boundary countries in order to prevent water reserves depletion in neighboring countries.

In most cases the given matter concerns usually two neighboring countries exploiting the same aquifer for water supply or irrigation. Here, the most important task is to determine the position (sizes) of the depression cone at the current stage of water extraction and at the predicted stage of water withdrawal, taking into account an admissible (by hydrogeological criteria and criteria of environmental protection) level decrease in the aquifer for 25 or 50 years of exploitation.

3.2. Regional estimation of natural groundwater resources of an exploited aquifer

Natural resources characterize the part of water which is continuously being renewed during general water circulation at the expense of infiltrated precipitation, absorbed river runoff and water seepage from other aquifers. Average multi-year groundwater recharge excluding evaporation is equal to a groundwater flow value. Therefore in regional evaluations the natural groundwater resources are often expressed in average annual or minimal groundwater flow modulus. Natural groundwater resources represent the upper limit which determines the productivity of continuously functioning water well fields. The productivity is provided by their natural recharge during an unlimited exploitation period (except water well fields the yields of which are formed from additional reserves involved during exploitation). The methods for regional estimation of average multi-year values of natural groundwater resources are sufficiently well developed and described. These methods are the following: genetic separation of hydrographs of rivers draining groundwater from basic aquifers for a multi-year period; hydrodynamic calculations of flow rates, including modeling; analysis of low water runoff of rivers draining groundwater; water balance and calculation of infiltration recharge of groundwater, etc. Each of these methods has certain advantages and disadvantages. Possibility to use a particular method depends on geological and hydrogeological conditions of a studied territory and availability of reliable factual data. However, all above-mentioned methods have certain advantage. Using these methods it is possible to carry out regional estimation of natural groundwater resources by means of analysis. Also available information can be obtained without conducting special expensive drilling and experimental and filtration works. To determine the prospects of groundwater use, it is important to estimate not only the average annual, but also seasonal (especially minimal) values of groundwater renewal. This can be done by analyzing the multi-year observations of groundwater level regime.

3.3. Assessment of a hazard of groundwater pollution in transboundary aquifers and development of joint recommendations preventing such pollution

Numerous facts show that groundwater pollution is often of regional character. It restricts the possibility and prospects of practical use of fresh groundwater including fresh groundwater in boundary regions. Therefore, the regional assessment and mapping of groundwater protection against pollution in transboundary aquifers become of a great importance in conditions of existing and possible hazards of pollution to groundwater as a source of domestic and drinking water supply. Under “groundwater protection” one should understand the environmental possibility to preserve the composition and quality of groundwater during a predicted period (25 or 50 years), meeting the appropriate requirements of practical water use. The concept opposite to the given one is “groundwater vulnerability” to pollution. This term is widely used in the foreign literature. The higher (better) the protection of groundwater is, the lower is its vulnerability and vice versa.

Two different approaches can be distinguished. The first one is assessment and mapping of groundwater vulnerability on any territory without taking into account the characteristics and properties of particular pollutants. The second one is assessment and mapping of a natural system applied to a particular type of pollution.

The majority of methodologies are based either on qualitative or quantitative analyses of different factors affecting groundwater vulnerability. Usually a degree to which unconfined groundwater or groundwater in the upper confined aquifer is protected is being assessed.

Results of quantitative assessment and mapping of groundwater vulnerability to pollution can be used in the following concepts: development of a strategy for groundwater use and protection in areas with different natural vulnerability; substantiation of plans for location and development of large industrial and agricultural objects with hazardous liquid and hard wastes; hydrogeological substantiation of different water-protective measures; selection of places for accumulation and storage of wastes.

One of the most important practical results of assessment and mapping of groundwater protection is the possibility to compare different territories concerning groundwater protection against pollution and decide which territory is protected better. Assessment and mapping allows to find out where a high risk of pollution of water well fields exploiting groundwater for water supply exists, as well as to learn where water protective measures are primarily necessary.

Geofiltrational models of Russian and Estonian, and Russian and Ukrainian border regions have been developed in recent years in Russia to determine the prospects of transboundary aquifers use. Modelling results are shortly stated below.

3.4. Russian and Estonian border

Russian and Estonian hydrogeologists teamwork resulted in integrated Russian-Estonian geofiltrational model of lomonosovskiy-voronkovskiy aquifer. The model is based on the analysis of available hydro-geological information on the Estonian Republic territories, the Leningrad and Pskov regions of Russia. Water containing formations of this aquifer are presented by quartz sandstones with interbedded clays with total thickness of 30 meters. The thick stratum of loptovskiy clays serves as their upper aquiclude and clays of upper Proterozoic appear as their bottom. This aquifer is subartesian one with pressure value about 100 m. Water levels in wells are established at depths of 15-45 m. The aquifer is maintained in border regions of Russia and Estonia. Three possible variants of development of hydrodynamic situation in Russian and Estonian border area have been considered in the regional model: They are the following: 1) the new water intake in Ivangorod with productivity of 3000 m3 per day is added to the already operating water intakes with existing productivity; 2) water withdrawal from all water intakes on the Russian territory, including the new one in Ivangorod, has increased twice, and Estonian water intakes yields remain constant; 3) Estonian water intakes yields are decreasing twice. As a result the groundwater overflow through Russian-Estonian border under the influence of water withdrawal has been determined to be much lower than their natural discharge through it. Even double decrease in water withdrawal from this aquifer on the Estonian territory will not change the current hydrodynamic conditions. Only the high increase in water intake on Russian territories can change the hydrodynamic situation up to the complete inversion of the natural flow.

Researches of Russian and Estonian transboundary aquifers were the first and almost the only joint work of experts from neighboring countries concerning transboundary groundwater studying. These researches can be an example of the international cooperation on this challenge (Mironova, Molskii, Rumynin, 2006).

3.5. Russian and Ukrainian border

The integrated base of cartographic and factual data for the general mathematical model of transboundary aquifers of Dneprovo-Donetsk artesian basin is created. The model covers the territory of 248×276 km, a grid step is 1 km. Northern part of model includes the Belgorod region of Russia, southern part comprises the Kharkov region of Ukraine. 4 aquifers and three relatively impermeable layers are considered vertically. The basic regional water intake is coincided with the second one which consists of maastriht-turonskiy and alb-senomanskiy aquifers.

On model living conditions the specifications of existence of regional hydrodynamic flow for undisturbed filtration regime have been reproduced. Hydro- and pezoizogips maps for 4 aquifers and a water exchange map between them have been constructed as well. Also the data on balance components have been obtained. Besides, graphic representation of groundwater flows for simulated aquifers concerning state borer is received.

To reproduce the disturbed filtration conditions all existing water intakes of the Belgorod region for the periods of 1970, 1980 and 1990 have been set with prolongation of ten-percentage increase in water withdrawal till 2009.

Maps of levels decrease in exploited aquifers and also tables of certain hydrodynamic balance components on calculated time steps are received.

The analysis of structure of groundwater resistance indicators and their quality for transboundary aquifers of the Dnepr and Don River basins showed that the Dneprovsko-Donetskiy basin is characterized by an high resistance indicator, and the Donetsk basin has extremely low groundwater resistance indicator to anthropogenic impact (Belousova, 2005).

4. CONCLUSIONS

In conclusion, it should be noted that transboundary problems of groundwater development are rather acute for Russia as it has land boundaries with 13 countries. Basic tasks concerning solution of these problems at the current stage are the following: - development of principles and criteria for admissible groundwater extraction by the neighboring countries regarding nature protection restrictions, including groundwater protection against depletion and pollution; - development of constantly functioning models of groundwater fields in boundary regions of neighboring countries in order to determine groundwater balance elements in particular hydrodynamic flows and their interaction with each other and with surface waters both in natural and anthropogenically disturbed conditions; - determination of prospects for joint use of groundwater on the basis of large-scaled assessment and mapping of groundwater safe yield taking into account its protection against pollution.

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Transboundary Aquifers: Challenges and New Directions: Characterisation of a transboundary karst aquifer: the Classical Karst

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ABSTRACT

In the hydrogeological sense the karst aquifer of Classical Karst / Kras is a uniform unit, but politically divided between two countries. The main part of the aquifer is located in Slovenia, but the whole karst coast and the springs area are located in Italy. To understand its functioning and to preserve it properly a close co-operation between experts from both countries is necessary.
Classical Karst / Kras is a limestone plateau of 900 km^2 that extends from SE-NW direction between Brkini hills in Slovenia and Isonzo River in Italy. To understand the functioning of the transboundary karst system many researches were performed in a close co-operation between Italian and Slovene researchers. One of the primary goals was the protection of the aquifer, in which large quantities of groundwater are stored. The springs of the Timavo River are one of the highest-discharge regions in the Mediterranean region (medium discharge of 40 m^3/s, maximum of 175 m^3/s). Close to the springs, on the Slovenian side, groundwater is pumped for the supply of several municipalities. In Italy, the Sardos and Moschenizze Nord springs are still used at present for water supply of Trieste.
The hydrodynamics and chemical characteristics of springs are well known, but there is a lack of informations about autogenic and allogenic recharge. Only few data are available about hydrodynamic behavior within the hydro-structure. For these reasons the spatial hypogean development of the karst phenomena is very unpredictable. Karst voids organization is driven by several aspects: geological and structural settings, climate characteristics, geomorphological context etc. Due to the high heterogeneity of the underground karstification is still very complex to model the groundwater circulation, to define the underground karstification development and the karst voids connection especially in a mature karst.

Key words: hydrogeology, karst aquifer, karst waters management, transboundary groundwaters monitoring, Classical Karst / Kras

1. INTRODUCTION

1.1. The Classical Karst

Classical Karst / Kras is a limestone plateau of 900 km^2 that extends NW - SE 50 km long from the Isonzo River to Brkini hills near Skocjan (Slovenia). It is 15 - 20 km wide, gentle dipping toward NW from 550 m asl in Postojna and 450 m a.s.l. in Skocjan (Slovenia) to the sea level (Timavo Springs in Italy).

The plateau is mainly composed by carbonate rocks of Cretaceous to Eocene in age, which make up the so-called Comeno / Komen Unit (Placer, 1981, Cucchi et al, 1987), an important geological-structural unit involved in the Dinaric Alpine crustal shortening. The structure is a large anticline with a NW-SE axis. The northern side, where another important, Trnovo Unit (Placer, 1981) thrusts, has mild inclination and is affected by several reverse faults with a strike-slip character parallel to the axis. The southern side, has an inclination that gradually increases towards the SE as the Unit trhusts on another (the Ciceria plateau) through a series of low angle trhusts. The thickness of the sedimentary sequence is up to few thousand meters: the origin is carbonate, the top is a siliciclastic turbidite. The plateau can be considered as a carbonate prism, more or less karstified, confined at the top and at the side by impermeable formations not karstified. The state border cuts the plateau leaving in Italy about 200 km^2 with almost the all springs area, and in Slovenia, in the remaining 700 km^2, the wider and more developed sinkholes and dolines.

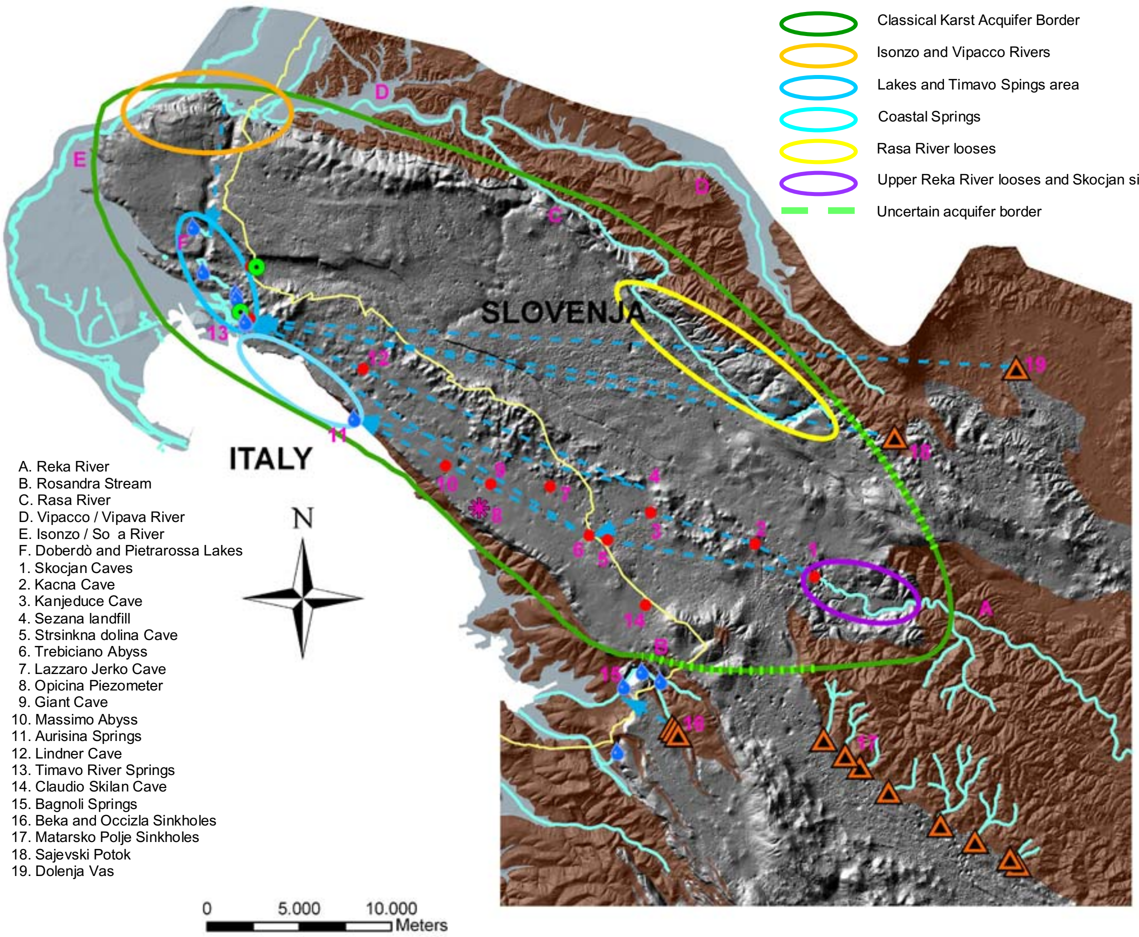

Figure 1: Hydrogeological map of the area. Limestone in grey; flysch in brown; green points are water supplies; blue drops are springs; triangles are sinkholes; red points are caves; asterisk is the deep piezometer; dotted blue lines are verified water connections by tracers.

1.2. The Classical Karst aquifer

The average rainfall in the Classical Karst and in the Vipacco / Vipava watershed varies from 1000mm/y along the coast to about 1800 mm/y in the hinterland. At this rate of rainfall corresponds an average evapotraspiration rate varying from 450 to 750 mm. Reka watershed has an average rainfall of about 2000-2600 mm/y, higher values of rainfall are typical of Isonzo mountain basin in which prevail rates of 2000 mm/y with wide areas at even higher rates of 3200 mm/y.

The corresponding hydrogeological model recognize, in principles, three zones with a hydrogeological significance:

1. transfer zone from epigean to hypogean flow, where water from non karstic valleys sinks underground;

2. the Karst Plateau. Allogenic water flows deep below the surface along well karstified epiphreatic phreatic zone. The autogenic water fron precipitation passess up to 400 m thick vadose zone to reach the level of groundwater;

3. the spring area where waters comes to light and flow to the sea. This last zone correspond to an area rich in lakes and springs, including Timavo Springs.

The first zone is fed by the water belonging to the superficial Notranjska Reka (upper Timavo River), Isonzo / Soča and Vipacco / Vipava Rivers watershed. The Reka (about 330 km^2 of watershed), was born on the Mt. Dletvo slopes at the border between Slovenia and Croatia, and flows for about 40 km on marly arenaceous sediments until Škocjan where it sink into a magnificent complex of underground channels of the Škocjan cave system, a natural monument nowadays in the list of UNESCO World Heritage. The mean discharge evaluated 8 km upstream the sinkhole (hydrometric station of Cerkvenikov Mlin) in the time interval 1961-1990 is reported to be 8,26 m^3s^{-1}, with a minimum (18.08.1988) of 0,18 m^3s^{-1} and a maximum value (16.05.1972) of 305 m^3s^{-1} (Environmental Agency of the Republic of Slovenia, 2010).

Isonzo / Soča River watershed is large (about 1600 km^2 in Slovenia) and articulated (the main channel extends approximately 100 km) with abundant water due to the high rainfall. The average discharge (data coming from the hydrometric station of Solkan) in the time interval 1961-1990 is reported to be 95,5 m^3s^{-1}, with a minimum (30.10.1985) of 5,58 m^3s^{-1} and a maximum value (1.11.1990) of 2134 m^3s^{-1}.

Vipacco / Vipava watershed is less extensive (about 594 km^2) and has less water supply. The average discharge (hydrometric station of Miren) in the time interval 1961-1990 is reported to be 17,9 m^3s^{-1}, with a minimum (12.09.1954) of 1,15 m^3s^{-1} and a maximum value (28.09.1965) of 353 m^3s^{-1} and it is largely fed in turn by karst springs placed at the foot of the Trnovski Gozd plateau (Environmental Agency of the Republic of Slovenia, 2010).

Side losses that feed the karst aquifer in the Isonzo River sector mainly occur along a dozen kilometres long section, just downstream from the confluence with Vipacco / Vipava River: from a quantitative point of view, the sinkholes should contribute at least 10 m^3s^{-1} to the karst system.

The second sector is the Classical Karst that contains, what is generally called, the hypogean Timavo net, that surely has an articulated development, with several drainage ways and with frequent changes in direction of the main outflow.

This is an intensely karstified area characterized by the high density of caves and surface karst morphotypes. In the limited area of the Italian Karst (about 200 km^2) there are over than 3500 known caves (of which over 150 have a development for more than a hundred meters and a dozen develops for a thousand meters), 80 sinkholes more than 100 meters wide, and limestone pavements with total surface area of several km^2.

The hypogean Timavo course should have a development of 70-80 km, with frequent changes of direction in the preferential flows. The travel time under high water level conditions, is about two days.

During the low and mean water conditions the water table is at altitude of 2 - 5 m a.s.l. at the headwater area of Monfalcone – Jamiano – Sistiana (Ita), at 12 – 13 m in the Prosecco (Ita) – Sesana (Slo) area and at about 150 – 190 m in the Kačna Jama at Divaca (Slo). The surface of the water table is irregular due to high differences in hydraulic conduictivity. During the periods of high water level the amplitude in the epiphreatic zone is, as said, variable, not only depending from the extend and type of high water level power, but also depending on the speed side transmission pulse. It is not said, in fact, that the gaps are sufficiently continuous, connected and wide to allow the whole hypogean volume to always be completely filled. The water in Trebiciano abyss rises up to 110m a.s.l. Similar level rise and dynamics is observed also in Lazzaro Jerko cave, Strsinkna dolina cave and Kanjaduce cave. In the upper caves, Kačna and Skocjan, the level is controlled by local restrictions and therefore exibit different dynamics. High fluctations of water level are present in Massimo abyss and in the Linder cave.

The third sector corresponds to the spring system of Timavo at San Giovanni di Duino, from Doberdò and Pietrarossa lakes, from the springs that feed Lisert and Moschenizze channels (an area of about 30 km^2), from the marine-coastal springs scattered along about 8 km of the coast of the Trieste Gulf. These are waters coming from different watershed but hydraulically interconnected, with an estimated total average discharge of 40 m^3s^{-1}, and a maxima up to 175 m^3s^{-1}. At San Giovanni di Duino, Timavo springs consist of four pools collected in three "brances": their average discharge is about 35 m^3s^{-1}, with a minimum of 10 m^3s^{-1} and a maximum of 150 m^3s^{-1}. Speleologists investigations revealed a well developed complex caves system explored to -83 m below the sea level and total length of more than 1500 m. Two pumping station used for the water supply are positioned in this sector: the Klariči pumping station, used for the water supply on Slovenian side and the one for Trieste aqueduct (Randaccio station) that uptakes the waters from three springs (Sardos, Timavo and Moschenizze Nord).

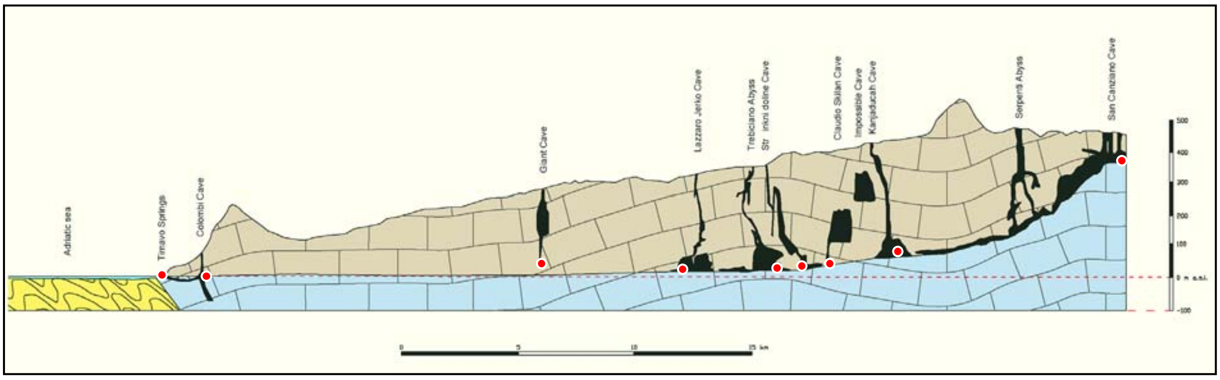

Figure 2: Simplified cross-section of the Classical Karst aquifer. Flysch in yellow; limestone in grey; caves in black; water in pale blue; red points are monitoring stations.

2. RESULTS

The Geosciences Department and the Park Skocjanske Jame with the collaboration of Karst Research Institute realized a continuous monitoring network to study the water dynamics by placing sensors at the sinkhole, in several caves and at the uptake works. The monitoring network is shared, since the involved subjects are exchanging the data measured in the respective studied areas. Are measured in continuum discharges/levels, conductivity and temperature.

The data analysis highlights the circulation complexity inside the hydrostructure: during the flood the flow is conditioned by the Reka River regime while, during low-water, the circulation is more influenced by the infiltration due to the rainfall and from the Isonzo River contribution. The circuit connecting Skocjan cave with Timavo springs is characterized by a series of large pipes that allow the flood impulse transfer within 1-3 days.

The monitoring carried out showed that during the floods the most part of the circuits are under pressure and only a comparative analysis for levels and conductivity permits to correctly evaluate the water transit times. Infact, if the rising water level in the caves is simultaneous due to the increasing hydraulic load upstream, the changes in conductivity are different from site to site and allow to intercept the incoming flooding water and to estimate correctly the propagation water velocity (Fig. 3 and 4).

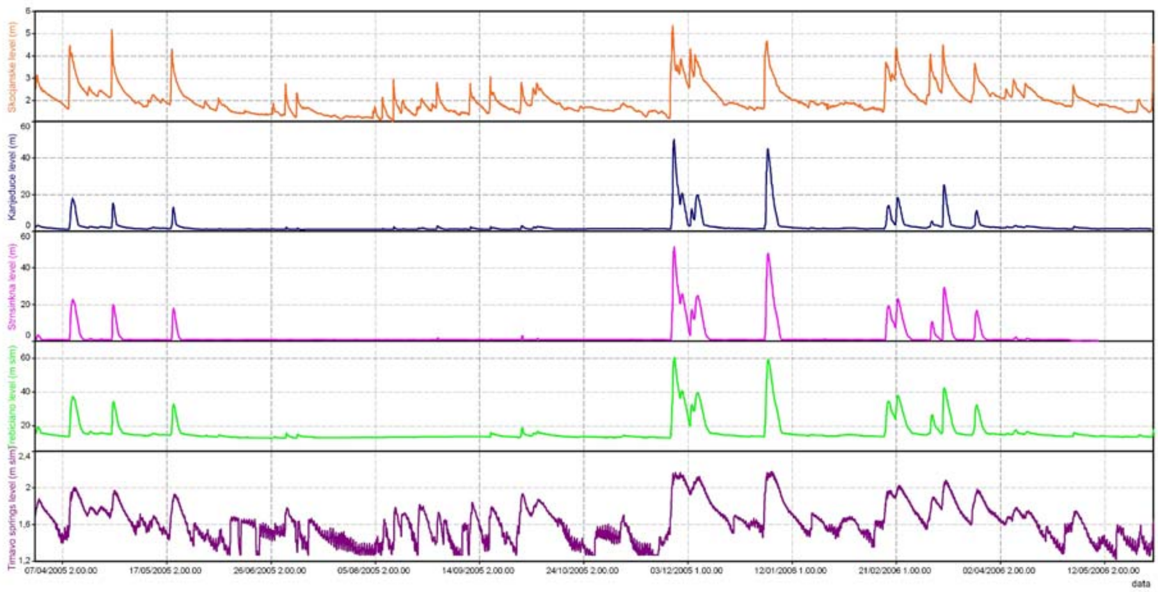

Figure 3: Water level in Škocjan cave (orange), Kanjaduce cave (blue), Stršinkna cave (magenta), Trebiciano abyss (green) and Timavo springs (violet).

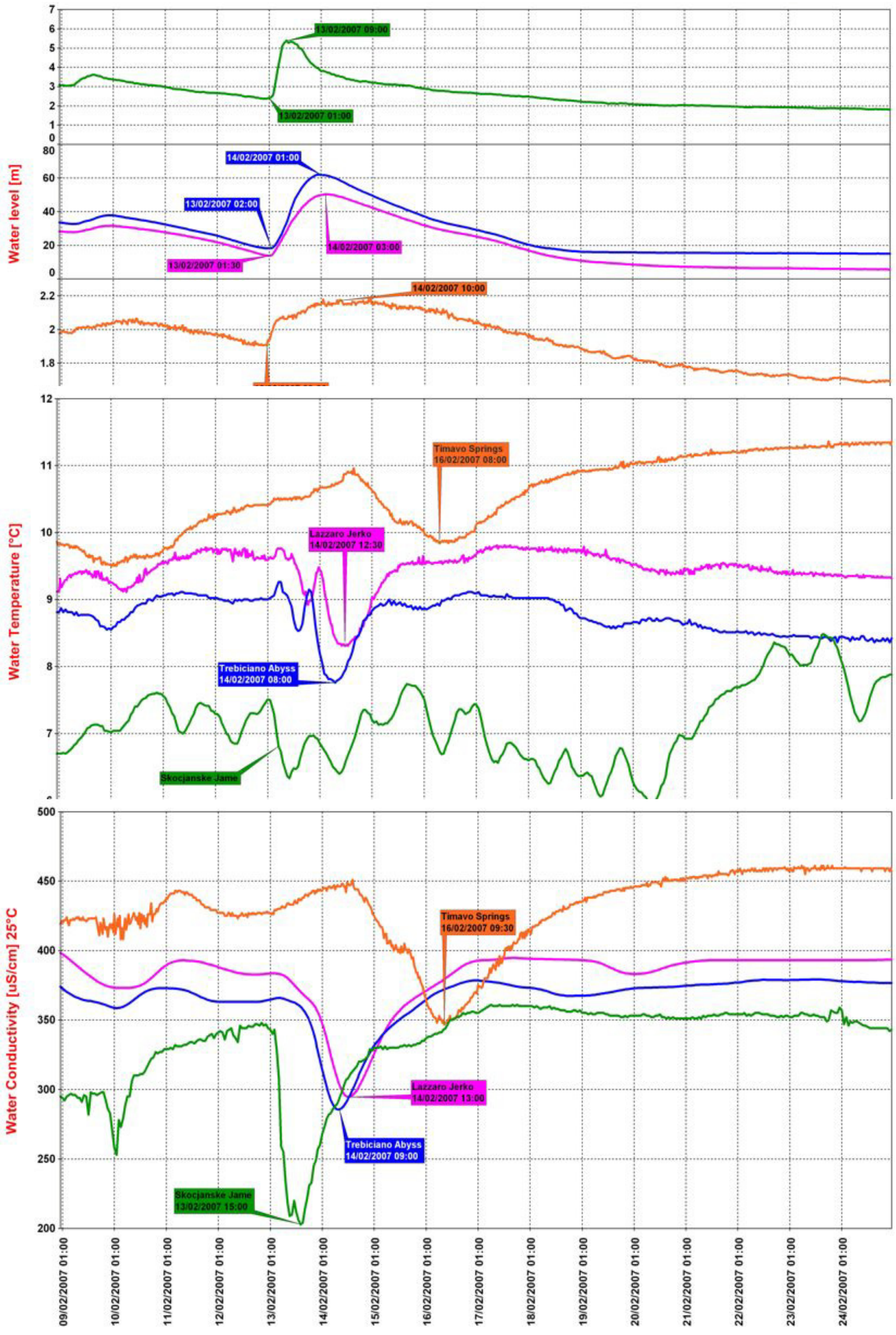

Figure 4 Water monitoring (level, water temperature and conductivity) in Škocjan cave (green), Trebiciano abyss (blue), Lazzaro Jerko cave (magenta) and Timavo springs (orange).

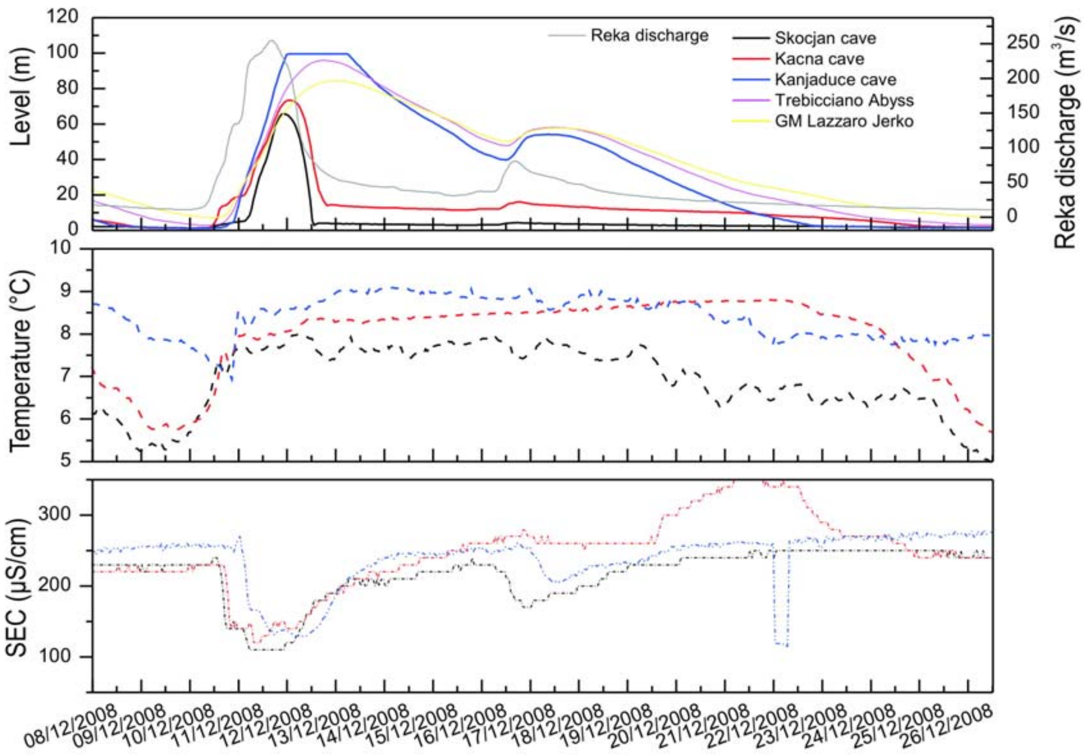

Figure 5 Level, water temperature and conductivity in Škocjan cave, Kacna cave, Kaniaduce cave, Trebiciano abyss, Lazzaro Yerko cave, during highest flood pulse in December 2008.

Different is the northern sector - Iamiano (Ita) and Miren (Slo) where the circulation is dispersed and lower flows are underlined. The beginning of the floods is often delayed compared to the outfall and it is partially due to the water tamponage coming from the Reka – Timavo circuit.

3. CONCLUSIONS

Classical Karst waters have for a long time been a strategic resource for the economical and social development of this region. In the springs area are located the uptake works for the Slovenian (Klariči station 250 l/s) and Trieste aqueducts (Sardos and Moschenizze Nord springs about 250 l/s) are located. The water quality is good, and the amount of the reserve is high, but as highlighted by the monitoring surveys and the tracing tests, is a highly vulnerable resource.

The last tracing test performed near a landfill close to Sežana in Slovenia (n. 4 in figure 1) showed up an increasing in karst permeability and the lack of protection afforded by the unsaturated zone. (Kogovšek J. & Petrič M. 2007). Only 12 days after the injection, the tracer was detected at the Timavo springs and 31 days after at the Aurisina springs. During floods, pollution from Reka river can reach the springs in 2-3 days.

In the last years, thanks to the fall of borders, the urbanization in the Karst area has increased a lot with a growth of commercial and industrial activities.

The risk of pollution is rising, but real collaboration between the Italian and Slovenian institutions in order to define the security zones to protect the Classical Karst aquifer has not yet started. A policy border that secures the resource that is essential for any future development for the aquifer protection is still missing.

Instead, the researchers from the two countries are already collaborating, as highlighted in the present paper, creating the first concrete step to increase the knowledge to protect the territory.

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TOPIC 2
Managing transboundary aquifers: challenges and opportunities

Sustainable Development of Non-renewable Transboundary Groundwater: Strategic planning and strategic alternatives for the Nubian sandstone aquifer system

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ABSTRACT

The sustainable development of a resource that will be surely depleted is an extremely challenging process. The sustainable development in that case refers to prolonging the use of such resource as much as possible by applying relevant management tools and measures. Much complexity is added when the non-renewable aquifer of interest is shared between different countries. The unwritten rule of shared resources will then be applied. The rule entails that what is left today will not necessarily be saved for tomorrow, but will be exploited by other partners.

The Nubian Sandstone Aquifer System (NSAS) is a good example of a transboundary non-renewable aquifer with motivated riparians. Egypt, Libya, Sudan, and Chad have shown much interest in cooperation and have responded positively to many initiatives.

The authors have previously studied different scenarios for the safe future utilization of NSAS in Egypt. This study focuses on the four riparian countries altogether. Scenarios will be drawn based on the developmental needs of all countries. A total management plan can then be proposed. The optimum management plan to achieve the maximum possible sustainability of NSAS could be divided into two main parallel axes, the first is decreasing the consumption, and the second is recharging the aquifer. As for decreasing the consumption, among all water use sectors, the domestic sector in all four countries has the highest priority; it should be the only sector using abstracted fossil groundwater. Other sectors can rely on other water sources such as treated waste water which appears to be the most affordable option to NSAS countries or desalinated water. Using treated waste water in agriculture will make a significant difference towards sustainability, as the agricultural sector is usually the highest consumer.

The future development plan for NSAS will clearly identify its life expectancy and accordingly, the maximum yearly drawdown. Alternative plans on utilizing other water resources such as seawater desalination will be set up and ready for execution before the end of the aquifer's life expectancy.

Keywords: Transboundary, Nubian Aquifer, Fossil Groundwater, Non-Renewable, Sustainable Development.

1. THE AQUIFER AND THE RIPARIANS

1.1. Introduction

The Nubian Sandstone Aquifer System (NSAS) is a transboundary groundwater basin in the North Eastern Sahara of Africa (Fig.1). The international waters of this regional aquifer are non-renewable and shared between Chad, Egypt, Libya and Sudan. The area occupied by the Aquifer System is 2.2 million square km; 828,000 square km in Egypt, 760,000 square km in Libya, 376,000 square km in Sudan, and 235,000 square km in Northern Chad. The volume in storage represents the largest freshwater mass in the whole world. The total recoverable volume of about 15000 cubic kilometers was assessed based on 100m drawdown in the unconfined aquifer and 200m drawdown in the confined aquifer (AbuZeid, 2003).

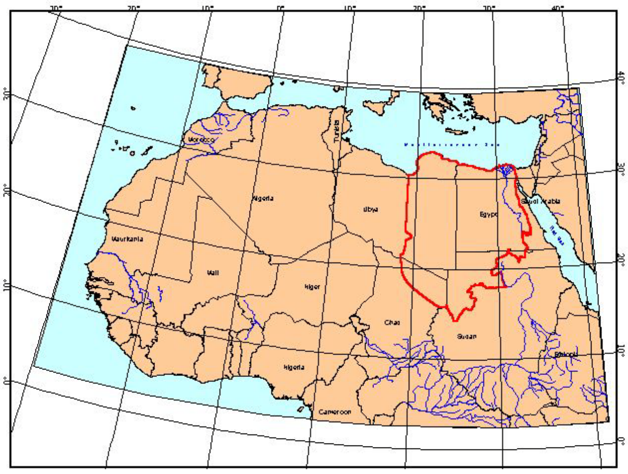

Fig.1 Location of NSAS

The increasing demographic growth and the lack of renewable water resources in this arid region have resulted in an increasing attention to the groundwater potential represented by the NSAS (AbuZeid, 2003)

The four countries sharing the NSAS represented by their National Coordinators adapted a regional information network aiming for cooperation and knowledge exchange in order to achieve the best scenario for sustainable development, and agreed to continue the monitoring of the aquifer through a mechanism specified in two agreements. Regional thematic maps, regional mathematical model, and a regional information system were developed. Also, a regional strategy was developed based on extensive data collection and Numerical Modeling (CEDARE, 2002). Throughout the regional programme as well, the role of the Joint Authority for the Study and Development of the NSAS was revitalized. The countries agreed to update the information by continuous monitoring and sharing of the following information; Yearly extraction in every extraction site, Representative Electrical Conductivity measurements (EC), and water level measurements (AbuZeid, 2002).

Information about the NSAS in Chad is limited (IAEA, 2010). It is well known that the agricultural sector provides the life blood of almost the entire population with livestock farming being the second most popular activity (WRI, 2009).

Being under severe water pressure, Egypt has realized the importance of expanding development to the desert since the mid seventies. The NSAS is the only source that can replace the Nile River. However, the sustainability of utilising the NSAS is highly questionable as fossil water could not be a reliable water source for new settlers. A scheme that involves conjunctive use of Nile Water and NSAS water would sound more reasonable, especially if other non-conventional water sources are utilised such as treated waste water.

Revenues from oil exploration and abstraction projects greatly helped the Libyan government to invest in water investigations which lead to the establishment of the biggest groundwater conveyance system in the world. The "Great man-made river" has cost Libya no less than 30 billion USD. The Project will eventually convey over six million CM of water per day from the Sahara Desert to coastal population centers including the capital Tripoli. (IAEA, 2010)

The cultivable area in Sudan is estimated at about 105 million hectares which accounts to about 42 percent of the total country area, however, in 2002 the cultivated land was 16.65 million hectares which only accounts to 7 percent of the total country area and 16 percent of the cultivable area (WRI, 2010). As in the case of Egypt, the Nile has also become a strained water resource, in light of the country´s growing human populations and migrations of younger generations from rural to urban areas. To the north of the country, life is confined to the narrow, low areas adjacent to the Nile. Government policy has called for increased wheat production in the two northern states which has further strained limited water resources there. The NSAS area in Sudan is predominantly desert in the north and central parts changing to semi-desert in the south. It has a population size of about 285 000 people with 77% living in North Darfur State and the rest in the Northern State. Development policy has called on increased exploitation of the NSAS which has recently been fuelled by the country´s strong oil revenue base (IAEA, 2010).

1.2. Objectives

The main objective of this paper is to draw variable scenarios for the four riparian countries to utilize NSAS sustainably. The sustainable development of a resource that will be surely depleted is an extremely challenging process. The sustainable development in that case refers to prolonging the use of such resource as much as possible by applying relevant management tools and measures.

All scenarios will have the year 2010 as a base year and a starting point for calculations. Population data for the year 2010 were acquired from the Egyptian population clock, Chadian census, Sudanese census, and the 2008 UN population estimate for the year 2010. Annual growth rates were taken from recent World Bank assessments. Other Water Resources related data were acquired from FAO AQUASTAT database.

The recoverable volume for each country was assumed to correspond to the NSAS area included in each country. Table 1 shows some of the important and assumed data that will influence the scenarios build-up.

Country	Population	Population Growth rate (%)	Total Area (km^2)	Aquifer Area (km^2)	Cultivated area (km^2)	Recoverable Volume (CM)	Annual Renewable Water Resources per capita (CM)
Chad	11,274,106	2.7	1,284,000	100,000	43,300	6.38298E+11	3940
Egypt	78,826,000	1.82	1,001,450	850,000	35,380	5.42553E+12	702.8
Libya	6,546,000	2.01	1,759,540	650,000	20,500	4.14894E+12	95.33
Sudan	39,154,490	2.24	2,505,810	750,000	195,460	4.78723E+12	1560

Table 1 Basic data and assumptions

2. UTILIZATION SCENARIOS

The first scenario will work on securing all future population needs in the four riparian countries; the water poverty index has been set at 1000 cubic meters per capita per year. Table 1 shows that Egypt and Libya are well under the water poverty limit. In an imaginary scenario, fulfilling 1000 cubic meters per capita per year will have different effects on the aquifer's sustainability for the four different countries as countries with highest populations will be affected the most as shown in table 2a. There are so many reasons that make the previous scenario un-realistic, a country like Libya has always accommodated its development plans to 95 CM/ Capita/ year, a sudden increase to 1000 CM/ year will be too drastic. Chad will not benefit from this scenario at all as they are already well over the water poverty index. Also, relying on NSAS alone for securing future needs is not practical, given the fact that it will always be a temporary water source.

Therefore, reducing the annual per capita share to 500 will be a reasonable compromise to the first scenario, the NSAS sustainability for each country is shown in Table 2b.

Under the assumption that 80% of the abstracted water will be used for new agricultural development, Fig.2 shows the new cultivated land in each country during the years in which the NSAS is exploitable.

Country	Sustainability(end year)
Egypt	2054
Libya	2141
Chad	2044
Sudan	2068

Table 2a Scenario 1 (1000 CM/Capita/year)

Country	Sustainability(end year)
Egypt	2079
Libya	2174
Chad	2062
Sudan	2093

Table 2b Scenario 2 (500 CM/Capita/year)

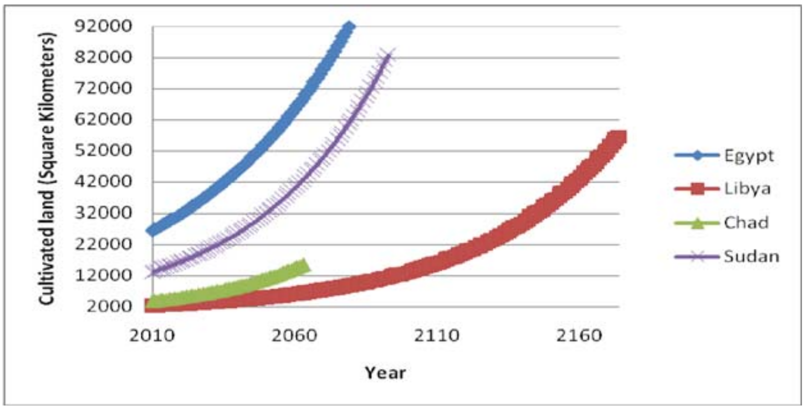

Fig.2 New Cultivated land according to Scenario 1

While the first scenario honoured agriculture as the main activity in the four NSAS countries, the second scenario will assume that industry will be the main activity of future generations in these countries. Therefore, the per capita share of water to be exploited from NSAS is 150 CM in the second scenario, which covers the municipal needs as well as the industrial needs. Agriculture will be a secondary activity that will depend on treated wastewater, in other words, NSAS water will be used by the municipal and industrial sector and then reused by the agricultural sector. Table 3 shows the sustainability that could be achieved through the second scenario, while Fig.3 shows the new cultivated land in each country during the years in which the NSAS is exploitable

Country	Sustainability(end year)
Egypt	2132
Libya	2233
Chad	2099
Sudan	2142

Table 3 Scenario 2 (150 CM/Capita/year)

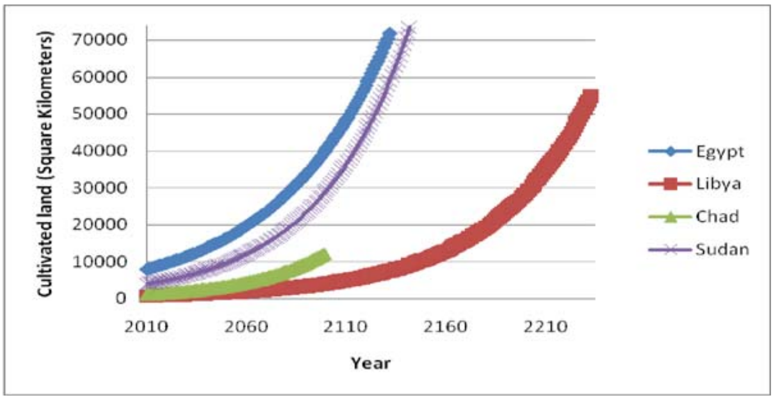

Fig.3 New Cultivated land according to Scenario 2

The third and last scenario will follow the same concept of the second scenario which is prioritizing municipal and industrial water needs; however, it will not be utilized for the sake of the whole country population as in the previous two scenarios, it will rather be exploited for a target population. As commonly practiced by transboundary water resources law experts, dependency will be the main criterion for selecting the target population in each country.

In Egypt, the western desert is the place that will most likely depend on NSAS in the near future as it is isolated from other water sources. In Sudan and Chad, picking a target population is an easier task as the aquifer only bounds the Northern part of both countries as shown in Fig.1. The aquifer occupies the areas of least population density in Sudan which gets as low as 1 capita per square kilometre. Whereas in Chad, the aquifer occupies a troubled area, the northern Borkou-Ennedi-Tibesti region is characterized by the presence of un-cleared minefields and significant rebel activities. Even though the Chad/Sudan border is open to overland traffic, it is not currently advisable to travel on the main route from Chad into Western Sudan, which is a huge obstacle to development. The unstable security situation in Darfur is has significantly added its toll to the problem. However, the third scenario assumes that future conditions will be more suitable for development in the NSAS area.

Libya will be the only exception in this scenario, as the dependency criterion set above entails that the whole population is the target population. In the other three countries, it will be assumed that the annual population increase will immigrate to the new communities, 150 cubic meters per capita will be exploited for the municipal and industrial sectors, and the resulting waste water will be treated and used for agriculture. Table 4 shows the sustainability achieved under scenario 3 while Fig. 4 shows the new cultivated land under the same scenario.

Country	Sustainability(end year)
Egypt	2348
Libya	2233
Chad	2231
Sudan	2311

Table 4 Scenario 3(new communities) (150 CM/Capita/year)

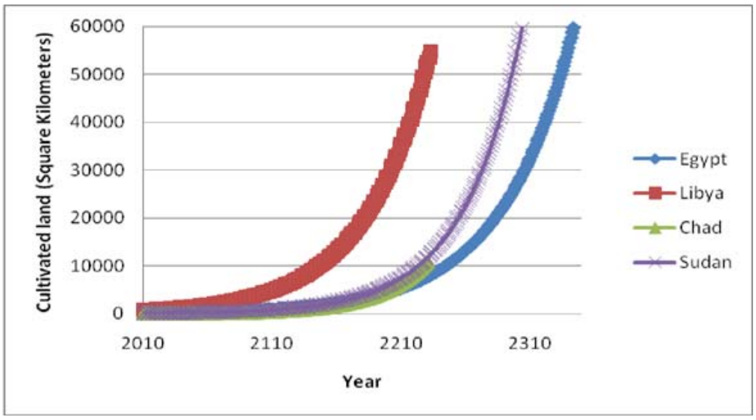

Fig.4 New Cultivated land according to Scenario 3

3. CONCLUSIONS AND RECOMMENDATIONS

Three scenarios have been presented in this study, the main difference between the first two scenarios considered the whole population of the four NSAS riparian countries with the main activity being agriculture and industry respectively. The third scenario supports the formation of new communities in all countries; it also supports prioritizing the municipal and industrial sectors among all other sectors.

Scenario 3 is favoured and recommended as it has the highest sustainability as shown in tables 2 through 4. It seems to be the best optimized solution for the four NSAS country as each country will gain at least one benefit. The Libyans will get 150 CM/capita/year which is a reasonable amount for a country that gets as low as 95 CM/ capita/ year of renewable water resources, Libya was also given an advantage over other countries due their existing dependence on NSAS. This scenario will also help a large area in Egypt in refraining from relying on the Nile River water for a considerable amount of time that is long enough to think of future alternatives after NSAS ceases to exist. Sudan and Chad will revitalize their northern parts in a manner that can possibly enhance trade and other bilateral activities.

An important question that needs to be answered is what will happen after the end years of scenario 3. For Libya and Egypt, expansion in sea-water desalination seems to be the immediate solution, however, it takes huge funds to convey desalinated water from the northern Mediterranean shore to the South of both countries, and therefore, revenues from the new industrial community should be allocated for such future plans. The problem of "What happens next?" is less complicated in Sudan and Chad as they are not water stressed countries, however, expanding in waste water treatment may do both countries good as a water scarcity shelter.

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Water Resources and Management Issues

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ABSTRACT

The Gaza Strip is located on the extreme edge of the shallow coastal aquifer that borders the eastern Mediterranean Sea. There is little rainfall and no reliable riparian flow; hence water supply for Gaza residents is limited to that available from the part of the coastal aquifer. The exploitation of the coastal aquifer has resulted in continuous lowering of regional water levels and the worsening of water quality. The greatest threats to existing water supplies are seawater intrusions and up coning of deep brine fossil water. There are serious water quality problems in the Gaza Strip's Aquifer. The population of the Gaza Strip will grow to over two million by 2020, and the demands for water will far exceed the sustainable capacity of the aquifer. Continuous urban and industrial growth will place additional stress on the aquifer system, unless appropriate integrated planning and management actions are instituted immediately. It is evident that drastic action must be taken quickly to support its people in the future. This paper presents overall guidelines for the management through year 2020, with associated investment requirements for infrastructure facilities to meet all goals and objectives. It has been estimated that a capital investment program of about US$1.5 billion is needed to finance the implementation of such plan. It has been concluded that seawater desalination as well as brackish water desalination are the main components of the domestic water management plan that will have overall beneficial impacts on the socioeconomic aspects in addition to protecting people lives in Gaza.

Keywords: groundwater**,** water demand, resources management, desalination, water supply.

1. INTRODUCTION

The Gaza Strip is a very small area of land with a total area of only 360 km2. It is underlain by a shallow aquifer, which is contiguous with the Israeli Coastal Aquifer to the north. See fig.1. Gaza is the downstream user of the Coastal Aquifer system, and hence water abstraction in Gaza does not affect Israeli water supplies. The Gaza Aquifer has a natural recharge rate of approximately 65 million cubic metres (MCM) of water per year from rainfall and lateral inflow of water from Israel and Egypt (CAMP, 2000).

This aquifer is essentially the only source of fresh water in the Gaza Strip. By 1967, when Israel occupied Gaza, the sustainable yield of the aquifer was being fully utilized (Nasser, 2003). Since then, as the population has grown, so too has the demand for fresh water. No serious attempt was made at exercising any water management strategy in the Gaza Strip during the Israeli administration, with the number of registered wells increasing from 1200 in 1967 to 2100 in 1993 (Nasser, 2003). Abstraction from the aquifer was approximately 110 MCM per year by 1993, resulting in falling water levels and degrading water quality due to seawater infiltration, caused by the over-pumping that had been taking place. Likewise, there was little investment in maintaining or improving the deteriorating water infrastructures of Palestinian municipalities during this period, despite taxes being paid by Palestinians to the Israeli government (World Bank, 1993).

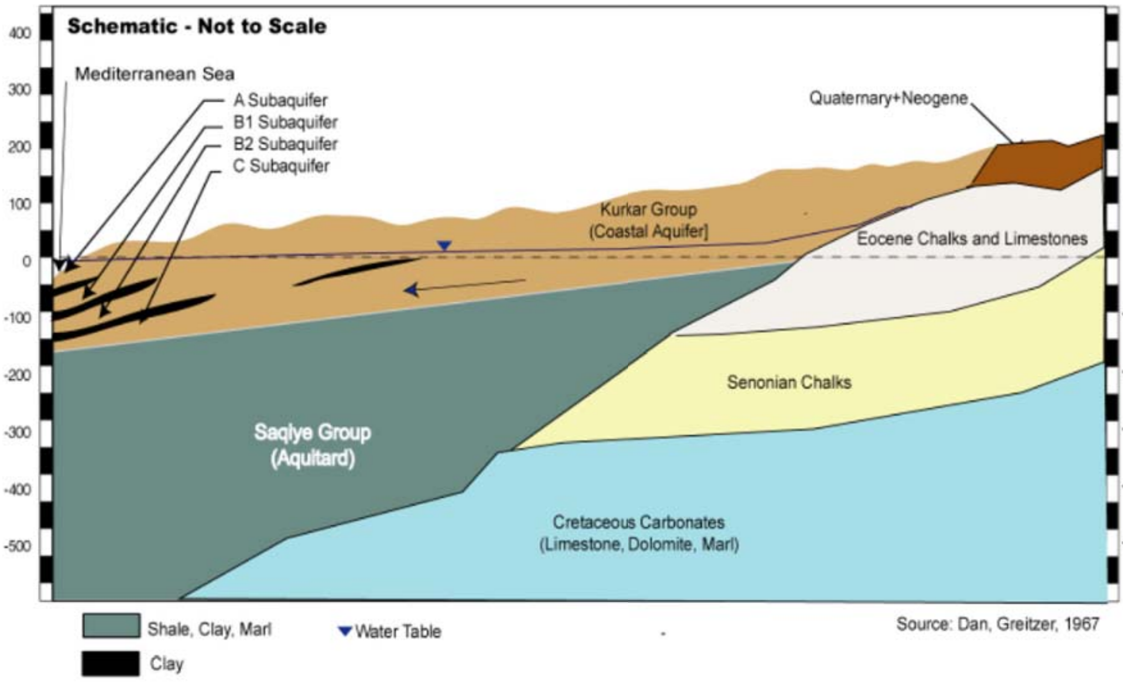

Fig.1: Schematic hydro geological cross section of Gaza aquifer

2. WATER RESOURCES

Gaza has a sub-Aquifer, which is a part of the Coastal Aquifer that lies along the Mediterranean coastline of Israel and the Gaza Strip. Studies of the Palestinian Water Authority (PWA) show the people of Gaza over abstract (over-pump) between 180-190 million cubic meters (MCM) of water from the coastal aquifer per year, but the natural (such as rainwater) and anthropogenic (agricultural return flow and waste water) replenishments between 110 – 140 MCM/yr. These figures reveal that Gaza has a current water deficit of approximately 50-80 MCM/yr.

In addition, population density determines how much water is needed within a geopolitical area, even if the hydro-geological and topographical landscape does not have the natural resource capacity to satisfy the number of people living there. The Gaza Strip is also one of the most densely populated areas in the world and there are approximately 4,300 people per square km.

With a growing population expected to exceed 2.1 million by end-2020, there will be over 5,800 people per square km. As a result of population increases the water deficit will be more exacerbated if more water and resource infrastructure are not in effect within the next years.

3. WATER CONSUMPTION AND DEMAND

The present situation concerning water availability and quality in Gaza is little short of catastrophic. As a result of such concerns the water situation in Gaza has been recognized for some years as a critically important issue, but the situation continues to worsen inexorably over time.

Although the World Health Organization (WHO) calls for minimal water consumption of 100 liters per capita per day (l/c/d) for a quality level of health; PWA shared that Palestinians average 70-80 liters (l/c/d) see fig.2. Moreover, Israeli capita usage averages 400 l/d and Israel settlers in the Palestinian Occupied Territories average 800 l/c/d. Thus, Israelis average almost five times more water consumption than Palestinians.

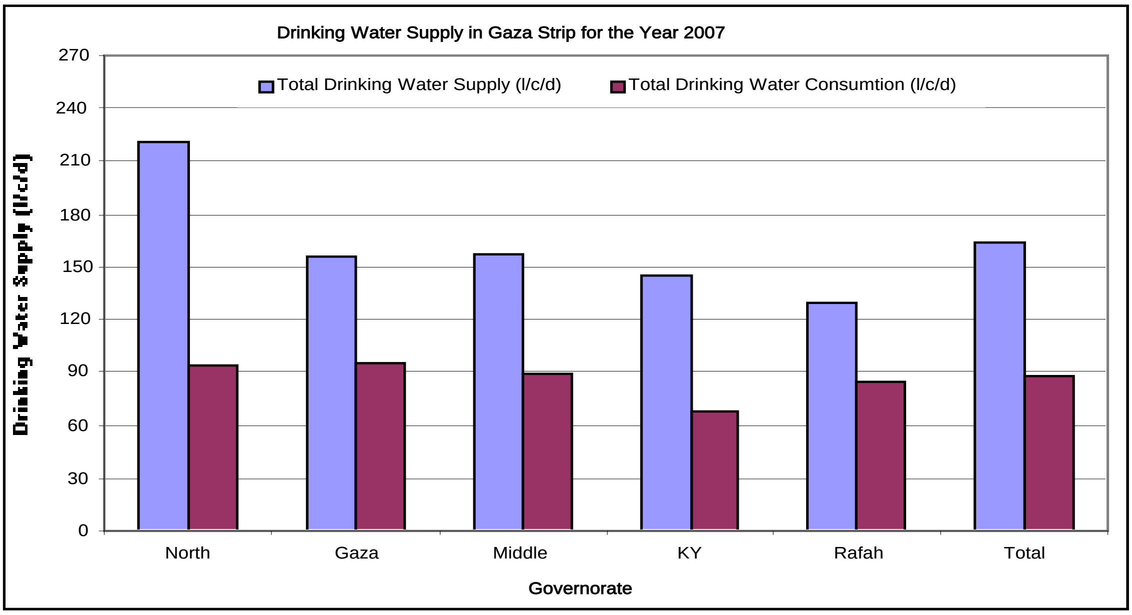

Fig.2: Drinking water supply and consumption in Gaza Strip

For the 1.5 million Palestinians living in Gaza Strip they consume approximately 190 MCM/yr; and this figure includes domestic, agricultural and industrial consumption. However, 6.4 million Israelis have a total water consumption of 2,129 MCM/yr.

A large groundwater aquifer basin underlies the West Bank and supplies high quality water to both Israelis and Palestinians. It is composed of three sub aquifers: the Western, the Eastern and the North-eastern Aquifer Basins. Since Israel controls the water, they allow Palestinians in the West Bank 114 MCM/yr only -- they have to purchase another 30-40 MCM/yr for the West Bankers and 4 MCM/yr for Gazans from Mekorot, the Israeli water company.

In Gaza, Palestinians consume roughly 190 MCM/yr of which around 70 MCM is due to over abstraction of the Gaza Aquifer. The Palestinians are over-pumping the aquifer through around 6,000 wells within the Gaza Strip. Although most of the wells are used for agricultural purposes, there are 4,000 illegal wells. Moreover, illegal wells drains the already stressed aquifer.

4. How is the exploitation of the water table affecting the Coastal Aquifer?

It is increasing the rate at which saline ground water naturally flows from the eastern part of the Coastal Aquifer toward Gaza, which is salinizing the freshwater in the western part of the aquifer at an accelerated pace, see fig.3. Moreover the study concluded: If pumping continues at these unsustainable rates, it will destroy the aquifer's capacity to resist sea water intrusion from the west and saline ground water from the east, thereby making it totally unsuitable for human consumption or for irrigated agriculture with the next few decades.

The exploitation of the aquifer has damaged the water's quality already. One can say that 90 per cent of the aquifer's water is brackish water: saline water due to over-abstraction.

Unfortunately, as there is no alternative, people in Gaza are drinking this water and they are experiencing health problems.

5. WATER QUALITY AND ITS IMPACTS ON HUMAN HEALTH

WHO established international standards for salt levels of chemical compounds in water, such as nitrate and chloride. For safe and healthy human consumption of drinking water these concentrations can not exceed the WHO guidelines. For nitrate, the WHO standard is 50 mg/l and for chloride it is 250 mg/l. The Gaza aquifer has nitrate levels over 100 mg/l and chloride levels averaging 1000 mg/l. Therefore, these unsafe levels are affecting the health of Palestinians, see fig. 5&6.

The health problems are: 50 per cent of Gaza's children have a parasitic infection; children and adults suffer from diarrhea; high chloride levels causes kidney disease; consumption of saline water leads to salt levels in humans that causes kidney

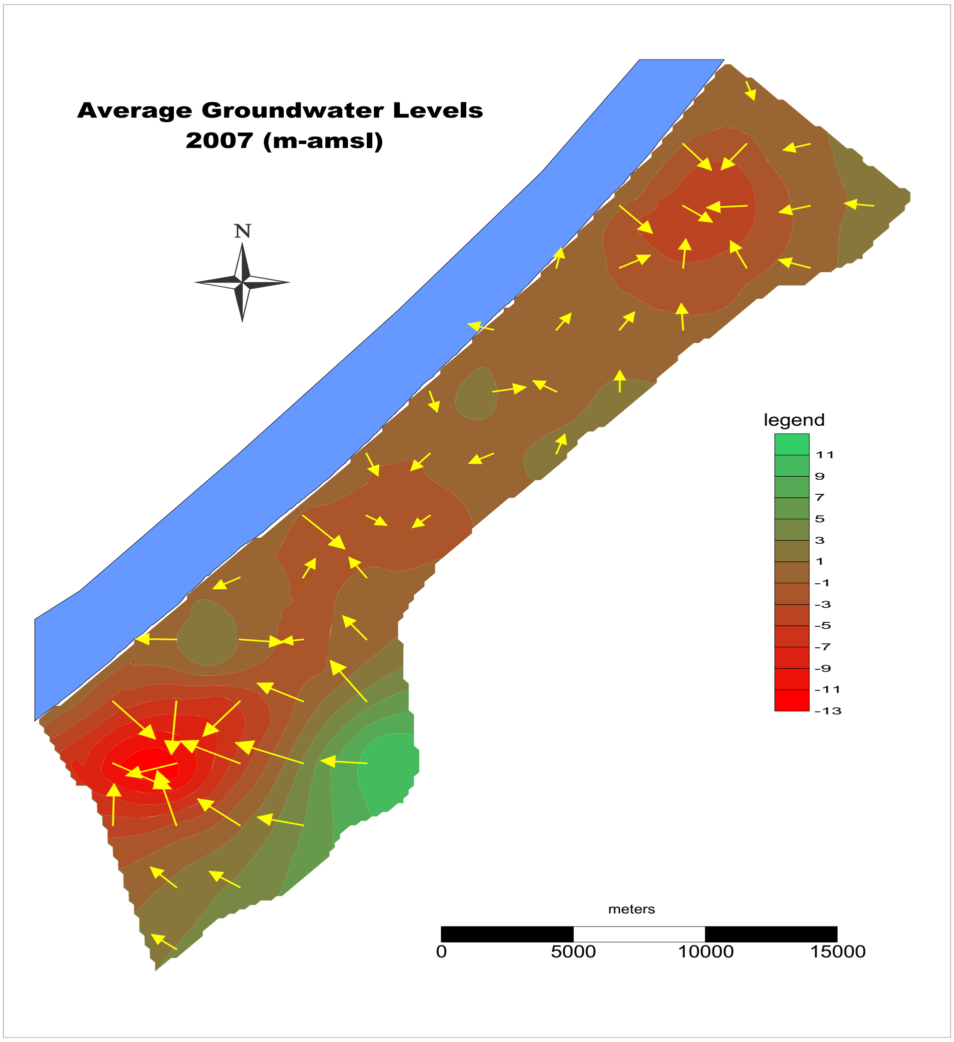

Fig.3: Average groundwater levels in the Gaza Strip

dysfunction, heart failure, neurological symptoms, lethargy, and high blood pressure; excessive levels of fluoride are toxic, causing gastritis, ulcers, kidney failure, bone fluorisis (bone fractures and crippling), and teeth fluorsis (black lines around gums and tooth decay); and high nitrate levels causes "blue baby" syndrome, also know as methaemoglobinaemia and gastric cancer.

6. DRINKING WATER SUPPLY

Around 98% of the Gaza Strip's population has piped water supply systems. The remainder depends mainly on cisterns and springs for their water use. The overall loss of water in the Gaza Strip through

the system is estimated at 45% of which 35% is due to physical losses and 10% is due to unregistered connections.

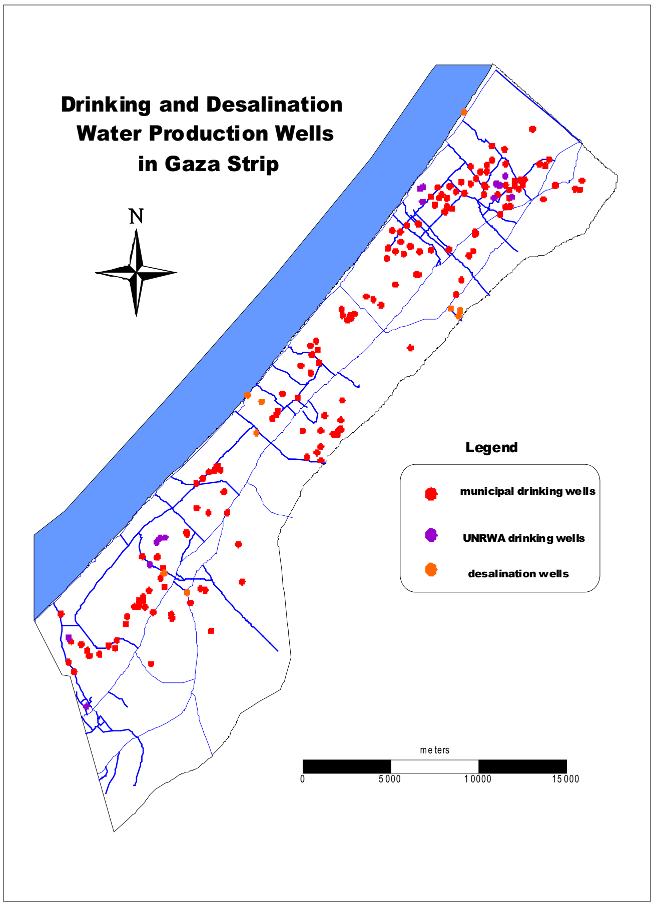

Fig.4: Location of municipal and desalination water wells

Drinking water is mainly supplied by Coastal Municipal Water Utility, which manages and operates about 170 water wells distributed all over the Gaza Strip see fig.4. These wells produce about 85 MCM per year, while the actual water consumed does not exceed 55 percent of this amount. However, UN- water and sanitation department supplied part of the refugee camps with clean water. The total quantity of such water is just 2.5 MCM per year and pumped from 15 wells. In addition to these quantities, another 2 MCM per year is produced by desalination plants. Moreover, the major amount of such water is distributed to consumers by tankers in different areas in Gaza.

7. WATER DESALINATION

The only technology in water desalination applied in Gaza is Reverse Osmosis (RO). The first RO plant in the Gaza Strip was built in 1993 in Deir al balah town by EMS a subsidiary of Mekkorot company. This plant is constructed to desalinate brackish water and has a capacity of 45 m3/h with a recovery of 75%. After that between 1997- 1998 and through an Italian development cooperation program two RO plants were constructed in Khan younis to desalinate two brackish water wells. Each RO plant has a capacity of 50 m3/h to supply a part of Khan younis town with potable water.

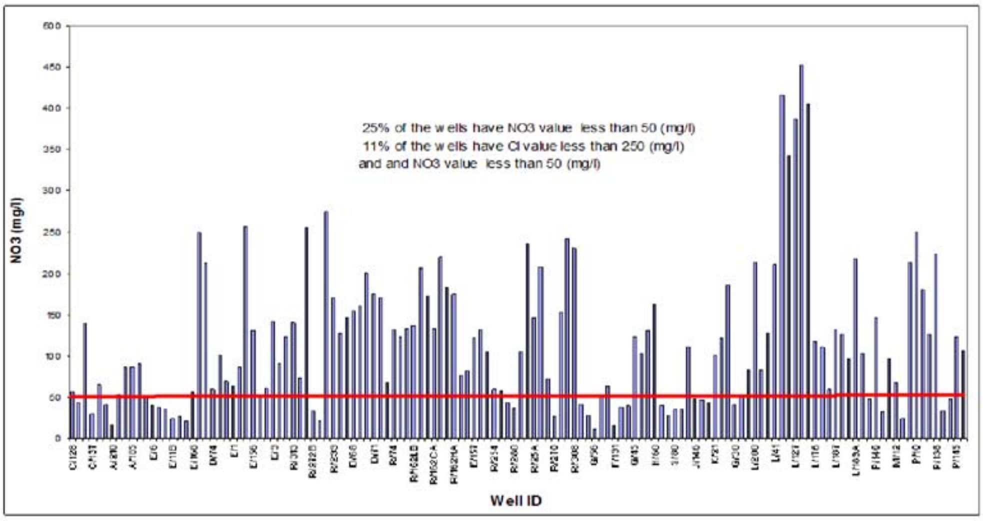

Fig.5: Average NO3 concentration in municipal water wells

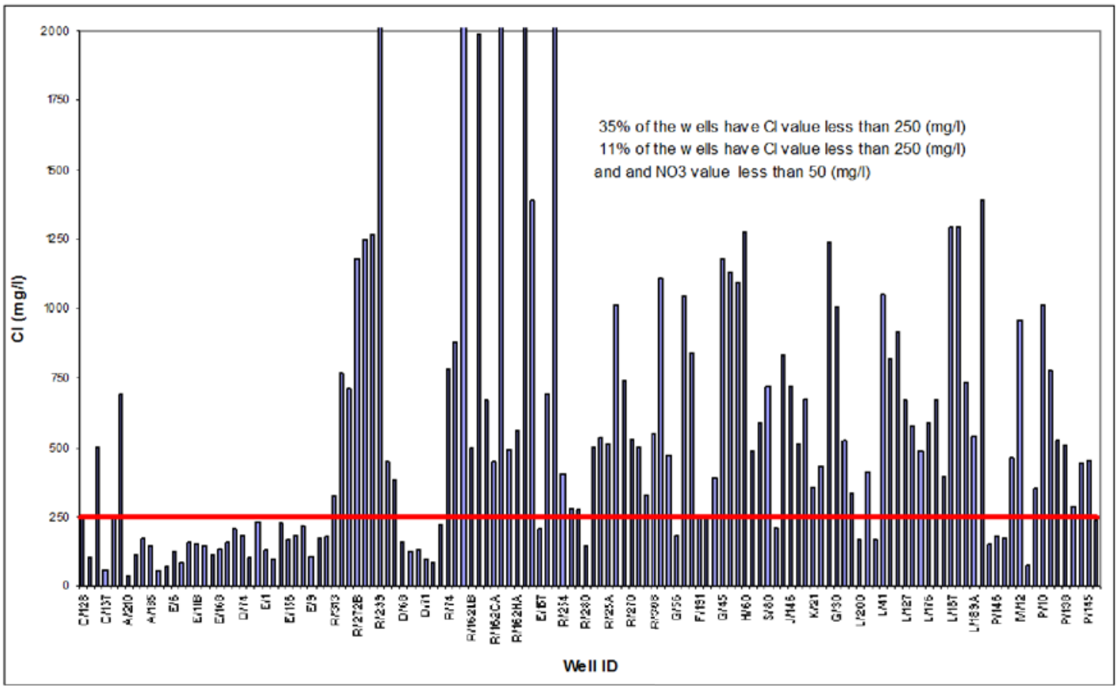

Fig.6: Average Cl concentration in municipal water wells

In 1998, USAID financed a BWRO plant built by an American company Metcalf and Eddy in Gaza Industrial Zone. This plant has a capacity of 40 m3/h and was designed to supply water to the surrounded industrial complexes and adjacent part of Gaza city. In 1999 the private sector – local companies- started to invest in the desalination field. They installed small scale BWRO plants with different capacities to desalinate low brackish water wells in various areas in Gaza Strip. Such plants have current capacities from 10 to 200 m3/d and recoveries ranging from 40 to 70 percent. The total amount of desalinated water produced by such small plants range from 1 to 1.5 million cubic meter per year where the number of these plants does not exceed 80 units.

CONCLUSION AND RECOMMENDATIONS

- Sustainability of the water, wastewater and agricultural reuse water systems is a primary goal of PWA. To make these systems sustainable, there must be:
  Sufficient funds collected to recover costs: operations and maintenance, administration, depreciation and debt service.
- In term of quality more that 90% of the pumped water is far from the drinking standard and can be used only for domestic purposes.
- The network distribution system efficiency in all Gaza governorates is very low (40-50%) and that affects negatively the actual water per capita consumption.
- CMWU should improve the system efficiency in order to increase the per capita water consumption.
- PWA is not in the favor of drilling new wells for domestic use.
- New resources such as seawater desalination should be considered by the CMWU for fulfilling the domestic water needs.
- Brackish groundwater desalination should not be considered as an option for domestic water supply at least for the short term (5-years).
- Pumping rates from the different wells as well as pumping duration should be minimized to the levels that have been recommended by PWA.
- Wastewater treatment and reuse projects are considered by PWA as very important component in the water resources management and CMWU should consider that in their short and long term demand management plan.
- The operation water distribution system in all the Gaza Strip governorates should be revised taking in consideration the related hydraulic model that was established through the Finland/PWA project, which will improve significantly the network efficiency and the water per capita consumption.
- No new wells should be drilled in the near future in all the Gaza Strip governorates except for Rafah.
- There is no domestic water supply shortage in all of the Gaza Strip Governorates except for Rafah governorate in terms of quantity.
- The illegal domestic municipal water wells should be licensed following the PWA's regulation.

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Getting Riparian States to Co-operate in Transboundary Groundwater Management: Challenges and Opportunities to Water Security

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ABSTRACT

Transboundary riparian ecosystems and transboundary groundwater are as interdependent as flora and fauna found anywhere. Nonetheless, conflicts characterize the management of transboundary riparian ecosystems and transboundary groundwater. Conflicts on the obscured groundwater are envisioned to worsen and magnify in the face of increasing water scarcity and global environmental change. To surmount these management conflicts, water experts worldwide suggest several management approaches which can be broadly categorized under co-operative, non-co-operative and myopic ones. Most promisingly sustainable, practical and popular among them is the co-operative management approach which evolves a single comprehensive plan to manage transboundary watersheds. However, there are issues with the co-operative management approach which arise as a result of cultural, political, economic, legal, geographical, technical, historical, and institutional differences from one stakeholder (user or right owner) to the other within and across boundary. Stakeholders may view these issues as challenges or opportunities. But the best way forward is the evolution of a single co-operative transboundary watershed management approach using stakeholders who have learned from success and failure management practices in component riparian ecosystems and are strongly motivated to bring all their experiences to the development of a comprehensive plan which manages transboundary watersheds as a whole.

Key words: watershed, conflict, cooperative, way, forward

1.0 INTRODUCTION

Transboundary riparian ecosystems with its rich flora and fauna are critical to the sustainable management of transboundary groundwater in as much as transboundary groundwater is critical to the sustainable management of transboundary riparian ecosystems. Interdependence of these resources is even more crucial in the face of increasing water scarcity and global environmental change where water experts cannot readily detect initial subtle but somewhat permanent variations in the hydrological and hydraulic cycles (Melvani, 2009 and Wiseman 2009). Characteristics (health status) of transboundary riparian ecosystems are as good an indicator of the quality and quality of transboundary groundwater.

Nonetheless, the management of transboundary riparian ecosystems and transboundary groundwater are characterized by conflicts. Conflicts on the obscured groundwater are envisioned to worsen and magnify in the face of increasing water scarcity and global environmental change.

Nonetheless, conflicts characterize the management of transboundary riparian ecosystems which are envisioned to worsen and magnify with the obscured transboundary groundwater in the face of increasing water scarcity and global environmental change (Eckstein & Eckstein, 2005 and Matthews, 2005).

To surmount these management conflicts, water experts worldwide suggested several management approaches which can be broadly categorized under co-operative, non-cooperative or myopic ones. Most promisingly sustainable, practical and popular among them is the co-operative management approach which evolves a single comprehensive plan to manage transboundary groundwater (Chermak *et al*. 2005; Rowland, 2005; Feitelson, 2004 and Froukh, 2004).

However, there are issues with the co-operative management approach which arise as a result of cultural, political, economic, legal, geographical, technical, historical, and institutional differences from one stakeholder (user or right owner) to the other within and across boundary. Stakeholders may view these issues as challenges or opportunities

Thus, this paper looks at the challenges and opportunities associated with the co-operative approach for transboundary watershed management. Further, it prescribes the best way forward.

2.0 CHALLENGES

As stakeholders, within and across boundary, take different interest in watershed resources so do they manage them differently in different cultural, political, economic, legal, geographical, technical, historical, and institutional contexts which are challenges and possible precursors to conflict in themselves.

2.1 Cultural

Culture of watershed stakeholders varies within and across boundary (Hassan, 2003). Thus, views of stakeholders on watershed management vary as widely as culture does within and across boundary.

2. 2 Political

Needs and wants of watershed stakeholders vary within and across boundary. One stakeholder deciding to dam, reserve water or preserve certain flora and fauna may disadvantage and displease the other (Tamas, 2003). But the two must reach an agreement for their continued survival.

2.3 Economic

Economic circumstance of watershed stakeholders varies within and across boundary. One who is economically stronger will have an edge over the other in the use of watershed resources (Trottier, 2003).

2.4 Legal

Though legal principles are deeply rooted in moral principles, they are difficult to apply and do not always result in practical watershed management (Cosgrove, 2003). International watershed laws have changed with changing nature of international conflicts, but have not changed with ever growing and complicating intra-state conflicts (Lorenz, 2003). As a result, co-operative management approaches are hardly working across riparian states.

2.5 Geographical

Physical environments which surround watershed stakeholders vary within and across boundary. Nonetheless, the type of physical environment that surrounds a stakeholder largely affects the patterns of water flow (Calder, 2002).

2.6 Technical

Data and information about watersheds are scattered and unsystematically synthesized and presented within and across boundary. Map scales and symbols differ form one riparian country to the other. Differences in data collection facilities form one riparian country to the other produces data discrepancies, resulting in inaccurate identification of transboundary aquifers and inconsistent labeling of aquifers (Arnold and Buzás, 2005).

2.7 Historical

History and identity of watershed stakeholders vary within and across boundary. Yet so-called co-operative watershed management plans often ignore historical values and stakeholder identities and rather accept a lot of scientific models which are incomplete in themselves (Cosgrove, 2003 and Reuss, 2003).

2.8 Institutional

Institutions involved in the management of watersheds have various clear mandates. Yet transboundary riparian countries cannot see the collective effect of these institutions on watershed management. This is so not because of poor institutional organizational structure or the far-fetchedness of international protocols, treaties or conventions to institutions but rather as a result of lack of democracy and good governance; trained human capacity, and financing and developmental support in institutions (Cosgrove, 2003).

3.0 OPPORTUNITIES

Where there is strong will, even the most complex of watershed stakeholdership can turn challenges into co-operation opportunities, and all it only requires is an enabling cultural, political, economic, legal, geographical, technical, historical, and institutional environments.

3.1 Cultural

Stakeholders can certainly share values which encourage judicious use, protection, sharing, equity, and justice of watershed resources within and across boundary. Thus, comprehensive co-operative watershed management approaches should be ones which seek to strongly promote common cultural values among tansboundary riparian states. All it only requires are effective methods for exploring, accessing and evaluating cultural values, which are to be integrated into co-operative watershed management plans (Dixion *et al.*, 2001).

3. 2 Political

The resolve of stakeholders to agree on all issues of justice and equity in satisfying their needs and wants is all that it takes to arrive at a comprehensive co-operative watershed management plan. It all requires conscientious lobbying, open and hidden negotiations, non-violence, network building, recourse to international organizations, and the actions of elites (Artiga, 2003).

3.3 Economic

How economic edge is managed is very crucial to the success of a co-operative watershed management plan. A stakeholder with an economic edge should always use it to alleviate the poverty of the other(s) in mutually beneficial projects if co-operative watershed management plans are to succeed (Nicol, 2003). For instance, stakeholders that are heavily dependent on the export of primary commodities are more liable to conflict (Tamas, 2003).

3.4 Legal

Stakeholders ought to try their best to make intra-statal by-laws as re-enact-able as possible, so that they can re-adjust co-operative management approaches by the second to address issues on the ground. Intra-statal by-laws may well be customary laws (Lorenz, 2003 and Jennifer Mohamed-Katerere & Zaag, 2003).

3.5 Geographical

A practical co-operative watershed management plan should be one that takes the geographical advantage or disadvantage of stakeholders into consideration. Geographical circumstance of stakeholders should determine justice and equity in watershed management plan based on accurate geographical data (Zainun *et al*., 2007).

3.6 Technical

Collaboration between stakeholders should lead to the production of accurate data and useful information within and across boundary for cross disciplinary and sectoral consumption (Haddadin, 2003).

3.7 Historical

Stakeholders are more likely to develop a comprehensive co-operative watershed management plan if they share a history of rapport which shows in their every endeavour (Muckleston, 2003 and Frijters & Leentvaar, 2003).

3.8 Institutional

Transboundary riparian governments should revamp their institutions in charge of watersheds management and seek to collaborate to capitalize on institutional strengths and weakness.

4.0 THE WAY FORWARD

The best way forward is the evolution of a single co-operative transboundary watershed management approach using stakeholders who have learned from success and failure management practices in component riparian ecosystems and are strongly motivated to bring all their experiences to the development of a comprehensive plan which manages transboundary watersheds as a whole.

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The Guarani Aquifer and its Systems:
About Rules Profusion and Implementation Scarcity for Ground Waters

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Abstract.
Adopting a Brazilian focus on international regional ground waters, building capacities and strengthening institutions in the Guarani Aquifer area presents renewed challenges. Relevant legal texts have been approved in the past two years, both in the domestic and in the international domains. Can it be asserted that they constitute legal and institutional advances? A new Regional Commission will deal with Guarani Aquifer uses and Members States; or will it be just a cotton cloud between four crystals? Environmental concerns are they really at stake when Blue Gold is the aim?
Keywords: International Ground Waters Regime. Regional Rules for Guarani Aquifer

1. INTRODUCTION

1.1. The Guarani Aquifer parameters

Guarani Aquifer is said to be one of the huge fresh groundwater reservoirs of the planet. It is located under the territories of four countries of South America: Argentina, Brazil, Paraguay and Uruguay. This abstract underlines dimensions of the legal problems of the Aquifer: 1) the legal frame for ground waters is far from able to give effective guaranties for the present and future generations, from both the stand points of: a) domestic rules of each of the four countries and b) International River Law, either as formulated by the 1997 United Nations' New York Convention and La Plata international watershed, or drafted in regional contacts; 2) the conviction that exist safe reserves, for the future, in the Aquifer, leads certain executive branches of both govern and private corporations to misunderstanding and omission, as far decisions concern the surface waters effective protection in real public policies. The worse way to draft the problem can be the easiest answer for some executives: why do we need to use carefully surface water to day, if we have a big quantity already saved for to-morrow?

Guarani Aquifer surface territory is shared by four States: Argentina (228.255 km^2); Brazil [(735,916 km^2; which Members States respectively have: Goiás (39.367 km^2), Minas Gerais (38.585 km^2), Mato Grosso (7.217 km^2), Mato Grosso do Sul (189.451 k^2), São Paulo (142.959 km^2), Paraná (119.525 km^2), Santa Catarina (44.132 km^2), Rio Grande do Sul (154.680 km^2)]; Paraguay (87.536 km^2) and Uruguay (36.171 km^2). Guarani Aquifer, with an estimated reservoir of 30000 km^{3}, was considered possibly the one of largest extension in the world, until the recent discovery of *Alter do Chão* Aquifer, which lays under the State of Pará, in the Amazonian region, estimated the late one could contain 80.000 km^3.

Unlikely the word *reservoir* suggests, Guarani Aquifer is not a groundwater tank. It is a disrupted chain of eventual opportunities of getting fresh water in many places. Common actions in the border areas could be of more effect than treaty signature without practice goals and common concern. A good ground and starting point for international cooperation could be the common identification of the similar national rules in all the States of the same aquifer concern. Is it possible?

1.2. Social, political, environmental and legal simultaneous challenges

When people starts looking to ground waters for supplying all human necessities, surface waters are already in such bad conditions that they turned total or partially useless.

Legal existing providences require detailed analysis, to know whether comprehensive regimes are effectively preventing irrational uses of ground waters or tolerating, through inadequate management of public decisions, their progressive and non-return consumption and pollution. A *both ends* legal methodology must consider, on one hand, the legal effects of rules on all the uses and on water quantity and quality and, on the other hand, integrate into the official practices the challenge of promoting full effective respect for rules and management decisions. Planned results should only consider preservation of the previous quality and quantity and operational standards. These standards generally exist in most countries, but suffer erosion of two main constraints. The first one is the breach of implementation due to the lack of public control and water administration police. No rule of any kind is spontaneously respected by any group of people if it does not seem there is some kind of blame, fine or other penalty for the ones who don't comply the law. Water legal regime is not a goal per se; it's just a mean that needs other measures to fulfil its contents. Water Guard is just a necessity. The second constraint is the hidden effects of pollution.

As a check and balance of actual practices in the four Guarani Aquifers countries, it can be stated that ground waters have national regimes and lack an integrated previous vision and field application of the rules of law. Very few is done do prevent pollution before it happens, in order to create a common concern and ban harms and risks; and include the application of effective penalties.

Recent balance of the common activities has fortunately revealed that the four countries of the Aquifer managed elaborate a basic hydro geological map of the SAG –System Aquifer Guarani-, on the ground of 191 maps of regions of the four countries; this result overrides the lack of common information and allows the confection of a single common map for all the Aquifer.

The attempt to mature an international global regime for groundwater (UN/GA Res. 64/123, 2009) lasted minus than the 25 years spent in putting order in surface water resources and offer the 1997 New York Convention to signature. This gives matter for reflexion. Why would it be easier to get a consensus on groundwater?

2. OF TEACHERS AND PRINCIPLES

Is there any tradition of rational, equitable or balanced, surface waters apportionment?

An historical overview could give some answers and would able to check the real limits of legal constructions. After 1945, important changes were induced by two orders of factors: the scales of international trade exchanges grew and the resources were turned a problem of scarcity.

2.1. Teachers worked right

In the new frame after 1980, consensus was no longer a matter of European concern; and no more a matter of homogeneous Doctrine; except for fresh water? The works of *International Law Institute* and *International Law Association* –ILA, could illustrate this issue; especially Clyde Eagleton, for example, in ILA 46th Conference (Edinburgh, 1954) and in New York (48th Conference, 1958), when he presented his Report. The new conceptions for International River Law included some notions about pollution. ILA hold important traditional notions, but opened views on liability: each State would be liable for any activity, either public or private, which would modify a waterway regime in prejudice of other State, if it would not give evidence of due diligence, inclusive on pollution issues. Principle V of Dubrovnik Declaration induces taking into account: a) the right of every State to use water in a reasonable way; b) the proportion in which every State depends on the waterway at stake; c) the social and economic benefits for every State of the waterway and for the whole of the riparian States (notion of equitable apportionment); d) the existing treaties between the States; e) the situation which results from prior utilization of the waters by one of the States. Dubrovnik Rules even strengthen that if it is foreseen that planned works of a State could influence the uses of waters by the others, the *Entrepreneur* State should previously consult them. In case they disagree, States must consider creating a technical commission, and arbitration in case it fails. The VIII Dubrovnik Principle states that Riparian should cooperate to guarantee the complete exploitation of the hydraulic resources and therefore, on the one hand, consider the watershed as an integrated unit, without ignoring, on the other, none of the uses of water, so that all users can have the best benefits.

These very considerations also can be met, in the same period, in the works of UN Economic Commission for Europe, particularly in the *Pierre Sevette Report* (1952). One of the simple ideas of the Report was to give a receipt for the optimum use of an international river, in order to chose the best place for the building of a dam: choose a group of engineers; take the borders off; study and fix the best place regardless of the politic limits, then build the dam and replace the boarder… The idea sounds so good that no few people wonders whether it's not used.

2.2. Principles worked wrong?

The best "principles" as regards water law are quoted by some of the well-known UN studies on water resources. The Water Series nº1 started a quest on "principles and rules of International Law as generally applicable to that waters of common concern, the way they gradually appeared", but failed in identifying a more consistent reference than "the geographical principle of coherence – sic utere tuo ut alienum non laedat (to use one's heritage so as to do no wrong)"(ST/ESA/5, 1976)

A FAO's publication identified "General Principles of Law as applied to International Water Resources". FAO Legal Office stated that: "A reconstruction of general principles may open up interesting avenues of enquiry for verifying the existence or otherwise of international rules. Such a reconstruction has been made through judicial decisions and in learned writings, which, in striving to affirm limitations on the sovereignty of a State in the case of international water resources, have been based for the most part on:

(a) the principle that there shall be no abuse of rights;

(b) the principle of good-neighbourly relations;

(c) the principles embodied in the water law of individual States." (Caponera, 1980)

Other experts of the UN had looked for principles and observed: "States […] have a readymade start point in the principles and rules of international law generally applied to these waters of common concern, as they pointed out in the late years". This could be a good seed to grow the tree of solutions; but other principles must be quoted.

The Stockholm Declaration (1972) and the UN/GA Resolution 2995 (XXVII) illustrate the quest for diplomatic solutions. Principle 21 is often quoted as a (*soft?)* ruling demonstration of the Conference. According to it: "States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."

This Principle, which did not reach consensus when debated in Stockholm, turned to be object of debates in UN XXVII Session in New York. It was adopted as Resolution 2995 (XXVII), in Dec.15, 1972, with the same basis of Principle XXI and the express mention that the reception of data and informations from a State which intends to explore and exploit its natural resources will not allow the State which receives the informations to delay or impeach programs and projects of data rising, exploration and exploitation of the natural resources of the State that furnishes the data.

Resolution 3281 (XXIX), Dec. 12, 1974, Chart of the Rights and Duties of the States, Art. 3: "In the exploitation of the natural resources common to two or more countries, each State must cooperate on the ground of a system of informations and previous consultations in order to guarantee the best exploration of these resources without harms for the interests of other State." Nevertheless, these successive trials to define obligations remind another obstacle for cooperation in the field of waters of common concern: no one seems to accept evoking liability either.

In the Case of the leaks of chemicals into the Rhine River bed, from BASF factory in Basel and downstream, 1986, A.C. Kiss had no doubt in stating that the Helvetic Govern should have applied Stockholm Principle 21 (Kiss, 1987), but did not. On the other hand, this Govern never admitted that its international liability could be engaged; nor the States which territories suffered harms and pollution demanded the application of the arbitration compromise included in the Bonn Convention. “Once more, one avoided to deal with the issue on the ground of state liability and clear preference was given to negotiated solutions”(Kiss, 1987). This could not be said a strict application of Stockholm Principle 22, *verbis*: “States shall cooperate to develop further the international law regarding liability and compensation for the victims of pollution and other environmental damage caused by activities within the jurisdiction or control of such States to areas beyond their jurisdiction.”

In the context of ground waters resources, it seems there is even lesser sound references. There is no convention on pollution of ground waters, neither customary law, concluded Julio Barberis on the issue (Barberis, 1987). He stated, too, that Resolutions 2995 (XXVII), 2996 (XXVII), 3129 (XXVIII) and 3218 (XXIX) “constitute a considerable contribution of the General Assembly to the strengthening of the principle of previous information and consultation”(*idem*) between States that share a natural resource.

3. LEGAL SOLUTIONS FOR THE GUARANI AQUIFER?

3.1. Emphasis on sovereignty

The emphasis given by the *International Law Commission* to the aquifers States sovereignty has already been considered “a wild card into the field” (McCaffrey, 2009), as “sovereignty over shared groundwater should have no place in any set of rules governing the use, protection, and management of shared freshwater resources”(idem). Sovereignty is a real problem, for the prior decisions in upstream-located uses generally have harmful consequences for the downstream riparian. The problem seems even worse if taken into account that harms due to pollution, in ground water, will be for ever: growing population and needs addicted to clean water will have no conditions to wait for the (possible?) cleaning of an aquifer. Much uses of aquifers resources are already (2010) not reasonable, neither fair nor equitable; and it is of no help to “give” the access to water and basic sanitation as a human right if there is no warrant to give the liquid with the right. The same challenge has to be considered for groundwater exploitation. It is not sufficient to re-grant State sovereignty without underlining old and new aspects of liability.

The four Members States of the Aquifer surface territory have seed the roots of some solutions, in an International Law perspective, by signing on August 2nd, 2010, in San Juan (Argentina) a Treaty which could briefly be in force: thirty days after the fourth ratification.

The treaty can be said respectful of the provisions of the Resolution adopted by the General Assembly (64/123) on the Law of the Transboundary Aquifers-A/Res/64/123, on January 15th, 2009. Their respective substantial disposals can be briefly evoked:

UN Resolution on the Law of Transboundary Aquifers sets some principles: sovereignty of aquifer States; equitable and reasonable utilization of ground waters; duty to restrain from causing harm to another State; obligations of cooperation and promotion of a regular exchange of information; and last: recommendation that all States should adopt regional or bilateral agreements.

The Agreement of San Juan on the Guarani Aquifer refers to the respect to a number of complex obligations: a) principle of sovereignty (art. 2); b) "sovereign right to promote the management, monitoring and sustainable use of water resources of the Guarani Aquifer System", using criteria for rational and sustainable use and avoiding appreciable harm to other parties or to the environment (Art.3), […] under general International Law "(art. 5); c) Parties shall promote the protection and preservation of the SAG "in order to ensure the multiple, rational, sustainable and equitable use of water resources" (art. 4); and d) Parties must respect International Law Rules, avoiding harms to other Parties or to the environment, in their activities, studies and works related to the aquifer (arts. 5 and 6). The twice repeated notion and obligation of “adopting the necessary measures” (Art. 5 and 6) concerns the obligations to avoid prejudice and, in case of harm, to react by the adoption of efficient providences.

The implementation of the Treaty will be in the hands of a Special Commission, created within the frame of La Plata Basin Treaty (23/4/1969) and with some both diplomatic and legal responsibilities: "coordinate the cooperation between them in order to fulfill the principles and goals of the Treaty" (Art.15) and constitute a special step in case of some misunderstanding between the Parties. Art.17 allows that the Special Commission, "according to previous exposition of respective positions, evaluate the situation and, eventually, formulate recommendation" in a delay of sixty days. Nevertheless, as the intervention of the Commission could not be adequate in certain case, the Parties establish that they would appeal to an arbitration settlement by the means they will create (Art.19)

3.2. Which warrants for ground waters Policies?

It is often stressed that in the relations of two or more States, these have no prior obligation to establish or practice among them the same rules they may have, all of them, in their respective domestic normative orders. That's the true challenge for ground waters. It will be illustrated by the new regime recently approved in Brazil for monitoring the domestic ground waters issues, and other rules for the water resources, both ground and surface waters. Resolution nº 107 of Brazilian CNRH (*Conselho Nacional dos Recursos Hídricos* / National Water Resources Council), of 4/4/10, "establishes directives and criteria for planning, implantation and operation of the National Web of Integrated Qualitative and Quantitative Monitoring of Ground waters".

As it is not possible to quote all the measures that are listed in the Resolution and should be implemented, the indication of some of them will testify he concern of the CNRH:

Art.3 states that "the choice of monitoring points will consider: I- the use and occupation of soil; II – the demand for ground water: a) density of wells; b) volume of exploitation; c) population density and growth; d) use of water for public supplies; e) type of economic activity; and f) conflictive areas; […] VI – natural vulnerability of aquifers, risks of pollution of ground waters and contaminated areas; […]"

Art. 4º establishes that the National Web for monitoring Ground Waters shall specify, for every aquifer: I – The quantity and spatial distribution of georeferred wells to be build exclusively for monitoring purposes; II – the quantity and distribution of existing georeferred wells to be integrated to the National Monitoring Web; III – water quality parameters selected after Resolution nº 396, of 3/4/08, of the *Conselho Nacional do Meio Ambiente –CONAMA* (National Environmental Council) for the wells enunciated in items I and II.

CONAMA Resolution nº 396 covers five pages of the *Diário Oficial da União* and reminds, in its initial *Considering…*, some of the paramount and correct points that were already taken into account in prior paramount rules, e.g.:

- the necessity of integration of National Policies for Environmental Management, for Water Resources Management and for use and occupation of soils, in order to warrant the social, economical and environmental functions of the ground waters;
- [the fact that] the aquifers appear in different hydrogeological contexts and may extend over the limits of watersheds, and that ground waters have physical, chemical and biological characteristics, with hydro geochemical variations, making it necessary that their quality classes be classified in these specificities; […]
- [the fact that] classification expresses final goals that have to be reached, it being possible to fix intermediate progressive binding goals, aiming at its effectiveness;

It must be noticed that there is no previous legal text of this nature, in Brazil, with a disposition concerning "intermediate progressive binding goals, aiming at its effectiveness", nor is it the case of CONAMA Resolution nº 396 . This introduces such an effect of uncertainty in the legal text, that it is doubtless whether it can be binding and in which extent. Before this text, many doubts were born, too, from the poor implementation of the Law nº 9433/97 *Política Nacional de Recursos Hídricos* (8/1/1997: National Water Resources Policy). Who will monitorate the water policy monitor?

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Reviewing the criteria for the sustainable management of the Carboniferous Limestone Aquifer at the Belgium-France border

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ABSTRACT

In Western Belgium qualitative good groundwater is poor. The Carboniferous Limestone Aquifer which is occurring in the southwest of Belgium and northern France is a very important reservoir of groundwater for the whole region. The aquifer has been exploited strongly by industry and drinking water supplies in both France and Belgium. The intensive use combined with poor feeding induced a continuous water level drawdown since the beginning of the 20th century, except for the war periods and a brief period after the `Kain incident'. In 1977, a part of the bank of the Scheldt River collapsed. This had a temporary very negative impact on the water quality in several abstraction wells when the rising water washed oxidized sand. In 1997, a reduction plan for the exploitation of the Carboniferous Limestone between Flanders and Wallonia was accepted: 'the Transhennuyère-agreement'. In consequence of the rigorous compliance of the agreement, in combination with decreasing water abstraction in France, it was possible to stabilize the water level in the beginning of the 21th century. Since 2007 after the last reduction step of 'the Transhennuyère-agreement' water levels increased strongly. As after the Kain-incident, a negative influence on the water quality in different wells now occurs. This case shows that a sound balance between piezometric level, quality and abstraction should be the target of the aquifer management. The quasi-permanent consultations between technicians of both Regions ensure that these matters can be discussed and that experience and knowledge can be exchanged. With the French stakeholders there is consultation in a broader context within the framework of the International Scheldt Commission. The new ongoing Scaldwin modelling project could be an important trigger for deepening the collaboration. One can conclude that continuous monitoring and re-evaluation of the impact of policy decisions is necessary. Protecting the quality and quantity of the strategic groundwater reserve is vital in a period of fast climate change and ambitious ecologic objectives.

Key words: transboundary aquifer, confined aquifer, water table rise, quality deterioration, monitoring

1. INTRODUCTION

The Flemish water supply company (VMW) is the biggest drinking water company in Flanders (northern Belgium). Each of the regions in Belgium has its own water authority and water supply companies.

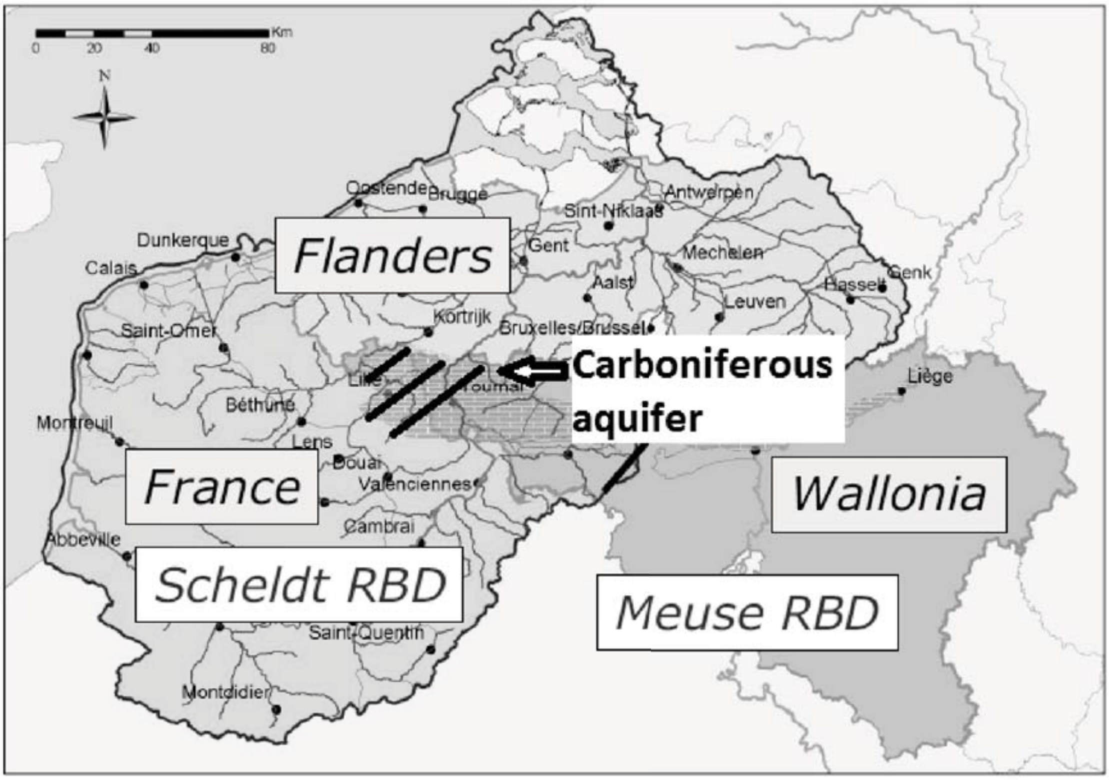
Also in the southern part of the province of West-Flanders VMW is responsible for the water supply. In Western Belgium qualitative good ground- and surface water is poor. Except for the Carboniferous limestone aquifer. This aquifer extends only in the extreme southern part of West-Flanders, but also in Wallonia and France (Fig. 1). In the beginning of the realization of the water supply network in the Flemish region the Carboniferous aquifer was the main source. Therefore water catchments in Pecq and Saint-Léger (Wallonia) and in Flanders (Spiere-Helkijn) were built. For water supply and industry in Wallonia also several catchments are being exploited. In France the water supply of the city of Lille depends partly on this aquifer. Also industry, as textile industry near Roubaix, were very important users. This increasing demand in the 20^{th} century lead to fast decreasing water levels in the confined part of the aquifer. In the second period of last century the decline was dramatic (2 meters/year).

Since the beginning of the 21^{st} century water levels stabilised and now there is an important increase of the levels. This for several reasons. In France the textile industry is no longer an important player. The water supply in France can also count on surface water and on an important aquifer in the Cray layers. In Belgium an interregional agreement (Transhennuyère-agreement) was established for rehabilitation of the aquifer. In this agreement VMW and Walloon water companies are forced to reduce their pumping rates on yearly basis in the confined part of the aquifer. The deficit is delivered by a new duct with water originating from the unconfined part of the aquifer in Wallonia and with surface water from a new modern water factory near

Harelbeke (Flanders). The follow-up of the agreement in Belgium is in practice ensured by a technical working group who reunites on a regular basis.

For the European Water Framework Directive the aquifer is the subject of 3 water basin management plans; one for Wallonia, one for France and one for Flanders. The overall objective is to achieve a good quantitative and chemical status of the water bodies by 2015. According to the declaration of Ghent the partners work together in the International Commission of the Scheldt in view to harmonize the plans.

Figure 1. Location of the confined part of the Carboniferous Limestone aquifer on the Belgium-France border and on the Flanders-Wallonian regional border (adapted from Ph. Meus, 2007)



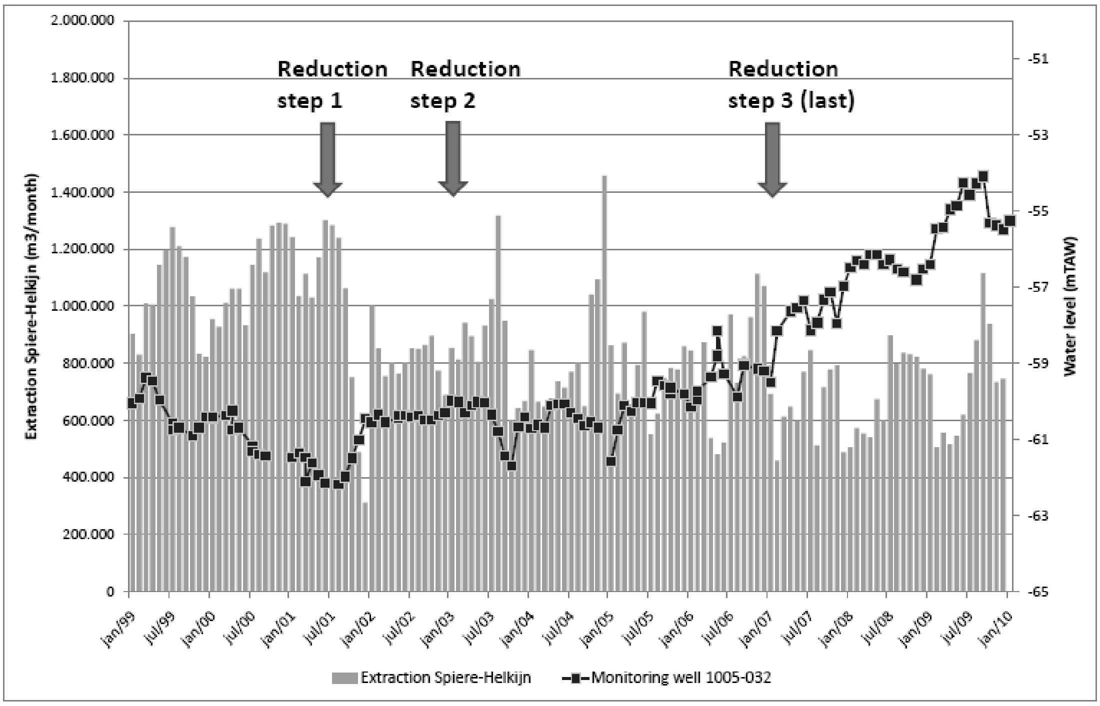
2. OBJECTIVES

Exceptions on the decreasing water level trend in last century were the war years and a sudden rise in 1977. This last rise over the complete surface of the confined part was induced by a collapse of the river Scheldt bottom near Kain (Belgium, Wallonia). The collapse was due to instability in the Carboniferous aquifer induced by the drainage. Immediately after the incident a sudden spectacular quality deterioration took place in several production wells. The phenomenon that is the cornerstone of the quality deterioration is the occurrence of sand with pyrite in and on top of the aquifer. This layer was oxidized when the water level in the Carboniferous decreased. When the level rose suddenly at the time of the Kain incident a portion of the oxidized layer was rinsed. With the experience of the 70s in mind one has built in several safeguards in the Transhennuyère-agreement in case of quality deterioration. The abstraction quota were determined at the time by a compromise between different model results. Because of the degree of uncertainty a flexible process was incorporated to adjust when the increase would go too fast and would lead to quality problems. After the last quotum – decrease step of the agreement in 2007 several quality problems were detected that were very similar to the observations of the 70s. So the time had come to investigate the relations between water level increase, quality and pumping rates.

3. RESULTS

Figure 2 shows the water level changes in relation to the reduction steps and the actual pumping rates for the Spiere-Helkijn well field. One can see that the reduction steps had important influence on the water levels. Since the last reduction step of 2007 the rise in levels developed very fast.

Figure 2. Relation extraction – water level at the Spiere-Helkijn well field (1999 – 2010)



In the spring of 2007 the first problems occurred on production well 1005-004. A sudden rise in heavy metal and magnesium concentrations caused problems for meeting the drinking water standards at the water plant of Kooigem. In the case of this well the pyrite sands form a relatively thick layer on top of the aquifer (Fig. 3). After the last reduction in 2007 the rising water level reached the oxidised layer. After this observation the phenomenon on the well was studied more intensively (Fig. 4). One can see a positive correlation between the water level and the sulphate concentration, in particular in the beginning of the observations when the well worked intermittent. Later when the well was pumped continuously on a smoother rate the concentrations remained more constant.

In 2008 the drinking water treatment for manganese in the water plant of Saint-Léger became problematic. In several wells the concentrations reached high peaks. In the well 1006-014 (Fig. 5) manganese levels were more or less stable until 2007. Since 2007 very high peaks in manganese occur related to the higher rise of the water levels and discontinuous pumping. In the situation of this well the pyrite sands are fallen into the karstic aquifer.

The examples above show the 2 most extreme observations. Several other wells have similar problems on a lower level, for some wells one can expect problems in the future. In some wells there are no problems, nor to be expected (for example no pyrite sands present).

Figure 3. Sulphate concentration in relation to the water level rise and the occurence of pyrite sands (extraction well 1005-004, Spiere-Helkijn well field)

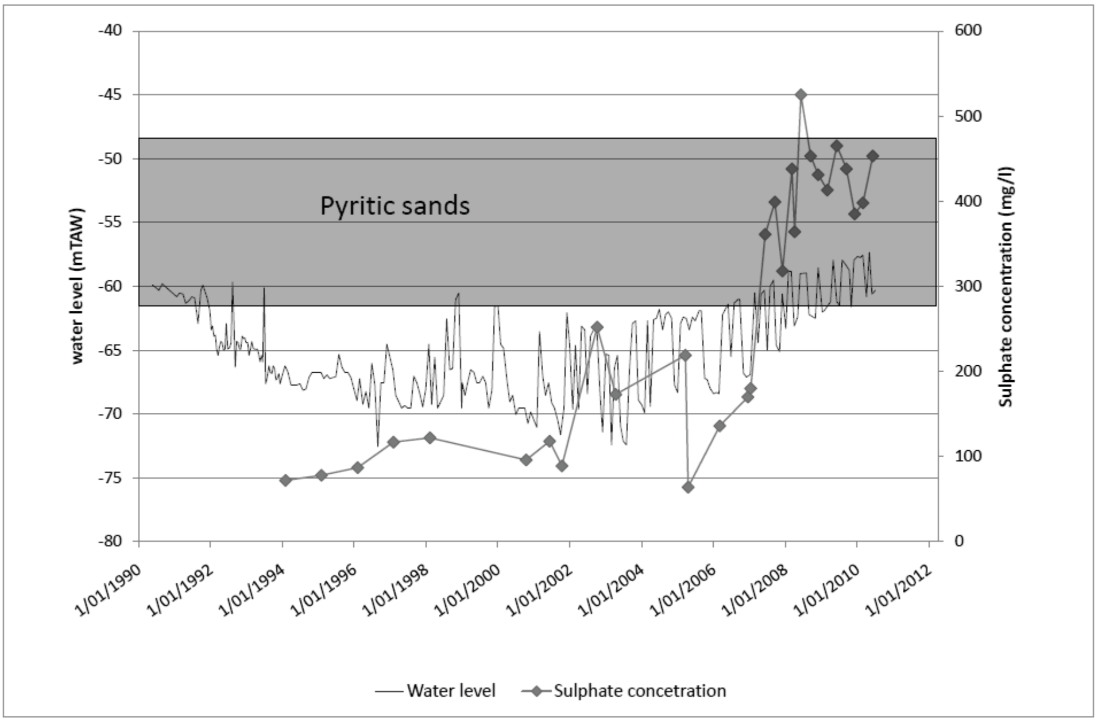


Figure 4. Detailed relation in between water level change and sulphate concentration (extraction well 1005-004, Spiere-Helkijn well field)

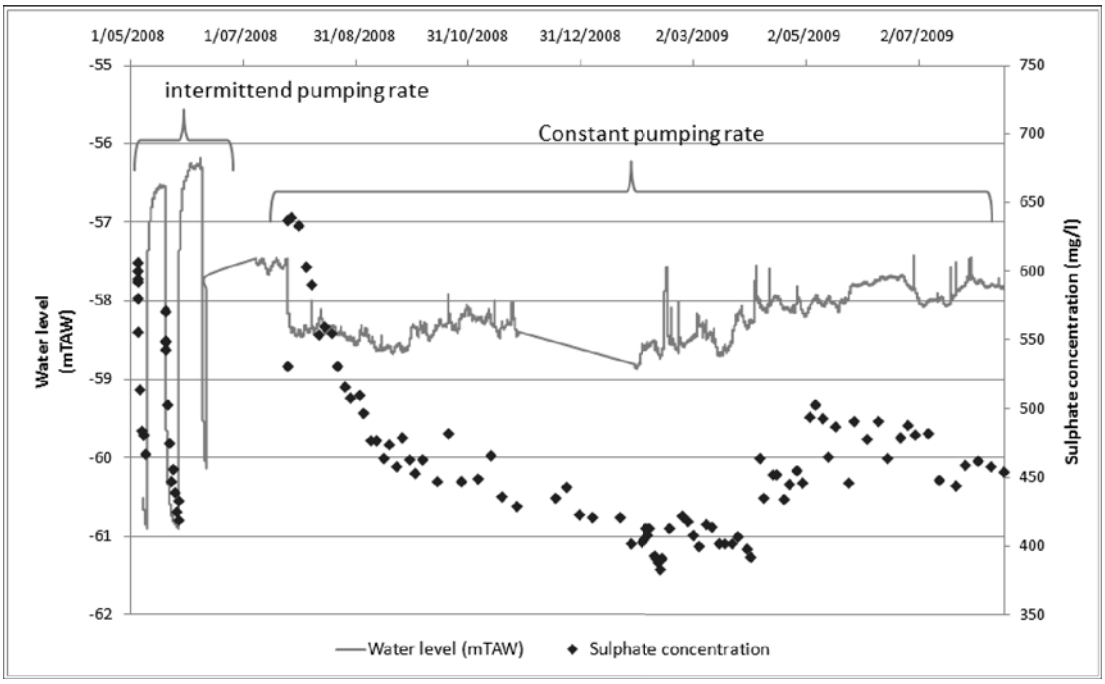
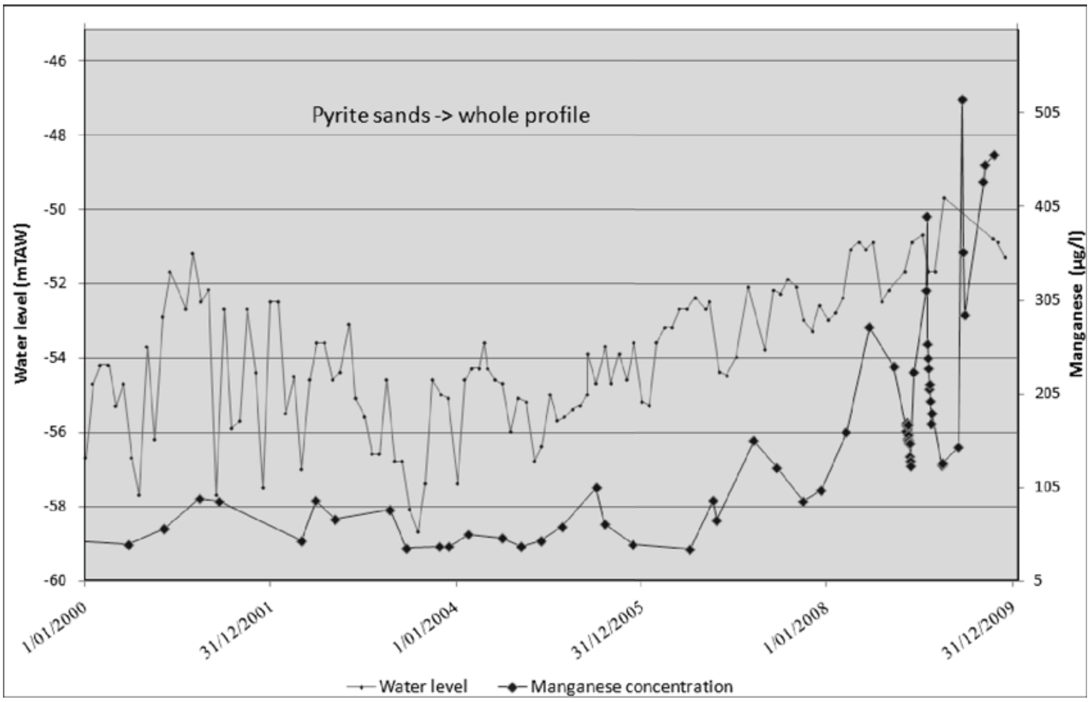


Figure 5. Relation in between water level and manganese concentration (extraction well 1006-014, Pecq – Saint-Léger well field)



4. DISCUSSION

One can conclude that for controlling the quality the actual rise is to steep. Another observation is the correlation between level dynamics and concentrations. To meet the quota at the end of the year it is necessary to built up reserves in the first months of the year in view of the climatologic unpredictable summer period. In the actual situation it is not possible to achieve a more or less stable rate during the year. In the working group of the Transhennuyère-agreement minds converge in the direction of a limited adjustment in order to establish a preferable stable smooth rise in order to meet the goals of the water authorities as to meet the interests of drinking water companies.

5. CONCLUSIONS

In the current situation several wells in the Carboniferous aquifer show phenomena of important quality deterioration . It was shown that with a more or less continuous pumping rate and a steady increase in water levels quality can be held more stable. The evolution of level and quality in the present context means that a level and quality driven management layer is the appropriate way for managing the aquifer. The almost continuous monitoring and evaluation of data is an absolute necessity in such a context. When the Transhennuyère-agreement had not taken into account level and quality evolutions much time would be lost. Moreover, the quasi-permanent consultations between technicians of both Regions ensure that these matters can be discussed and experience and knowledge can be exchanged. Fine-tuning of the agreement can be achieved in a sound manner. The ambition should be consultations with the French stakeholders in a similar way. Now there is already in a broader context consultation within the framework of the International Scheldt Commission. The new ongoing Scaldwin modeling project could be an important trigger for deepening. With regular transnational consultation and exchange of experience and knowledge one can quickly take effective action for achieving a sound and sustainable management of transboundary layers.

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Solutions for groundwater management in areas affected by high arsenic content: Vojvodina case study

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ABSTRACT

Drinking water supply in Vojvodina (Serbian part of the Pannonian Basin) depends entirely on groundwater resources, whose use in the past has led to problems reflected in insufficient water quantities and poor natural water quality. Quality parameters such as NOM, ammonia, methane, and boron, along with naturally high arsenic levels (in some parts in excess of 150 µg/l) in the groundwater, have become a serious health threat to the local population (DKMT, 2006). Increasing pressure on groundwater resources has already resulted in over-exploitation ("mining") of the aquifer, with the current rate of water extraction exceeding its sustainable yield. In order to provide sufficient quantities of high-quality drinking water, the opening of new renewable groundwater sources in the Danube alluvium is proposed. Field investigations and hydrodynamic analyses (NPV46B, 2006) have shown that sufficient quantities of groundwater can be provided from the Danube alluvium (Apatin-Bezdan and Kovin-Dubovac areas), and that the natural water quality is such that the application of basic treatment methods (aeration, retention, filtration and disinfection) will produce high-quality drinking water.

Key words: arsenic, alluvium, depletion, drinking water, Vojvodina

1. INTRODUCTION

Within the territory of Vojvodina (Serbia), public water supply predominantly relies on groundwater abstraction from the so-called "main" aquifer, in the southern part of the Neogene Pannonian Basin shared with Hungary, Romania and Croatia. Over-exploitation of groundwater in the past and insufficient groundwater recharge have resulted in aquifer depletion and lowering of groundwater levels, with every prospect that this trend will continue. Along with insufficient groundwater quantity, poor groundwater quality has become a growing problem for Vojvodina's 339 water supply systems. Quality parameters such as natural organic matter, ammonia, methane, and boron, along with naturally high arsenic levels (in some parts in excess of 150 µg/l) in groundwater, have resulted in a serious health threat to the local population (DKMT, 2006).

High concentrations of arsenic in groundwater are a common problem in all neighboring countries as well. In eastern Croatia, nearly 200.000 people drink water with arsenic concentrations ranging from 10 to 610 µg/l on a daily basis (Habuda-Stanic *et al.*, 2007). In Hungary and Romania, in the Maros Alluvial Fan and the Körös Basin, high arsenic concentrations trace to arsenic-bearing minerals, which erode and are transported to the basin not only from the Transylvanian Mountains (SUMANAS, 2008), but also from the catchment areas of the Danube, the Dráva and the Zagyva rivers (Csalagovits, 1999). Additionally, other chemical components such as iron, manganese, ammonia, organic material and methane trace to water-rock interactions involving subsurface flow over more than 10.000 years, according to environmental isotope studies (Deseo and Deak, 2007).

Numerous investigations have shown that long-term exposure to low arsenic concentrations in drinking water is a health hazard (WHO, 2001; UNICEF, 2006). Therefore, ensuring drinking water quality with regard to arsenic, consistent with WHO recommendations and the Drinking Water Directive 98/83/EC (As <10 µg/l), is a major challenge for the water supply industry in these countries. The Water Management Master Plan of the Republic of Serbia calls for the water supply problem of Vojvodina to be solved by forming regional water supply systems based on groundwater sources in the Danube and Sava alluvions, or by using existing local groundwater sources. For water supply in Banat and Backa, two zones have been identified as suitable locations for sources of considerable capacities: along an upstream stretch of the Danube (Apatin-Bezdan) and along a downstream stretch of the Danube (Kovin-Dubovac).

2. GROUNDWATER USE AND ARSENIC PROBLEM IN VOJVODINA

Over 2 million inhabitants and industry in Vojvodina use groundwater for their water supply, tapped from the aquifers formed at different depths, from 20 to more than 200 m. There are a large number of aquifers in water-bearing media of younger chrono-stratigraphic units – Quaternary and Pliocene, of which the most important for public water supply are:

- the "first" aquifers from the surface, in alluvial plains,
- the main aquifers formed within the basic water-bearing complex (so-called Main Water-bearing Complex, BWC), and
- the aquifers formed in Pliocene water-bearing media.

Nearly 70% of the groundwater abstracted in Vojvodina originates from deep, regional aquifers. The over-exploitation problem has been present in Bačka and Banat since the early 1980's, when the rate of abstraction for public and industrial water supply exceeded natural recharge of the BWC. The impact of over-exploitation is primarily seen in declining groundwater levels in the wider areas of groundwater sources (resulting in increasing abstraction costs), declining yield, and in some cases local land subsidence. Extreme drawdowns have been recorded in the wider zones of water sources; lowering of piezometric head over the past 3 decades is seen in northern Bačka and northern Banat (between 20 and 30 metres). A forecast of the effects of future groundwater abstraction at the current rate (roughly 4,5 m^3/s) or higher, showed that that there will be a further decline in groundwater levels, in some areas by several dozen meters (Jaroslav Cerni, 2000).

The quality of groundwater in Bačka, Banat and Srem is characterized by distinctive inequality, ranging from acceptable water quality to water that requires a high level of treatment. Groundwater chemistry in central Bačka is characterized by elevated concentrations of organic substances, arsenic, iron and manganese, while in the catchment area of the Tisa and in western Bačka (Odžaci), $KMnO_4$ demand is greater than 20 mg/l, and even as high as 100 mg/l (the prescribed limit value is 8 mg/l). Other characteristics of this groundwater include permanently elevated iron concentrations, sometimes as high as 3 mg/l, and the absence of manganese, nitrite and nitrate. Based on recorded values, there are several areas with extremely high arsenic concentrations (> 50 μg/l): northern, western and southern Backa, and northern and central Banat (Fig.1)(Table 1).

A relatively narrow zone between the towns of Zrenjanin and Žitište (central Banat), is characterized by highly-mineralized groundwater (in excess of 1200 mg/l), and high concentrations of iron (generally 0,4 but also above 2 mg/l), arsenic (up to 200 μg/l), and the ammonium ion (over 2 mg/l), as well as significantly high NOM levels in groundwater (with $KMnO_4$ demand occasionally exceeding 200 mg/l). Over the past decade, major efforts were made (especially in the Town of Zrenjanin) to find a suitable technology for the treatment of this groundwater; 9 pilot plants were installed and tested but the results were not satisfactory. A highly complex technology (aeration, flocculation/sedimentation, ozonation, multilayer filtration and disinfection, and in some cases reverse osmosis) is required to treat this groundwater (Stauder, 2007).

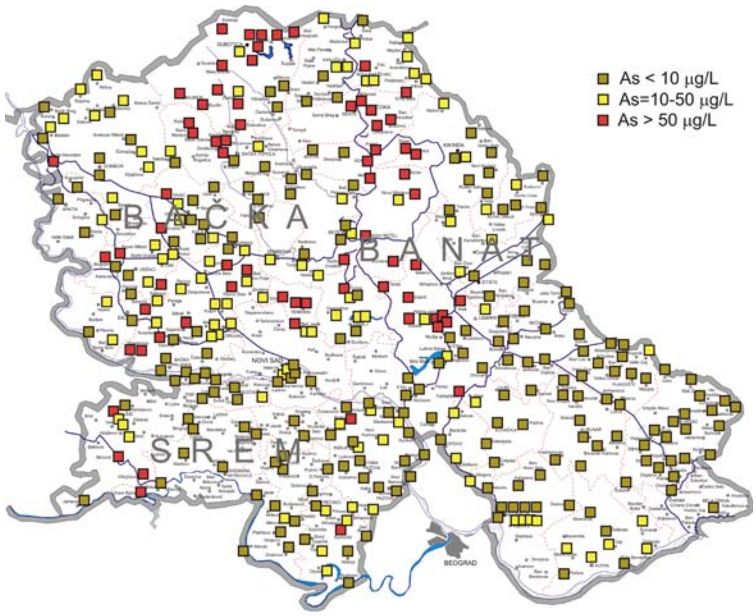

Fig. 1 Arsenic concentrations in public water supply wells in Vojvodina (based on Monitoring Report, 2009)

According to recent data, there are only a few areas in Vojvodina where background arsenic levels in groundwater are below the health limit. Also, there is no general rule that applies to the distribution of arsenic in different aquifers; while in western Backa and southern Backa the highest arsenic concentrations were recorded in groundwater generally tapped from between 100 and 200 meters (from BWC), in southern Banat only 5% of the groundwater samples collected from wells deeper than 70 metres exhibited As> 10 µg/l (Fig. 2). At the same time, arsenic levels occasionally vary to a large extent within in the same aquifer at small distances (i.e. the distance between 2 well fields, Sibnica and Gradska Suma, is less than 1000 meters).

Table. 1: Arsenic content in public water supply wells in Vojvodina (based on Monitoring Report, 2009)

DISTRICT	**TOWN**	**DEPTH (m)**	**WATER-BEARING FORMATION**	**CONTENT As (µg/l)**		
				MIN.	**MEAN**	**MAX.**
WEST BACKA	APATIN	<60	"First" aquifer	0,5	4,0	6,4
	RATKOVO	148-240	Pliocene	22,5	183,3	344,1
	RUSKI KRSTUR	200	Pliocene	38	47,1	55,9
	SOMBOR	65-70	"First" aquifer + BWC	4,2	5,4	6,6
		-	Pliocene	1,8	14,9	25,9
SOUTH BACKA	NOVI SAD	< 30	"First" aquifer	1,8	8,6	37,0
	BAČKI JARAK	130 - 185	Pliocene	28,8	63,6	107
	SIRIG	135	Pliocene	214	221	231
	OBROVAC	280-320	Pliocene	77	102	148
	TEMERIN	120 - 160	Pliocene	16	48,8	62,0
SOUTH BANAT	VRŠAC	80 - 95	BWC	< 0,5	0,7	0,94
	PANČEVO	36 - 54	BWC	1,1	13,7	45,4
	KOVIN	65 - 70	BWC	21,7	25,6	32
SREM	RUMA	50 - 54	"First" aquifer	2,5	3,0	3,7
		144 - 150	Pliocene	1,6	3,5	6,7
	ŠIMANOVCI	85	BWC	11	13,7	17
	OBREŽ	66 - 68	Pliocene	37	41	46
	KARLOVČĆ	80 - 120	Pliocene	45	60	76

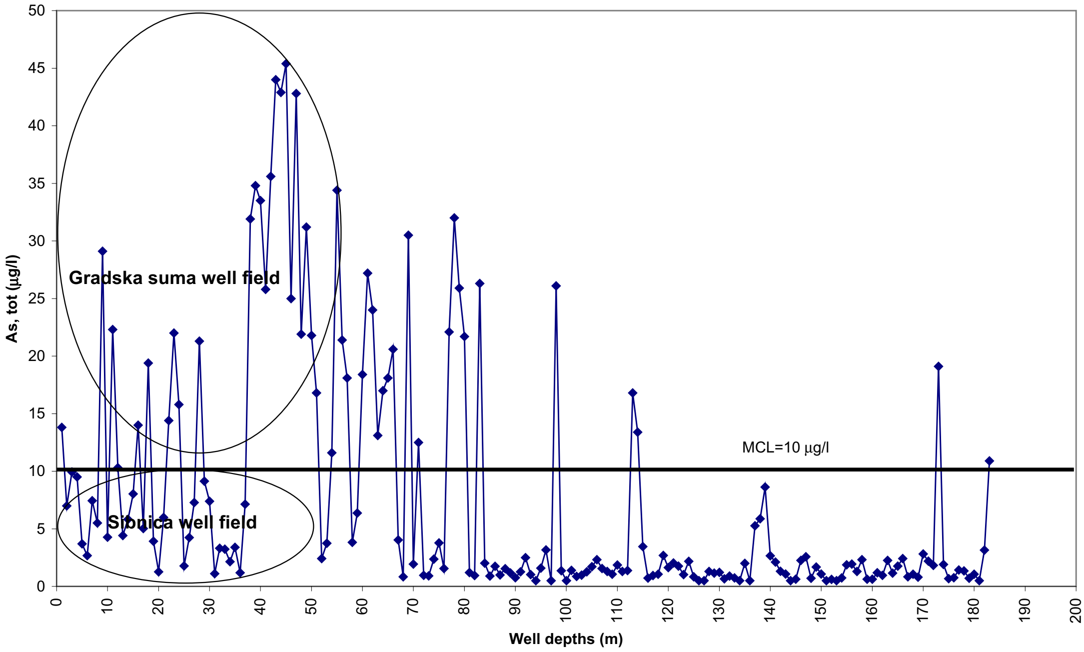

Fig. 2 Arsenic concentrations in public water supply wells in South Banat (Monitoring Report, 2009)

3. SUSTAINABLE GROUNDWATER MANAGEMENT SOLUTIONS AND IMPROVEMENT OF PUBLIC WATER SUPPLY

The inadequate natural quality of the water withdrawn from the main aquifer (As, NOM, NH_4, B...), as well as over-exploitation, prompted a search for sustainable groundwater management solutions. Sound groundwater management involves not only sustainable abstraction (the quantity aspect), but also the preservation of water quality. It is a decision-making process which encompasses all issues pertaining to groundwater abstraction and land use, including regulations and restrictions governing the establishment of wellhead protection areas, or the designation of areas in which aquifers are subject to special protection of groundwater quantity and quality (Dimkic *et al.*, 2008). Water supply issues in different parts in Vojvodina have led to the establishment of various solution selection criteria, the major three being:

1. *the availability of adequate quantities* of groundwater to meet the current and future drinking water demand, or to meet such demand with no adverse impacts (dramatic drawdown, deterioration of water quality, etc.)
2. *natural groundwater quality* that enables relatively simple (and economically-viable) water treatment processes to raise water quality to drinking standards, and
3. *feasibility of developing safeguard zones* around existing and future water sources for water-supply, while at the same time not significantly encroaching on other nearby facilities/activities.

Based on these criteria, two general water-supply solutions were proposed: the development of regional water sources in alluvial deposits of the Danube River (so-called regional or centralized water supply scheme), or the development or expansion of local water sources, along with complex treatment technologies (so called decentralized water supply scheme). According to Water Management Master Plan, water supply issues in the Province of Vojvodina need to be resolved through the formation of regional water supply systems, relying on groundwater sources in the Danube alluvium. Two zones have been identified as the best locations for large-capacity sources: an upstream stretch of the Danube (between towns Apatin and Bezdan) and a downstream stretch of the Danube (between towns Kovin and Dubovac). Toward this goal, activities to date included dedicated field investigations of potential locations for new regional sources of water supply, as well as the preparation of related feasibility studies of regional water supply systems for western Bačka and Banat.

A regional source for central and northern Banat (an area with some 600.000 inhabitants), would be formed in the alluvial plain of the Danube, between Kovin and Dubovac (Fig. 3). With regard to the geological structure, the most common are Pleistocene and Holocene gravels and sands, with a hydraulic conductivity of the water-bearing medium in the range from $1x10^{-4}$ to $1.2x10^{-3}$ m/s (NPV46B, 2006). The studied area is under the influence of backwaters caused by the construction of the Iron Gate Dam and is actively protected by a system of drainage canals and pumping stations that control groundwater levels. The formation of a groundwater source will have a positive effect in that it will relieve the stress currently imposed on drainage system capacity in the riparian area. A forecast of the influence of future groundwater abstraction on this area shows that up to 2400 l/s can be tapped from the riparian belt, 100 m from an existing embankment, with drawdowns of about 6 m. This water quantity is enough to meet the water demand of 13 municipalities in central and northern Banat through the year 2050. The water is of the calcium-carbonate type, moderately hard, with low pH fluctuations in the range of neutral reactions. Low values of sodium and potassium cations and chloride anions have been registered. Organic content ($KMnO_4$ demand) was detected at only two piezometers. In general, iron and manganese concentrations are elevated, while a somewhat high arsenic concentration (0.18 µg/l on average) was detected at only three locations.

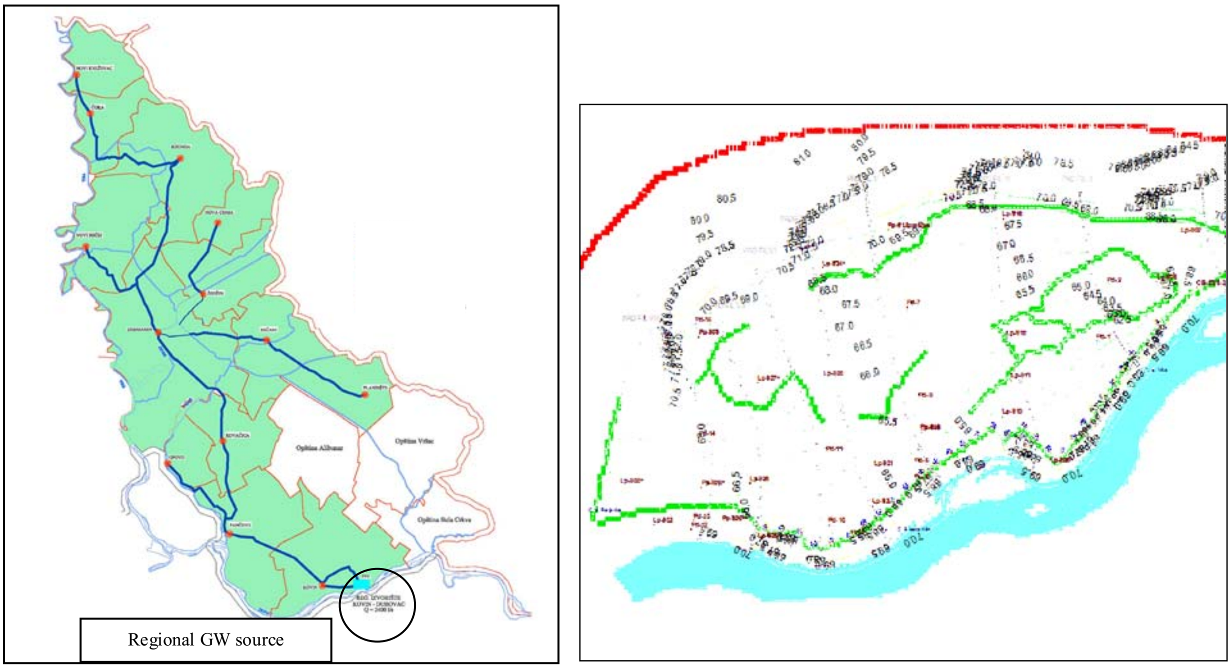

Fig. 3 Proposed regional water supply system for Banat
a) disposition of regional system and b) prognostic model calculations in the area of regional GW source

Feasibility analysis of Banat water supply system showed:

- Centralized water supply system is the more expensive solution compared to de-centralized one (investment costs 340 Mio € compared to 270 Mio €)
- Price of water production is higher in the case of de-centralized system (0,88 € compared to 0,57 €), mostly because of higher level of water treatment needed in case of local waterworks

In general, centralized water supply scheme is more expensive solution in the first 15 to 20 years of operation but after that period financially and by its structure, is very convenient and should be the goal for the future.

4. CONCLUSIONS

The conclusion of the feasibility analysis is that despite the high capital expenditure needed to resolve drinking water issues in Vojvodina by constructing regional systems, such an approach is deemed to be feasible and its benefits outweigh costs. By introducing new, alternative water sources and regional (or semi-regional) water supply systems, harmful health impacts of arsenic-bearing groundwater will be avoided, which is an important benefit of this solution. It would not only be a benefit to human health but also to the development of local communities. In addition to providing sufficient quantities of drinking water of good quality, these systems would ensure efficient use of slowly-renewable groundwater resources. Investigations and hydrodynamic analyses have shown that sufficient quantities of groundwater can be withdrawn from the Danube alluvium in the Apatin-Bezdan and Kovin-Dubovac areas, the quality of which is such that the application of basic treatment methods (aeration, retention, filtration and disinfection) will produce drinking water of good quality.

In addition to providing sufficient quantities of good-quality drinking water, these systems would allow for efficient utilization of groundwater resources from slowly-renewable aquifers. Such an approach to the threatened quantitative groundwater status is in accordance with the principles promoted by the WFD, especially with regard to transboundary water resources, shared with neighboring countries.

Acknowledgements
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Towards a concerted Management of hydrogeological risks in the Iullemeden Aquifer System (SAI)

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Summary

The Transboundary Diagnostic Analysis (ADT) recommended by Global Environment Facility (GEF) was applied to groundwater of the Iullemeden Aquifer System shared by Mali, Niger and Nigeria. Three major transboundary risks were identified: reduction in the water resource, the degradation of water quality, and the impacts of variability/climate changes. Their identification required also the development of a database gathering more than 17.200 water points, a Geographical Information System and a Mathematical model. The model, among others, highlighted the overexploitation of the resource as from 1995 and the interconnection between the Niger River and the groundwater. The good governance of this strategic resource led the riparian countries to adopt a draft-agreement for the establishment of a legal consultation framework for a concerted management and an equitable and rational exploitation of their common resources.

Key words

Shared aquifers, Transboundary Risks, Transboundary Diagnostic Analysis, Management tools, Legal framework, concerted management, West Africa.

1. INTRODUCTION

The Iullemeden Aquifer System consists of a number of sedimentary deposits containing two large aquifers: the cretaceous Continental intercalaire (Ci) in the bottom, overcome by the tertiary Continental Terminal (CT) **(fig. 1)**. It is shared by Mali, Niger and Nigeria and covers a total area of approximately 500.000 km ². It is crossed by part of the Niger River hydrographic network.

The SAI constitutes a strategic resource for the sustainable development of the concerned countries. However, it is:

- *exposed to a fragile and constraining environment*: 1) lower rainfall of about 20 to 30% since 1968; 2) reduction of the runoff of about 20 to 50% with sometimes severe low water levels moving to stop; 3) silting and establishment of sand dunes in the aquifer's areas recharge and in the Niger river hydrographic network;
- *facing several constraints in particular*: 1) difficulties of accessing groundwaters by places because of high depth (more than 600 meters); 2) degradation of water quality (pollution, withdrawing high mineralised deep waters); 3) shortcomings in shared groundwater management among riparian countries.
- *subjected to:* 1) increasing water demand linked to population growth (about 6 million inhabitants in 1970, 15 million in 2000 and a projected 30 million inhabitants in 2025); 2) an exponential rise in abstractions which went from 50 million m^3 in 1970 to 180 million m^3 in 2004.

To identify, analyze and evaluate the hydrogeological risks which can affect groundwater of the Iullemeden Aquifer System, the risk-based management approach was adapted and applied.

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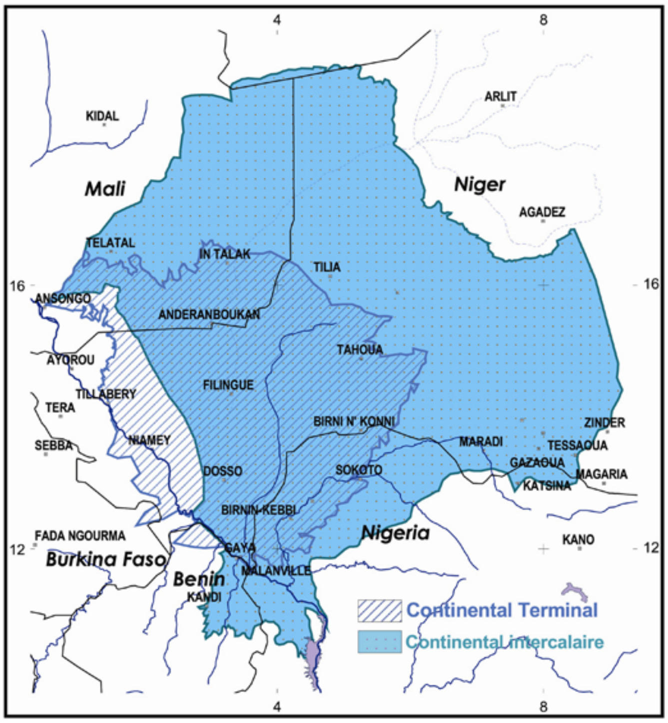

Figure 1: Limit of the Iullemeden Aquifer System

2. OBJECTIVE

The objective of this note is to present the identification of the transboundary risks and their analysis conducted to the groundwater resources of the Iullemeden Aquifer System by using GEF's Transboundary Diagnostic Analysis (TDA) process, which is the first step in GEF's TDA/SAP process that leads to the preparation of a Strategic Action Program (SAP).

The Transboundary Diagnostic Analysis (TDA) is an objective evaluation of the scientific and technical facts based primarily on the use of the best technical and scientific information available and checked. The TDA is used to determine the relative relevance of the sources, the causes and the impacts of the transboundary water issues. Therefore its objectives are:

- identifying, quantifying and fixing priorities for the environmental transboundary issues;
- to identifying their immediate, fundamental and root causes.

The TDA process involved several steps mainly the "prioritisation" of the risks, the causal chain analysis, and the water governance.

3. RESULTS

The analysis of each risk identified by each country (Mali, Niger, Nigeria) through several brainstorming undertaken by their respective national committees consolidated by the contribution of the experts, requires to insure in particular on: (1) the transboundary nature of the identified risk; (2) the outreach of the risk compared to the national priorities and to regional and international conventions as well as the various global initiatives; (3) the impacts of the risk on the economy, the environment and the human health; and (4) the expected profits from the examination of the risk.

The first fundamental sep to make sure of the transboundary characteristic of the risk is to understand the dynamics of groundwater flows in the shared Ci and CT. Important investigation were developed in these aquifers within their natural limits covering the three countries in order to integrate the information and data collected as well as the identified and quantified risks. The main results and outputs achieved are:

a) **Digitalized topographic map:** A topographic reference was elaborated on 1/100.0000 scale with *Arcview* software. The digitalized topography is accompanied by a Digital Elevation Model (DTM). The topographic map extends between the longitudes 0° and 15°E and the latitudes 10° and 22°N. The digitalized area is 2.219.000 km ². It gathers the SAI and part of the lake Tchad basin to examine all the assumptions on the hydraulic relations between the SAI and the other basins.

b) **Digitalized geological map:** The topographic map was used to digitalize the SAI geological map in the same area based on the existing geological maps at 1/500.000 scale in Algeria, Mali and Nigeria and 1/500.000, 1/2000.000 and 1/1000.000 scales of Niger.

c) **Database of the SAI:** The data resulting of more than 17200 water points (boreholes and well) collected in Mali, Niger and Nigeria, were structured, organized and stored in a relational database to the three countries in order to facilitate its use (updates, data retrieval). The Database has five sections: climatology, hydrology, hydrogeology, administrative districts and water use. This Database is linked to the Geographic Information System and the mathematical model in order to facilitate processing of the enormous mass of data.

d) **Geographical information system of the SAI:** From the data and information collected, the GIS layers are prepared in the form of thematic maps which make it possible to present data in a specific projection system. These maps, prepared to the scale of the Basin, make it possible to visualize the information and facilitate its processing. They include the map showing water point distribution per decade (1940 to date), North-South and East-West cross-section maps of the Basin, and piezometric maps of the Continental intercalaire and the Continental Terminal. These maps clearly present the water flow in the aquifers from Mali to Niger and from Niger to Nigeria.

e) **Hydrogeological Model of the SAI: For the first time in the Iullemeden Ba**sin, a mathematicl model was develpoped based on certain assumptions, notably those relating to water abstraction. The model yielded the first results on groundwater flows and estimates of groundwater exploitation status. Its initial results are as follows:

- revelation and quantification of groundwater supply to the Niger River flows; The Niger River receives about 46 million m^3/year from the Continental intercalaire and 79 million m^3/year from the Continental Terminal. River Rima (or Goulbi de Maradi in Niger), a tributary of the Niger River, supplies about 20 million m^3/year to the Continental Intercalary and receives about 12 million m^3/year from the Continental Terminal before its confluence with the Niger River. Hence, the latter is one of the main natural outflows of the system;

- a threshold of overexploitation crossed in 1995, year as from which the taking away (152 m3/an million) exceed the refill estimated at 150 m3/an million) in 1970 **(fig. 2)**.

- highlighting that the **overexploitation threshold was exceeded in 1995,** the year from which abstraction (152 million m^3/year) exceeded recharge which is estimated at 150 million m^3/year in 1970 (red line on fig. 2).

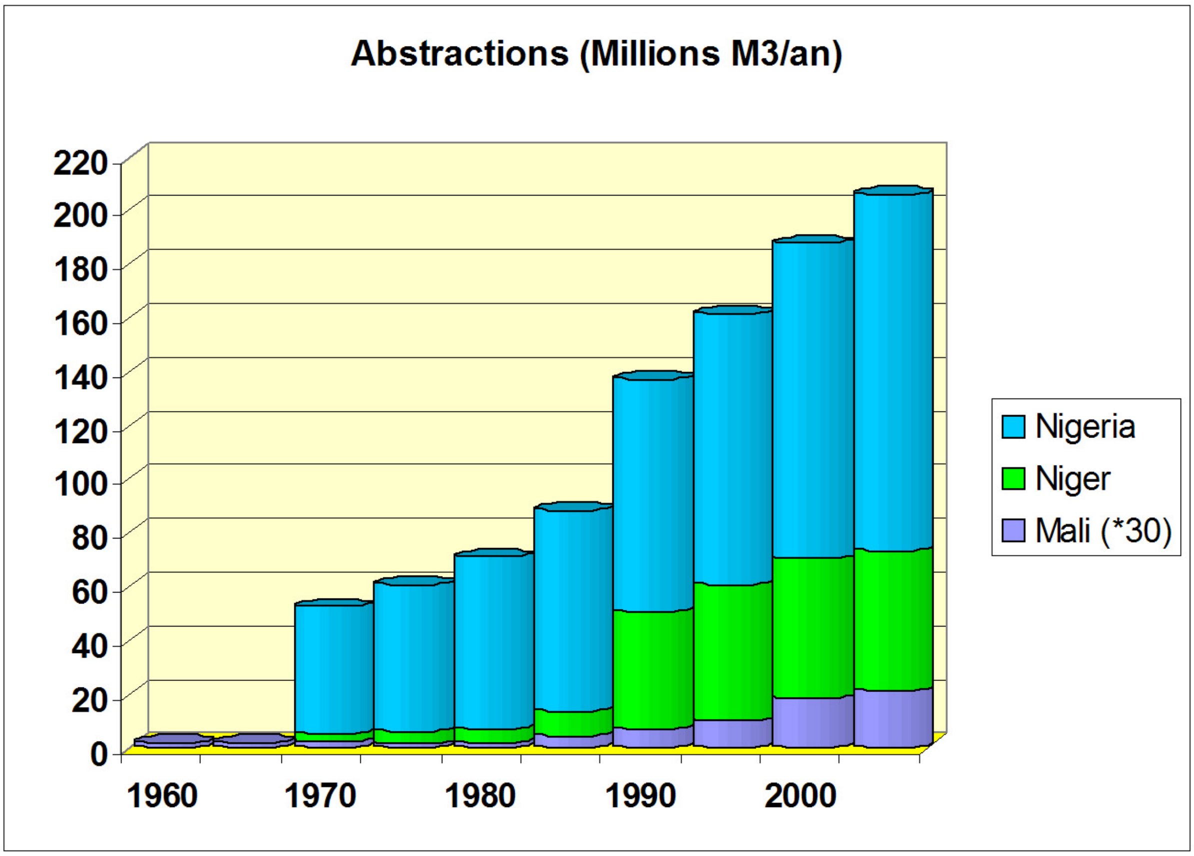

Figure 2: The overexploitation threshold was exceeded in 1995 according to the first estimates.

f) **Hydrochemical data on degradation of water quality:** The deterioration of the groundwater quality the SAI took place naturally because of the presence of undesirable chemical elements like excess of Fluorine contained in the fluorapatite, Ca5 $(PO4)_{3F}$ in the Continental intercalaire aquifer in the political border zone between Niger and Nigeria where the fluorine contents reach values ranging between 9 with 12mg/l (the standard being of 0,7 mg/l and 1,5 mg/l for respective values of temperature ranging between 8°C and 12°C, and 25°C and 30°C). That generated bony and dental fluorosis affecting in particular children less than the teenage. The groundwater quality and the Niger river in general can be also deteriorated because of the human activities (Adelana and al, 2003; Adelana, 2006; Traoré and al, 2006) and the exchanges between the hydrographic network and the shallow aquifer (Orange and Palangié, 2006; Ousmane and al, 2006). It is the case of the Niger River interior delta in the Malian part. The increasingly use of agricultural fertilizers affects the shallow aquifers in particular near to the principal main Niger River watercourse.

Thus the three major transboundary risks, for which one country can not find a sustainable solution, are described as follow:

1. **reduction in the water resources:** This type of risk is characterized by the modification of the groundwater potential in terms of water reduction or water scarcity. This reduction can be due to the combined effects 1) from the progressive water abstraction, and 2) the reduction of the recharge of the aquifers because of the reduction in rainfall. The results of the mathematical modelling of the Iullemeden Aquifers System made it possible to quantify this risk: the **overexploitation threshold was exceeded in 1995,** the year from which abstraction

(152 million m^3/year) exceeded recharge which is estimated at 150 million m^3/year in 1970 (red line on **fig. 2**)..

2. **the water quality degradation:** it was identified as the pollution of the groundwater (shallow aquifer mainly) because of (1) the infiltration of waste water with chemical concentration beyond the quality standards, and (2) the abstraction of (deep) groundwaters with high contamination (i.e. excess of fluoride) conducted by the geochemistry of the geological formation;
3. **(impacts of) the variability and of the climate changes:** This kind of risk is characterized in particular by 1) the silting process in the hydrographic network of the Niger River which reduces the groundwater supply (exchanges between River and groundwater) resulting from the Continental intercalaire (Ci) and the Continental Terminal (CT), supporting therefore frequent floods, 2) the establishment of sand dunes in the recharge areas and on land cover reducing the infiltration of rainwater in particular, 3) the destruction of the areas of hydraulic exchanges due to the migration of the population from arid zones of the wetland areas.

These three major risks t were analysed by using the Causal chain Analysis through their immediate causes, fundamental causes and roots causes **(tabl. 1)**. The root cause also integrates the water governance.

The development of strong foundations for water governance of these strategic resources took place through the development and the adoption, by the concerned countries of a draft-agreement with the enclosed roadmap in order to implement their consultation mechanism.

4. DISCUSSION

The Transboundary Diagnostic Analysis is certainly an effective method for identifying major transboundary issues based on technical and scientific information available, to examine the state of their environment and the fundamental causes of their degradation without being unaware of the concerns and the national priorities. The ADT is a participative approach involving all the stakeholders. For this purpose, it contributes to strengthen solidarity and confidence between them.

However, if it is true that the Transboundary Diagnostic Analysis offers flexibility in its concept, it was conceived, preferably, towards transboundary International visible waters namely: marine water, rivers (rivers and rivers), lakes, and wetlands).

The transboundary International surface waters are well monitored since several decades what is not the case for transboundary groundwater because of their "invisible" character. The monitoring of water level fluctuations is carried out mainly through the projects but not financed by the national budgets. When they are available, their data make it possible to build the common management tools (Database, Geographic Information System, Mathematical model, several thematic maps) which reinforce confidence and solidarity among riparian national teams and allow assessing and quantifying some risks.

Therefore, TDA application and adaptation to International transboundary groundwater need a revue of the ADT/PAS process while starting initially by studying and understanding the hydrodynamic groundwater flows of the systems aquifers shared by the countries concerned. In most cases, the aquifer systems shared by the riparian countries are studied within the political borders in each country without considering their natural limits.

5. CONCLUSIONS

The application of the Transboundary Diagnostic Analysis to transboundary groundwater of the Iullemeden Aquifer System of made it possible to identify three major risks which are: (1) the reduction of resource, (2) the water quality degradation, and (3) the negative impacts of variability/climate changes. TDA also promotes the development of management tools (database, Geographical, Mathematical model Information system) in order to assess and quantify the risks and their impacts on the groundwater resources.

These main risks will be well characterised through the development of the Strategic Action Programme.

6. AKNOWLEDGEMENTS

The authors express their deep recognition to the national focal points and the members of the national committees of coordination of Mali, Niger and Nigeria for their collaboration in the development of the Transboundary Diagnostic Analysis for groundwater that they exploit conjointly.

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Table 3: Causal chain analysis applied to the water resources of the Iullemeden Aquifer System (SAI)

Immediate causes	Major transboundary risks	Fundamental causes	Root causes
• Reduction of the rainfall • Reduction of the runflows in the Rivers • Reduction of recharge (filling of the recharge areas due to silting, etc.) • Réduction de la recharge (colmatage des aires de recharge par ensablement, etc..) • Frequently droughts	Reduction of the water resource	• Increase in water abstraction (increase in the water points) • Increasing water demand (growing population, activities in the social and economic sectors) • Reduction of the recharge because of silting in human activities the recharge areas– land use and land cover)	• Shortcomings in consultation among the riparian countries • Non-application of the laws and rules • Shortcomings in water governance and awareness • Decreasing livelihood
• Natural degradation controlled by geology (mineral paragenesis: strong concentration fluorine-Apatite, nitrates, etc…)	Water quality deterioration	• Pollution from various origins (domestic, industrial, mining, livestock, all kinds of waste water) • Agricultural activities (manures, pesticides) • Discharge of pollutants in the rivers having hydraulic connection with the aquifers • Land uses and change in land use systems	• Not respect of the current laws (Water code) • Shortcomings and lack of monitoring and assessing water quality • Inadequate water governance • Decreasing livelihood
• Increasing of greenhouse gases in the Troposphere	Impacts of variability & climate changes on groundwater	• Deforestation (production of firewood) • Clearing areas for agriculture and other land uses • Migration of the populations from arid zones to wetland areas • Land uses and change in land use systems	• Shortcomings in awareness at national and regional levels • Weakness or lack of commitment of the countries to their financial contribution in the research studies for sustainable solution • Shortcoming and lack of application of the results and outputs obtained from several studies on the climatic risks

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The hydrochemical characteristics and evolution of groundwater and surface water in the western part of the River Nile, El Minia district, Upper Egypt

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ABSTRACT

A combination of major and trace elements have been used to characterize surface water and groundwater in El Minia district, Egypt. The major object of this research is to investigate the groundwater quality and hydrochemical evaluation. The investigated aquifer is the Pleistocene, which composed of sand and gravel of different sizes, with some clay intercalation. The groundwater flow generally from south to north and diverts towards the western part from the River Nile. Fifty-sex, 11, 5, and 2 water samples were collected from the Pleistocene aquifer, River Nile, Ibrahimia canal, and Al Moheet drain, respectively. The water was analyzed for major and trace elements. The toxic metal concentrations of Al Moheet drain are higher than those in the River Nile and the Ibrahimia canal. Cr, Hg, As, and Cd concentrations in the River Nile and Ibrahimia canal are fluctuated above and below the WHO drinking standards. Se concentration in River Nile and Ibrahimia canal is below WHO drinking and irrigation guidelines. Total dissolved solid concentration in groundwater is generally low, but it is increased due the western part of the study area. The geographic position of the River Nile, Ibrahimia canal, and Al Moheet drain impact on the groundwater quality. The PHREEQC confirm the high mixing proportions from the River Nile into the groundwater and decline away from it. In addition to the thicknesses of the Pleistocene aquifer and aquitard layer enhance the River Nile and agricultural wastewaters intrusion into the aquifer system. The toxic metal concentrations (Pb, Cd, Cr, PO_4, Se, Mn, As, Hg, Ni, Al, Fe, and SIO_2) in groundwater were increased mainly in the northwestern and southeastern part (far from the River Nile). It is attributed to anthropogenic, high vulnerability rate (unconfined), and partially lithogenic. Most groundwater are unsuitable for drinking and irrigation purposes with respect to Se concentration, while they are unsuitable for dinking according Mn, As, and Hg contents. There are some Cd and Pb anomalies concentrations, which cause severe restriction if used in irrigation.

1. INTRODUCTION

Groundwater preservation and protection measures have been generally overlooked in the majority of the practices (Shaibani 2008). Groundwater chemistry depends on geology, degree of chemical weathering of various rocks, quality of recharge waters, and anthropogenic. The evaluation of groundwater resources for development requires an understanding of the hydrogeology and hydrogeochemical properties of the aquifer. The investigated Pleistocene aquifer is highly vulnerable to contamination because of unconfined permeable aquifer and fractured thin soils (Holocene). The heavy metals are widely distributed as an anthropogenic pollutant (Rangsivek and Jekel 2005). Cd is often present in artificial fertilizers and this heavy metals may accumulate in soils in areas that have been used for agriculture for long period (Rattan et al. 2005; Mahvi et al. 2005; Nouri et al. 2006). The objective of this study was to evaluate and map regional patterns of major elements and toxic metals (Pb, Cd, Cr, PO_4, Se, Mn, As, Hg, Ni, Al, Fe, and SIO_2) in groundwater system, River Nile, Ibrahimia canal, and Al Moheet drain in the western part of El Minia district **(Fig. 1).** The study area is delineated by latitudes 27^o 30' and 28^o 40' N and longitudes 30^o 30' and 31^o 00' E. The area is arid to semi arid, hot climate, dry, rainless in summer and mild with rare precipitation in winter. The rainfall average value for 15 y ranged from 23.05-33.15 mm/y, evapotranspiration in El Minia is 4897.91 mm/y (Korany 1980 and 2008). The min. and max. temperature are 4.5 (January) to 20.5 ^oC (August) and 20.7 (January) to 36.7 ^oC, respectively. The mean monthly relative humidity during daytime ranged from 36 % in May to 62 % in December (Korany 1984). The waterlogging problem is common in Nile Valley and affect plant growth and soil degradation. Therefore, the groundwater degradation resulted from waterlogging, lithogenic, and anthropogenic impact.

2. GEOLOGY AND HYDROGEOLOGY

The River Nile passes through high eastern and western calcareous plateaus with a general slope from south to north about 0.1 m/km (Korany et al 2008). The Nile tends to represent the eastern part of the Valley, therefore, the cultivated area is wider in western part than in the eastern. The investigated area was west of the River Nile (floodplain). Geomorphologically, the study area is moderately elevated plateau with respect to River Nile and composed of mainly limestone covered with alluvial deposits of sands and gravels **(Fig. 2).** The Eocene rocks constitute the main outcrops, capped by poorly consolidated sand, gravel, and clay (Quaternary aquifer). The Pleistocene sediments is the main aquifer in the Delta and Nile valley, it composed of massive cross bedded fluvial sand with gravel and clay sediments. The stratigraphic sequence is built up of from base to top as follows (Tamer et al., 1974); Middle Eocene limestone intercalated with shale; Pliocene undifferentiated sands, clays, and conglomerates; Plio-Pleistocene sand and gravel with clay and shale lenses; Pleistocene sand and gravel with clay lenses; and Holocene silt and clay. The groundwater exists in different aquifers; Pre-Tertiary Nubian sandstone; Eocene limestone; and Quaternary. The investigated aquifer is the Pleistocene, which composed of sand and gravel of different sizes, with some clay intercalation. The thickness of the aquifer ranged from 25 to 300 m, from desert fringes to central Nile Valley, respectively (Sadek 2001). The aquifer is overlained and underlained by semi pervious silt and clay and Pliocene clay, respectively. The semi confined bed (1-15 m thickness) is missed outside the floodplain and the aquifer become unconfined. The groundwater flow generally from south to north and diverts towards the eastern part, where large volume of groundwater are drained from the River Nile (Tantawi 1992). The aquifer is recharged by Nile water, irrigation system, drains, agricultural wastewater, vertical upward leakage from the deeper saline aquifers (Korany 1984). The study area is highly affected by faulting mainly in NW-SE direction **(Fig. 3)**. The Nile Valley is essentially of structural origin (Beadnell 19900; Ball 1909; Sandford and Arakell 1934; Attia 1954; Said 1962, 1981, 1993).

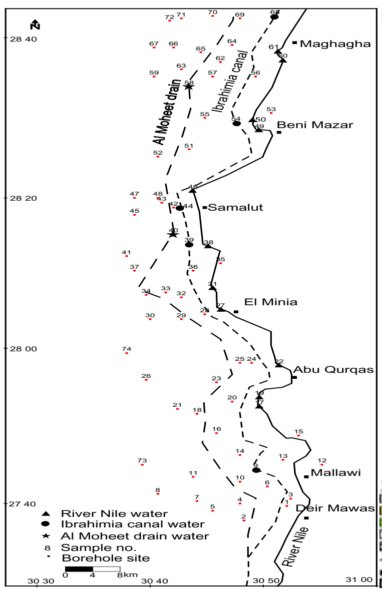

Fig. 1 Location map of the El Minia district

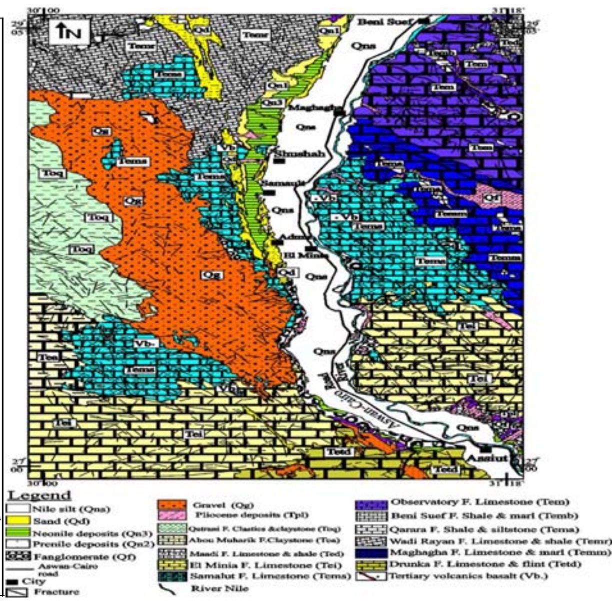

Fig. 2 Geologic map of the study (Conoco Coral Egypt 1987 and Heleika and Niesner 2008)

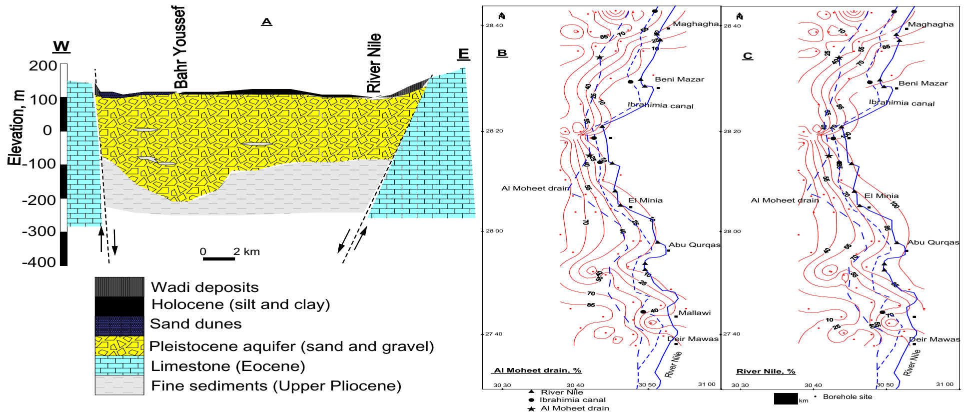

Fig. 3 Cross section across the Nile Valley (A) (modified after IWACO and RIGW 1986); percent proportions of River Nile (B); and Al Moheet drain (C) in groundwater, El Minia district.

3. MATERIALS AND METHODS

Fifty-sex groundwater samples were collected from the Pleistocene aquifer, 11 water samples from River Nile, 5 water samples from Ibrahimia canal, and 2 water samples from Al Moheet drain in El Minia district. Water analyses were completed during summer season (2009). The groundwater samples were taken by means of well pumps after a pumping period of at least 1 hr. The location site is determined by GPS instrument. Pre-rinsed polypropylene bottles were filled with the samples, sealed tightly. pH, electrical conductivity, and temperature are measured in situ using portable field kite. Cl, HCO_3, Ca, and Mg were measured by titration, while SO_4 is estimated by turbidity, and Na and K were analyzed by flame photometer. The samples were acidified with ultra pure nitric acid, after filtration, to avoid complexation and adsorption. The acidification was accomplished in situ and in case of toxic metals determination. Then the samples transported to laboratory and then stored in a refrigerator at approximately – 20 ^{0}C to prevent change in volume due to evaporation The toxic metals (Pb, Cd, Cr, PO_4, Se, Mn, As, Hg, Ni, Al, Fe, and SIO_2) were determined by the ICP (Inductive Couples Plasma)-AES (Optima 3000; Perkin Elmer). The analyses were carried out at Environmental monitoring in Embaba.

4. RESULTS AND DISCUSSION

4.1. Surface waters chemistry (River Nile, Ibrahimia canal, and Al Moheet drain)

Cr, Hg, As, and Cd concentrations are fluctuated below and above the WHO standards for drinking in River Nile and Ibrahimia canal **(Fig. 4a, b, c, and d)**. It is attributed to fertilizers applied that contained some impurities of these toxic metals. The Hg level for drinking water is 1 µg/l (Government of Nepal 2005), which is stricter than the WHO guideline (2004) 2 µg/l (Nathaniel et al. 2008). Cd seems to be related to agricultural activity, especially the use of fertilizers, which are dominantly of the super-phosphate type manufactured from marine phosphorite that contains up to 20 ppm Cd (El Kammar, 1974). Pesticides also could contribute to the high Cd content in the study area (Bowen, 1966). Cd was clearly remobilized from all marine sediments (Calmano et al. 1988). Symptoms of chronic As poisoning have been recorded in populations reliant on water supplies containing >50 µg/l As in several countries. This value currently constitutes the permissible limit of the European Union, the United States Environmental Protection Agency (1976) and most national governments with respect to As in potable water. Epidemiological evidence of adverse effects at lower exposure levels has, however, prompted the WHO (2004) to promote an interim guideline of 10 µg/l (Van Leeuwen 1993). They are much increase in Al Moheet drain than those in River Nile and Ibrahimia canal, cause by sanitary and agricultural wastewaters dump. They are below the WHO guideline for irrigation in River Nile and Ibrahimia canal, while Al Moheet drain exceeds the guideline. Therefore Al Moheet drain unsuitable for drinking and irrigation purposes. Se concentration in River Nile and Ibrahimia canal is below WHO guidelines for drinking and irrigation **(Fig. 4e)**. Ni and Pb are below guidelines for irrigation and drinking purposes, respectively **(Fig. 4f and g)**. Se, Ni, Pb, and PO_4 **(Fig. 4h)** concentrations increase in Al Moheet drain due to anthropogenic sources.

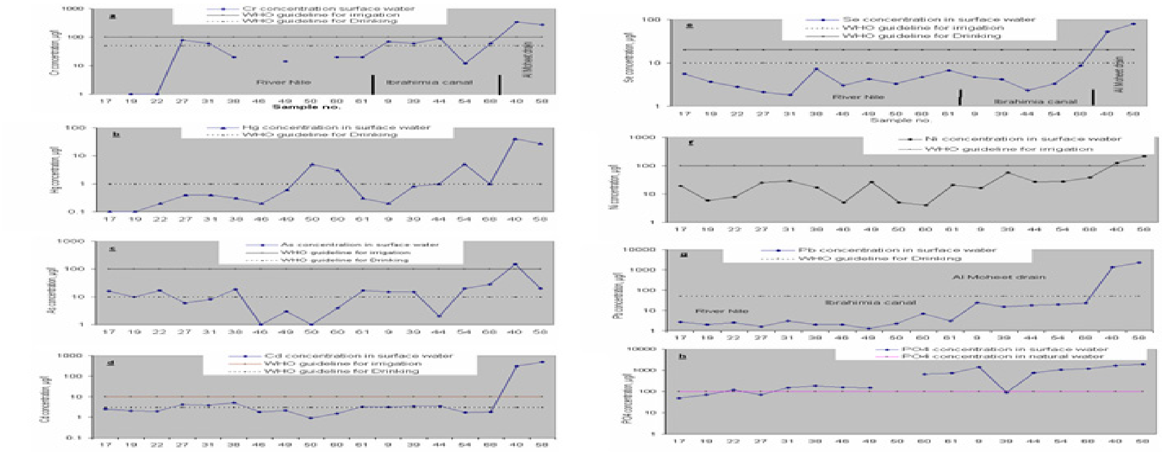

Fig. 4 Toxic metal concentrations in surface waters compared with WHO standards

4.2. Groundwater chemistry

The total dissolved solids (TDS) concentration is generally low, attributed to contribution from River Nile and Ibrahimia canal. The TDS concentration increased due the western zone of the study area, caused by low River Nile recharge, Al Moheet drain wastewater infiltration and agricultural wastewater leaching in the western part. The Quaternary aquifer thickness increased due the River Nile area and decreased in the desert fringes (western part). The aquifer receive low volume of fresh recharge water due the western part (low thickness), meanwhile the wastewaters infiltration increase the groundwater salinity. On the other hand, in the eastern part (high thickness), the aquifer receive much more recharge from the River Nile, which dilute the aquifer in the eastern part. The semi confined silt and clay bed (Holocene) increase in thickness due the River Nile area that decline the wastewaters infiltration than in the western part (low aquitard thickness and unconfined).

The aquifer in the western part is vulnerable to pollution than in the eastern part. The percent mixed proportions from the River Nile and Al Moheet drain, determined by PHREEQC model (AquaChem), was shown in **Fig. 3B & C**. It indicate that the mixing proportion from the River Nile and Al Moheet drain increased due the eastern and the western part, respectively. It confirm the aquifer dilution from the River Nile in the eastern part and aquifer contamination from the agricultural and sanitary wastewaters in the western part. Concentrations of Na, K, Ca, Mg, HCO_3, Cl, and SO_4 exhibits the same trend of the TDS concentration. They derived mainly from anthropogenic and partially from lithogenic sources. Overall, the water chemistry is characterized by Na (mean 27 mg/l) and Ca (mean 36 mg/l) as the dominant cations**.** The HCO_3 (mean 220 mg/l) and Cl (mean 25 mg/l) are the predominant anions. These fluctuated concentration ions vary geographically with groundwater flow, geomedia, River Nile, anthropogenic sources, and the interaction between the different aquifers.

The values of distribution of Pb, Cd, Cr, PO_4, Se, Mn, As, Hg, Ni, Al, Fe, and SIO_2 concentrations in groundwater of the studied region were presented in **Fig. 5a-l**. These maps provide a basis for making area-wide generatizations concerning the distribution of water quality parameters and serve to isolate water quality problem areas. There were differences between the contents of groundwater and heavy metals in each sub region, especially northwestern and southeastern part. The latter areas tended to be more concentrated in most toxic metals **(Fig. 5a-l)**, attributed to Al Moheet drain wastewater, agricultural infiltration, and partially lithogenic. Most of the groundwater are unsuitable for drinking and irrigation purposes with respect to Se **(Fig. 5e)** and unsuitable for drinking with respect to Mn, As, and Hg concentrations **(Fig. 5f-h)**. There are also some anomalies spots of Pb and Cd concentrations **(Fig. 5a and b)**, led to severe impact if used in irrigation. Most toxic metals derived from Al Moheet drain, agricultural wastewater (fertilizers, manures, and pesticides), and lithogenic dissolution. The latter process may contributed mainly to Mn, Fe, and Hg. The aquifer was enhanced by unconfined type in the western part to semi confined in the central and eastern part, therefore, the vulnerability rate is increased due the western part. The low concentration of SiO_2 in groundwater, reflect low solubility of feldspars, quartz, clay minerals and other common silicate minerals. The US Department of Health and Welfare (1962) recorded 10 ppm as safely values for household uses, which found in surface and ground waters. The phosphorus concentration in natural water is 100 µg/l (Bouwer 1978), the extensive use of super phosphate fertilizers contributed the PO_4, Cd, and Pb concentrations in groundwater.

4.3. Exchangeable estimated ratio and Hydrochemical ratios

The exchangeable sodium ration and magnesium hazard distribution increased in the eastern and western part, respectively. The magnesium hazard was attributed to contamination from lithogenic and anthropogenic in the western part. The sodium adsorption ratio (SAR) is low (SAR 0.69 to 1.5). Ca/Mg ratio decreased due the western part, indicate a contamination from the lithogenic (dissolution of carbonate sediments) and anthropogenic (agricultural wastewater). Girdhar and Yadav (1986) have reported that the lower Ca/Mg ratios in irrigated water (poor or good quality) and /or soil solution of both productive as well as salt affected soils induce dispersion and subsequently decrease crop yields. The Ca/Mg values below unity (northwestern part) may reflect the interaction between the groundwater and the host rock, which contain dolomite (Plummer et. al. (1976). Furthermore, values above unity (in the western part) clarify the dissolution of calcite/or gypsum minerals, which are actually represented in the lithological units. The Ca/SO4 ratio increased in the northern part and more or less due the western part. It attributed to the dissolution from limestone Eocene and agricultural impact, meanwhile the SO4 concentration decline by reduction. The Na/Cl equivalent ratios were > 2 in the northeastern part , indicate a sodium source rather than halite or surface irrigated water, such as rock-bearing minerals according to the following equation:

$$Ca^{2+} + 2Na\text{-clay} \rightarrow aNa^{+} + Ca\text{-clay}$$ (Afzal et. al. 2000)

Furthermore, the Na/Cl ratio is always above unity indicates that Na+ has been enriched in the water and of meteoric origin. The total hardness in groundwater ranged from moderately hard in the eastern part to hard and very hard due the western part.

5. SUMMARY AND CONCLUSIONS

The Pleistocene aquifer is vulnerable to contamination due to unconfined condition especially due the western part of the study area. The total dissolved solids concentration increased in the western part, attributed to geology, hydrogeology, and anthropogenic. Poor water quality irrigating water occurs mainly in the southwestern and northwestern part. Al Moheet drain contains higher toxic metal concentrations than Ibrahimia canal and River Nile.

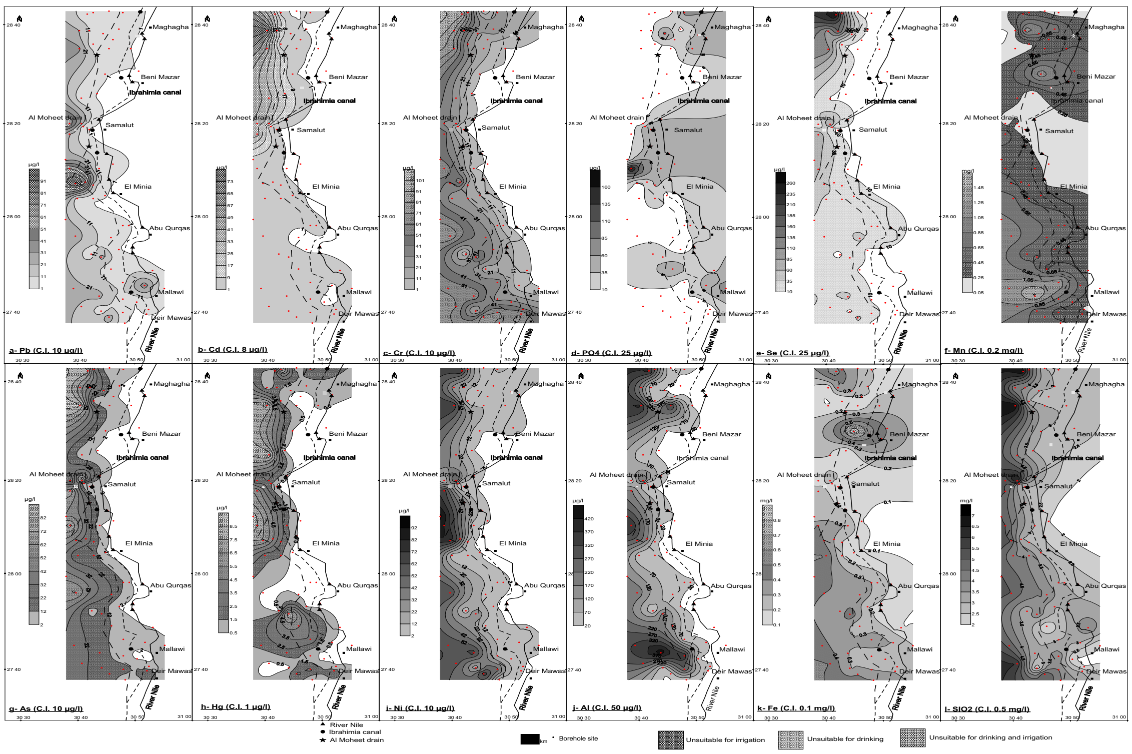

Fig. 8 Toxic metals distribution in groundwater in El Minia district.

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Guarani Aquifer System Project: Strengths and weaknesses of its implementation

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ABSTRACT

Between March 2003 and January 2009, with a budget close to U$D 27,000,000, the Project for Environmental Protection and Sustainable Development of the Guarani Aquifer System (*GASP)*, was implemented by Argentina, Brazil, Paraguay and Uruguay. These countries share one of the most important groundwater reserves in the world, covering an area of over one million km^2 with a population of approximately 90 million inhabitants. The magnitude and characteristics of the project, the various levels of knowledge and expectations of different sectors from the involved countries had an impact that went beyond the scientific-academic domain. Thus, the project aroused the interest of general society, motivating analysis, debate and sometimes questioning the implementation process. Considering the significance of the project and its pioneering nature in the field of cross-border groundwater at a regional level; the relevant aspects of the implementation of the *GASP* in Argentina were analyzed as "*lessons learnt*", pointing out strengths and weaknesses of its implementation. The concepts expressed in the document do not constitute an official position of the Republic of Argentina; but a display of the personal opinion from the authors who have taken an active participation in the project. Among other relevant matters, it strikes as evident that a cross-country project does not necessarily imply symmetry of knowledge, use, strategic importance and appraisal among the countries that share the resource. This scenario is currently repeated between the provincial governments of Argentina as a result of the Federal System of Government. It has also been demonstrated that long-standing projects of ambitious targets, dependent on top-level political decisions are affected by government's rotations. Therefore, it would be desirable to undertake initiatives of a lower scope, with more austere but attainable objectives, that entail a shorter run time that would avoid or mitigate these situations. With the experience that "urgent situations prevail on important ones", it is understood that: The end of international financing and the "preventive" character of the project, constitute risk factors for the continuity and realization of the objectives originally raised. In terms of optimization, we should achieve a constant coverage to avoid interruption and / or postponement of objectives.

Key words: Cross-border groundwater /Guarani Project / Lessons learnt

1. INTRODUCTION

The Project for Environmental Protection and Sustainable Development of the Guarani[1] Aquifer System *(GASP)* was created as a tool to support the governments of Argentina, Brazil, Paraguay and Uruguay, as well as for the establishment of a management framework of the Guarani Aquifer System *(GAS)*, which includes technical, institutional and legal aspects, required for its protection and sustainable use, (OAS, 2009).

Its implementation began in March 2003 and ended in January 2009 following the guidelines and procedures defined by the Global Environmental Facility *(GEF)*, the World Bank *(WB)* and the Organization of American States *(OAS)*. The project allowed the consolidation of technical and

[1] The name Guaraní derives that its extension coincides roughly with the great nation Guaraní, native people of the region.

scientific knowledge, public participation, education, communication, diffusion and the establishment of a coordination and management proposal of the transboundary aquifers.

Figure 1 shows various time-periods associated directly or indirectly to the development of *GASP*. Even though execution was estimated to take place in four years, some activities were developed in more than 10 years, during which multiple government renovations that influenced the progress of *GASP* occurred.

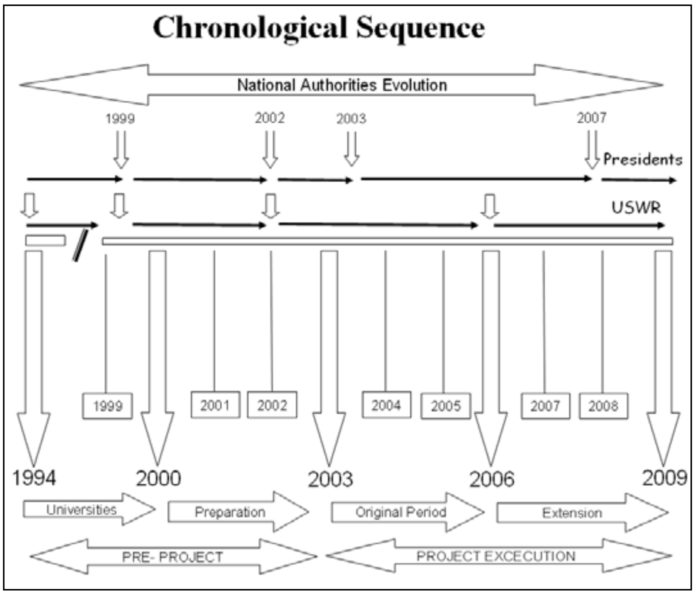

Figure 1 Activities related to the GASP

The *GASP* did not focus exclusively on groundwater research, but expanded its analysis to aspects related to the institutionalization, legislation and administration of the transboundary resources that constitute the necessary pillars for an efficient management.

In 2004, Foreign Office's authorities from the countries involved created an a*d hoc* group with the aim of elaborating an "agreement project" that could be used as a regulatory and institutional framework of the *GASP*. The group was in session until the end of 2005 and developed an agreement project that was finally not considered during the implementation period.

1.1. Organizational Structure

Water Resources, Environment and Foreign Affairs' Offices of Argentina, Brazil, Paraguay and Uruguay created the Project Steering Committee *(PSC),* with the support of a Collegiate Coordination *(CC)*, made up of National Coordinators *(NC)*. The administration of *GASP* was carried out through a General Secretariat *(GS)* that had technical and administrative supervision roles.

The National Units of Implementation of the Project *(NUIP)* were composed of public officials from each country with expertise in water resources, environment and foreign affairs. In Argentina due to the government's Federal System, the provinces have the head domain of the resources; therefore representatives from the involved provinces - Misiones, Corrientes, Entre Rios, Formosa, Chaco and Santa Fe - were also integrated. The organic structure was completed by Local Government Committees (*LGC)*, established in the pilot project areas. Argentina and Uruguay shared the Concordia (Argentina)-Salto (Uruguay) Pilot Project.

1.2 Budget

The total cost of U$D 26.760.000 was composed of 13.4 million from the *GEF* non-refundable fund, 12.1 million as matching funds to what was provided by countries and 1.26 million from cooperation agencies: International Atomic Energy Agency (*IAEA),* Geological Survey of Germany *(BGR)*, and the Bank Netherlands Water Partnership *(BNWPP).*

In the Project Implementation Plan *(PIP)*, seven components of compensation were defined: 1) General Studies 2) Nodes / *SISAG* / *TDA* / *SAP* 3) Public participation and diffusion 4) Follow up and monitoring 5) Pilot Project 6) Geothermic potential and 7) Operational expenses. Argentina committed 1.923.650 U$D and complied with it through i) taxes ii) acquisition and provision of services or public works, iii) operational expenses, and iv) Training activities. No compensations were identified in the form of funds' transfers.

There were differences connected to the increasing compensations' costs by budget's component in the *PIP* and those entered through the system implemented by the *GS*. These disparities derived from the underestimation or overestimation of the calculations at the preparation stage. The integration of the provincial operating costs also added variations to the initial budget. This led to an adjustment of the figures assigned to the *PIP* during implementation.

1.3 Legal and institutional aspects of Argentina

As a result of the Federal System of government adopted by Argentina, several jurisdictional levels are to be found: being national and provincial the most significant ones. Provincial states have the domain and jurisdiction over water resources and, consequently, they define their regulations, laws and administrative organizations.

The existence of multiple institutions with the competence to interfere in water resources – at a national, federal, regional, provincial and municipal level – results in a fragmentation and overlapping of the resources management. In addition, given the high percentage of water resources with an interprovincial nature, the national government has fostered the creation of watershed organizations to mitigate the dissolution of the water system and promote an integrated management of water resources.

The six provinces connected to *GAS* have diverse legislations and an organization with various levels of efficiency in its implementation. However, in spite of administrative differences, important similarities were found which allowed the creation of coordinated management policies.

2. LESSONS LEARNT

In the belief that "every experience is valid, even if bad, so as to not repeat it" we listed as *lessons learnt* the strengths and weaknesses related to the project's implementation.

2.1 Strengths

- The initial will declared by the four countries involved in the preparation and implementation of the *GASP*.
- Advances in groundwater knowledge of the *GAS*, were documented in more than ten thousand legal pieces.
- The hierarchical organization of the transboundary and interstate groundwater resources prompted a legal, institutional, national and regional development in water resources matters.

- The search for participation and social consensus during the implementation of the project.
- The consideration and participation of native populations in the *GASP*.
- The simultaneous regional and local levels of analysis. The regional level of analysis allowed a global and integrated vision while the pilot areas resulted in viable tools for coordinated work and the comprehension of crossborders local topics.
- The creation and operation of the *PSC*, composed of senior authorites, resulted in an efficient mechanism for the exchange and analysis of information. It also became an agile tool to make decisions and to search consensus on the guidelines of the project among the *NUIPs*' representatives.
- The integration of a local leader (facilitator) from the beginning of the project strengthened the activities developed in the pilot areas.
- The possibility of hiring an assistant to reinforce the activities of the National Coordination.
- The training of regional technicians and professionals in matters related to the knowledge and management of groundwater, particularly in the *TDA* and *SAP* methodologies.
- The adoption of an internship program allowed access to a specialized training to a large group of professionals from governmental institutions.
- The creation of specific university and citizenry funds favored the development of scientifc, technological and social activities.
- The creation and implementation of a diffusion plan of activities for the *GASP*.
- The co-financing of the venture through a compensations' system.
- The provision of equipment to allow the continuity of the *GASP's* activities.

2.2 Weaknesses

- Changes of representatives at the *PSC,* which generally derived from government's renewals in each country, resulted in delays and discontinuities in the development of the project.
- The creation of the *NUIP* did not take into account the federal system of government. Argentina had to accommodate its structure to incorporate the provinces which have domain over water.
- The organizational structure presented during the project showed the actors in a static way, which made difficult to identify the relationships among them (Fig. 2a). It is considered that the diagram in Fig. 2b would symbolize the functional relationship amid actors, as well as presenting the dynamics of the *GASP* in a more realistic approach.

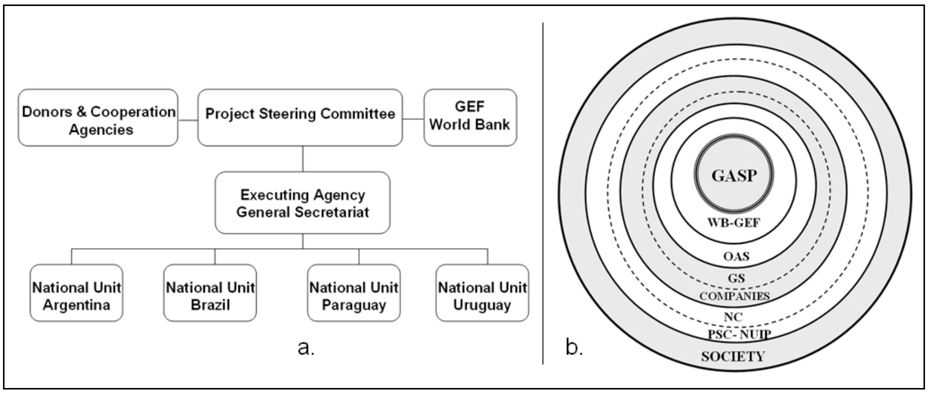

Figure 2 Functional relationships of *GASP´s* actors.

- The countries' limitations in the control and supervision faculties over the project's actions.
- The hydro-geological slant in the working team at the *GS* did not contemplate interdisciplinary aspects enunciated in the projects' goals.

- The delay in the implementation of the communication and diffusion plan, gave way to the propagation of the so-called "*hidromitos*" (groundwater myths) in detriment of the *GASP*.
- The delay in the development of the *GAS Information System, SISAG,* conditioned its full operation during the execution period.
- Modifying the due dates originally planned by the *PIP*. The extension of the implementation period, subject to a fixed budget, resulted in the reduction of planned activities, expanding administrative expenses in detriment of the committed actions.
- The incapacity to fulfill the formal goals of the project during the implementation period. The initial will of the countries was not legally reflected in a multilateral agreement that would allow the introduction of a permanent mechanism of coordinated management of the *GAS*.

Regarding the weakness presented, it is possible to highlight:

- Except for the first and the last, all weaknesses could be easily corrected.
- The strengths and weaknesses resulting from the *GASP*'s implementation, referred specifically to the Republic of Argentina. However, they could also be valid for the other participant countries.

3. EVALUATION

After listing the strengths and weaknesses of the implementation of the *GASP,* in a descriptive form, it is relevant to complement such an approach through an assessment analysis.

Failure to agree on the adoption of a management framework during the implementation period would, "a priori", cause to describe it as unfinished in regards to a formal compliance. Nonetheless, it is believed that given its pioneer and preventive nature in the field of transboundary aquifers, in addition to its regional magnitude and the obtained scientific and technical advances, it would be possible to evaluate the implementation process as a whole.

Based on all of the above, we firmly believe in the success of the GASP and the possibility of replication in other regions (*Giraut et. al.,* 2009). We point out some of the lessons that its implementation has left:

- The model of the implemented project, based on academic support administered by governmental agencies with broad participation, diffusion and awareness of the public and private sector, resulted appropriate for the goals of the *GASP*.
- The implementation design of the *GASP* had flexible and agile mechanisms that allowed making unexpected adjustments in the *PIP*.
- It was observed that long term projects with ambitious goals, dependent on political decisions are of difficult fulfillment in the implementation times.
- It would be advisable to initiate programs with more austere objectives, in shorter-terms so as to achieve the proposed goals and to avoid delays as a result of multiple government changes.
- It was understood that transboundary resources do not necessarily imply equal knowledge, use, strategic importance, evaluation, etc. among the countries sharing the resource. This scenario was also evident among the provincial states of Argentina, as a result of its Federal System of Government.

4. CONCLUSIONS

The *GASP* showed that a *Transboundary Aquifer Management System* requires the implementation of actions of diverse nature:

The initial challenge is to combine the will of the different members to achieve a common goal, respecting existing differences and moving forward gradually on the coincidences over the management of the transboundary resources.

Use a "*top - down approach*" to put actions into practice through the strengthening of the institutional capacities, legal reconciliations, and the adoption of common political decisions. In addition, a "*bottom - up approach*" fostering participatory systems through education and the culture of water which have been developed by the *SAP*.

The implementation of the project demonstrated the political will of the four countries to work together during six years in order to achieve the protection and sustainable management of the *GAS,* independently of the subscription to a multilateral agreement during the implementation period.

Even though the preventive nature of the GASP constituted a virtue during its implementation; it could become a disadvantage for the concretion of actions since there is a risk of postponement for urgency matters, dependent on each of the countries' reality.

5. ACKNOWLEDGEMENTS

It is acknowledged that the development of the *GASP* could not have been possible without the will of the countries involved, the financial support of the Global Environmenetal Facilty, the World Bank, the International Atomic Energy Agency, the Bank Netherlands Water Program Partnership, and the Organization of American States in its executive character. The authors also thank Lida Paula Roberti for the English version of the presented project.

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LIST OF ACRONYMS

BNWPP – Bank Netherlands Water Partnership Program
BGR - Geological Survey of Germany
CC – Collegial Coordination
NC – National Coordinators
GAS – Guarani Aquifer System
GASP – Project for Environmental Protection and Sustainable Development of the Guarani Aquifer System
GEF – Global Environment Facility
GS - General Secretariat
IAEA - International Atomic Energy Agency
NUIP - National Units of Implementation of the Project
OAS – Organization of American States
PIP – Project Implementation Plan
PSC - Project Steering Committee
SAP – Strategic Action Plan
TDA - Transboundary Diagnostic Analysis
SISAG - Information System on the Guarani Aquifer System
USWR - Under-secretariat of Water Resources
WB - World Bank

A hydro(geo)logical model for the Holocene history of the SW part of the Nubian Sandstone Aquifer System using climate model scenarios and analyses from Lake Yoa (Chad) sediments:
Can the use of information contained in lake sediments improve the level of knowledge of the aquifer?

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ABSTRACT

Recent lake sediment analyses in the Ounianga region (NE Chad) provide a unique climate archive in the Saharan region from Mid-Holocene on. A multidisciplinary project to reconstruct the environmental conditions is presented here, focussing on hydro & hydrogeological modelling as a key link between climate and lake-proxy. On the other hand, for such a large aquifer as the Nubian Sandstone Aquifer System, water resources evolution forecasting and management requires the knowledge of its properties as well as its long transitory trends. Improvement in the characterization of the history of the aquifer as well as the issue of the constraining power of lake sediment analysis on aquifer properties are addressed here.

Key words: NSAS, Chad, hydrological model, climate proxy

1. INTRODUCTION

The Nubian Sandstone Aquifer System (NSAS) is one of the largest African Aquifer systems, spreading over 4 countries (Chad, Sudan, Egypt, Libya). Its large extensions - roughly 2 millions of km and maximum depth of 4000 m (Gossel *et al.*, 2004) for a fresh water composition provide very large water reserves. The estimation of the available water volumes and of the aquifer hydraulic properties represents a first step to develop a pumping strategy including locations and associated rates. But the assessment of the impact of long term pumping strategies can't be computed considering for instance steady state conditions. Indeed, for such a large aquifer as the NSAS, the present piezometric conditions are the result of a long history of recharge and discharge events that require a transitory reconstruction of its paleo-evolution (for instance (Mahamoud, 1986) computes water velocities of 1 m/y proving that even if some lateral recharge through boundaries is possible, water movement to topographic depressions is too slow to create steady state conditions). Similarly, future evolution corresponds to the continuation of this transitory trend with additional human activities (e.g. water pumping, Great Man Made River) or in conditions of climate change. Several hydrogeological models were developed to account for the transitory evolution of its water levels and to study the impact of various pumping strategies to exploit its water resources (Gossel et al., 2004; Heinl & Brinkmann, 1989).

Nevertheless, the level of uncertainties remains large. Especially focussing on the SW part of the NSAS which is studied in the present paper, the local boundary conditions for the limits of the NSAS are coarse and differ between these authors and other sources (Schneider, 2004). The same is true for instance for system properties (3D heterogeneity vs 2D approach for nearly homogeneous aquifer) and recharge history. Present water head measurements interpolations differ among authors and are not all coherent with former models (Mahamoud, 1986; Schneider, 2004; Gossel *et al.*, 2004). Moreover, to our knowledge, no water analysis was carried on for the Chadian part of the NSAS, including for instance water dating (measurements reported by (Mahamoud, 1986) in Kufra Oasis in Lybia provides 10 Ky waters above 500 m depth and 30 Ky below). This indeed reflects the purpose of (Gossel *et al.*, 2004; Heinl & Brinkmann, 1989), studying the impact of water pumping in far away Egypt and the actual lack of recent characterization efforts for this Chadian part.

Recently, (Kröpelin *et al.*, 2008) published the analysis of Lake Yoa sediments (at Ounianga Kebir, see Fig. 1) allowing for a reconstruction of climate conditions from 6000 KyBP until now. They obtain a gradual change from a Savannah type landscape to semi-arid environment to present day hyper-arid conditions. The issue considered here is to what extent can this information be used to improve the knowledge of the NSAS history and reduce the uncertainties in its properties (e.g. flow parameters, boundary conditions, main geometrical features).

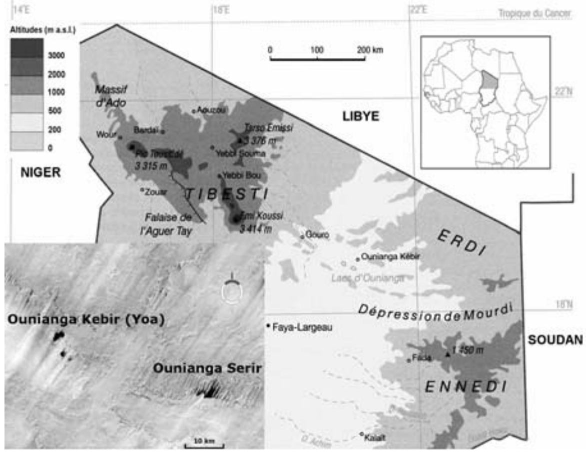

Fig. 1: Geography of the Ounianga region (NE Chad), aerial view of the desert landscape with two major lakes, Ounianga Kebir (including Yoa) to the West and Ounianga Serir to the East, fed by the NSAS.

2. APPROACH

The reconstruction of the SW part of the NSAS hydrogeology and hydrogeology (see Fig. 1) is addressed here. We mainly focus on the reconstruction of hydrogeological features. In this sense, it is complementary to (Grenier *et al.*, in prep) where the hydro(geo)logical models are presented in details and the ability to reconstruct the lake levels and composition is studied and compared with results issued from lake sediment analyses by (Kröpelin *et al.*, 2008). In the following, we present how the climate forcing history was constructed (treated in section 2.1), and the main characteristics of the hydro(geo)logical modelling approach (see section 2.2).

2.1. Selection of a climate scenario with an approach combining climate reconstruction from proxies and climate simulations

Reconstruction of paleo-hydro(geo)logy relies on good quality reconstruction of climate history, the forcing term for surface and underground flow. Advances were obtained for the region from the combined use of 1) a recent review of hydrological proxies (Lezine *et al.*, in prep) (time period 15 KyBP to present), 2) the recent analysis of Yoa lake sediments by (Kroepelin *et al.*, 2008) corresponding to the 6 KyBP to present, 3) climate simulations results from PMIP2 considering a local box around the Ounianga region, 4) dedicated climate simulation models with smaller grids and exploring some various aspects and hypotheses (e.g. with/without presence of large lakes in Africa; with/without freshwater inputs in Northern Atlantic).

Lake sediments provide through multi proxy analysis, a refined view of the evolution of the local system (roughly at the scale of a catchment area). We used the analysis from (Kröpelin *et al.*, 2008) providing major features of climatic evolution and estimation of precipitations. In addition, some of the information contained can be interpreted as hydrological proxies. For instance, until 4.7 KyBP, the large input of *Erica Type* pollens (plant growing in high altitude regions) shows that a river connection with the Tibesti existed. By 4.3 KyBP, the lake turned rapidly to a highly saline environment as a probable indication of the lake becoming endorheic. For older time periods (before 6 KyBP), the

review of (Lezine *et al.*, in prep) was considered to build a humid scenario from 11 KyBP on. The limitation of this approach based on proxy analyses is that these do not include quantification of uncertainties in the reconstruction. Further, an estimation of precipitation is provided but other variables required for the hydro(geo)logical models are not provided (potential and real evaporation rates for instance).
Climate modelling results provide independent quantitative estimates of all variables involved in the hydro(geo)logical modelling. The drawbacks associated with climate modelling is that the simulation grid size is large (e.g. of the order of 200 km for most PMIP2 cases, Paleoclimate Modeling Intercomparison Project, Phase II, site http://pmip2.lsce.ipsl.fr/) so that the impact of the relief is poorly included and the representation of monsoon regimes and time evolution should be improved. For the present study, specific efforts were put in 1) simulating with smaller grids (100 km), 2) simulating several scenarios. Here, the scenario including the presence of large lakes at 9.5 and 6 KyBP on a refined model (IPSL coupled ocean-atmosphere model and zoomed version of the atmospheric component of the coupled model - LMDz) was retained and provided a base to our climate scenario.

A best scenario was finally chosen, based on common discussions along the various scientific communities involved and combined used of proxies and climate simulation information. Table 1 provides precipitation and potential evaporation history selected for the best scenario. It results from joint proxy analysis and climate simulation snapshots at 9.5, 6, 4 KyBP. The reader is referred to (Grenier *et al.*, in prep) for further details.

	10.5 Ky	9.5 Ky	6 Ky	4 Ky	2.7 Ky	0 Ky
Precip. (mm/y)	317.8	317.8	308.2	183.4	5.0	5.0
Pot. Evap. (m/y)	1.0	2.0	3.0	3.0	6.0	6.0

Tab. 1 : Scenario considered (annual precipitation and potential evaporation rates) derived from snapshots at 9.5, 6, 4 KyBP and information at 2.7 Ky and 0 Ky with linear extrapolations in between.

2.2. Hydrological and hydrogeological approach

The hydrological and hydrogeological models were developed within the Cast3M code (www-cast3m.cea.fr). The hydrological model is built from topographic analyses and radar pictures to identify the paleo-river network and computation of Lake Yoa water catchment properties (area, former flow network, presence of lakes and their geometrical properties (Grenier *et al.,* 2009; Grenier *et al.*, in prep). Lake Yoa water catchment area includes several major depressions treated in the model as lakes (Lake Yoa, Ounianga Serir and 8 other "lakes"). The hydrological model computes a simple lake water budget considering precipitation and evaporation balance within the water catchment areas and on free water (lake surface), water losses from upstream lakes to downstream lakes and groundwater inputs obtained from a groundwater model. This hydrogeological model (SW part of the NSAS) is 2D, based on the non-linear Boussinesq equations (unconfined aquifer) with an additional treatment of simulated heads imposed to be lower than topographic elevation. This is achieved by removal of water above topography through a source term providing the groundwater input rate to topographic depressions (Grenier *et al.*, in prep). Results and information from the literature (Gossel *et al.*, 2004; Heinl & Brinkmann, 1989, Schneider, 2004) were included. The hydrological model considers instantaneous balance while the long time scales involved in the transitory evolution are contained in the groundwater input term.

3. RESULTS AND DISCUSSION

Results are analysed along two lines. First, the ability to provide a coherent view of the hydrology and the climate is described and some of the major features of underground and surface flows are provided. Second, the level of information contained in the lake sediment proxies to constrain the aquifer properties and parameter values is studied.

The hydrogeological model was run for the climate scenario presented in Table 1. The initial conditions are filled up aquifer by 25 KyBP, followed by a pure discharge (zero recharge corresponding to long arid period). From 11.5 KyBP, imposed recharge corresponds to 10% of the precipitation history. Results show that the total water volume within the aquifer slowly decreases in the first discharge phase while aquifer recharge is fulfilled within several hundreds of years to reach steady state conditions with roughly 20 mm/y of recharge (60 mm/y for regions above 1000 m asl). The dissymmetry of the answer to long draught and humid periods is related with the fact that for homogeneous aquifer, recharge operates on the total surface of the system while discharge of the aquifer corresponds to lower topographic locations. The variation of the total aquifer volume is provided in Fig. 2. Time evolutions of the groundwater inputs show similar time scales with additional local effects related with local topographic variability acting as reservoirs of various sizes (see Grenier *et al.*, in prep.).

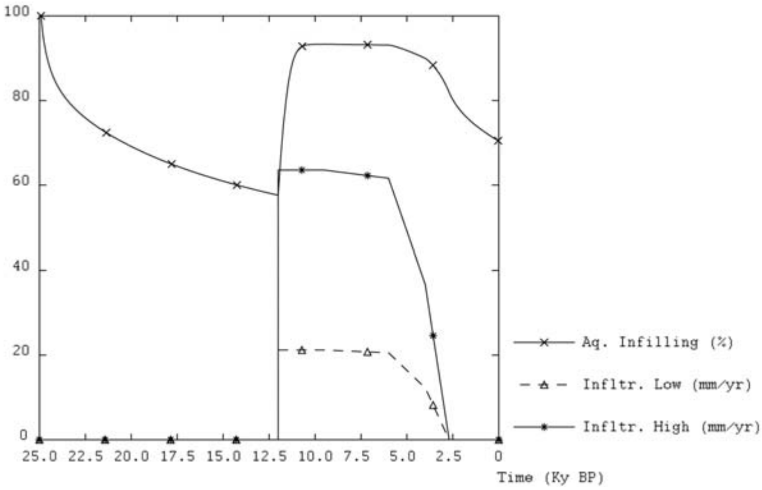

Fig. 2: Aquifer water resources (percentages of initial full filling, 25 KyBP). Recharge history derived from precipitation scenario (no recharge until 11.5 KyBP)

The lake level evolution for the 9 modelled lakes is simulated for the Holocene period. Results for Lake Yoa are easy to constrain to the lake sediment proxies, provided a higher level of precipitation is considered for zones of the water catchment area higher than 1000 m asl (Tibesti mountains). A coherent view of the paleo-hydrology and the climate scenario is thus achieved. The interplay between climatic and hydrogeological features is illustrated in Fig. 3 providing Lake Yoa budget evolution. Results show that Yoa receives no more input from upstream lakes at 4.7 KyBP, the last lake contributing having the Tibesti slopes in its catchment area. From then on its water inputs are dominated by precipitations from Yoa own catchment area (39 000 km², 58% of the total water catchment area). Lake Yoa becomes endorheic by 4.3 kyBP (zero Yoa output) mainly due in its final stage to a reduction of precipitation amplified by the size of the water catchment area. The groundwater inputs vary within a factor of 3 for moderate levels so that the impact of groundwater inputs becomes significant only after 3 KyBP. The present Yoa budget relies fully on underground inputs and the modelled level well balances the present lake surface and evaporation rates.

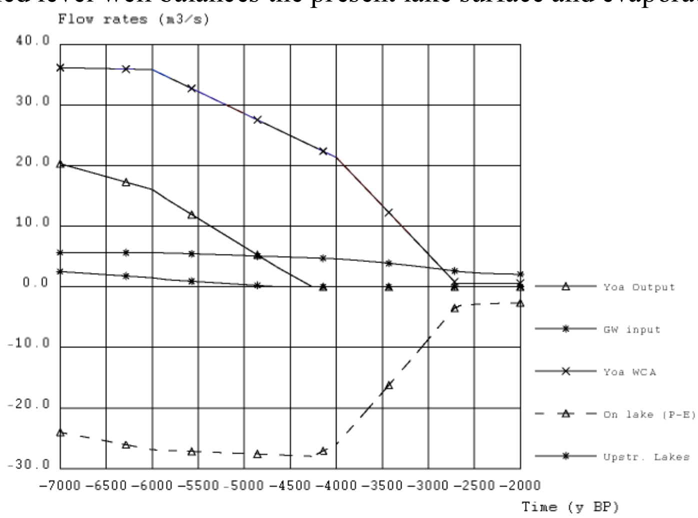

Fig. 3: Lake Yoa budget history including input from groundwater (*GW input*), from Yoa own water catchment area (*Yoa WCA*), from upstream lakes (*Upstr. Lakes*), lake budget (*Precip – Evap*) and Yoa output rate turning to zero when the lakes becomes endorheic at 4.3 KyBP.

A realistic reconstruction of underground flows in the NSAS along the Holocene period is limited by uncertainties in 1) system limits and associated model boundary conditions - differing between authors, e.g. (Gossel *et al.*, 2004; Heinl & Brinkmann, 1989; Schneider, 2004; Mahamoud, 1986) while present day head fields differ as well; 2) aquifer parameters (general agreement in the literature for permeability $K = 3.5\ 10^{-5}$ m/s, porosity $\varphi = 0.1$ corresponding to sandstone properties but the aquifer is heterogeneous including e.g. some clay units of undefined extensions).

We present here a sensitivity analysis to the permeability, *K*, and boundary conditions. The idea is to identify the constraining power of the information contained in the lake sediment proxies in terms of aquifer properties (here K and boundary conditions). The coupling between the underground flow and the lake model is represented by the groundwater input rate to Lake Yoa. Five simulation cases are considered (see Tab. 2 and results in Fig. 4) exploring the sensitivity of the groundwater input term to variations in permeability (*Base Case* multiplied or divided by a factor of 5 for *Case 1* vs *Case 2*) and modified boundary conditions from full no-flow boundary conditions to non zero flux from (a) the Western Tibesti region (inputs equivalent to infiltrations on a 10 km wide extended zone, *Case 3*); (b) the Easern limit (similar treatment, *Case 4*); the Southern boundary allowing outflow to the Faya region (outflux corresponding to 90 cm evaporation rate for a 100 km² region, *Case 5*). Results show that the sensitivity to permeability is large. Western and Eastern boundary conditions have negligible influence on the groundwater input term at Yoa, probably because they are very distant. The Southern limit has intermediate influence. Former results (see Fig. 3) showed that the groundwater input term plays a dominant role only for recent years (3 KyBP until now). This is due to the large water catchment size of Lake Yoa and the slow and low amplitude variations of groundwater input term. So, while modelling the lake levels is a key step in the modelling strategy to assess the coherence between the hydro(geo)logy reconstruction and the proxy record, the constraining power of lake sediment proxies is limited for the present case. It indeed finally boils down to the constraining power of present inflow rates from the aquifer to the lakes. They can be directly measured from present conditions considering the lake surface and evaporation rates. It is consequently not possible to differentiate *Base Case* and *Case 2* and *Case 3* while groundwater inputs allow some constraining power on permeability and Southern domain limit potentially providing water to sustain the Faya region high water levels. Our base case simulation leads to a 2 m^3/s value well balancing the present lake surface and evaporation rate.

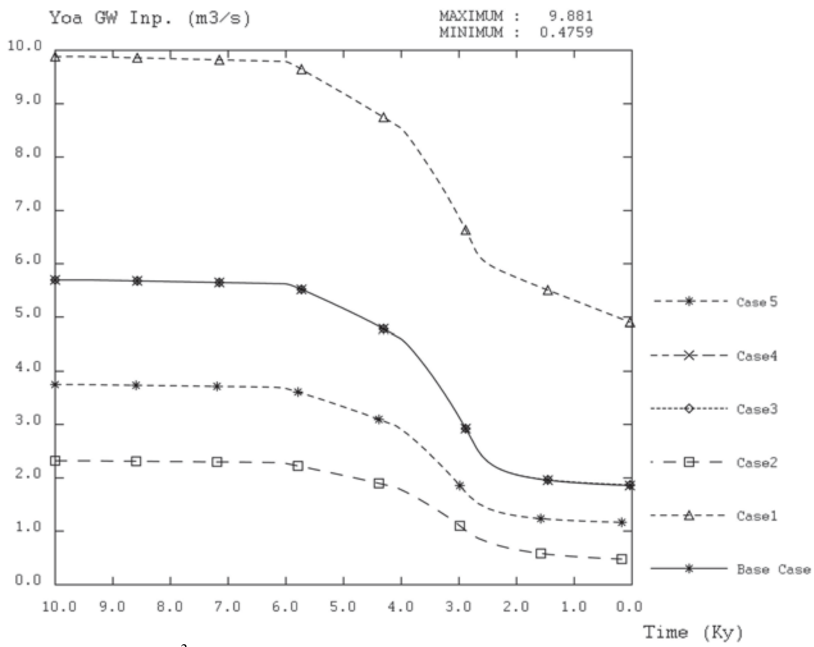

Fig. 4: Groundwater input term (m^3/s) to Lake Yoa from 10 KyBP to present considering the cases presented in Tab. 2. *Base Case* as well as *Cases 3 & 4* provide identical GW input rate histories.

	K (m/s)	BC North	BC West	BC East	BC South
Base case	$K_0 = 3.5\ 10^{-5}$	No flow	No flow	No flow	No flow
Case 1	5. K_0	No flow	No flow	No flow	No flow
Case 2	K_0 / 5.	No flow	No flow	No flow	No flow
Case 3	K_0	No flow	In flow	No flow	No flow
Case 4	K_0	No flow	No flow	In flow	No flow
Case 5	K_0	No flow	No flow	No flow	Out flow

Table 2: Overview of the simulation cases included in the sensitivity analysis. *Base case* is for permeability $K = 3.5\ 10^{-5}$ m/s, porosity $\varphi = 0.1$ and no flow boundary conditions

3. CONCLUSIONS

We demonstrate the importance of a good climate signal for the reconstruction of the history of such a large aquifer as the NSAS having such long transient history. In this region where lake sediment analyses were conducted, hydrological simulation plays a key role in simulating the lake levels (ie the lake sediment proxies) and thus assessing the coherence of the interdisciplinary Holocene reconstruction approach. The present knowledge of the SW part of the NSAS nevertheless bears large levels of uncertainties. The information contained in the lake sediments is related to aquifer properties by means of the groundwater input term in the lake budget. In the case of Lake Yoa, the groundwater input term has been a minor component of the water budget until recently (3 KyBP) when almost present conditions installed. So the proxy history has no constraining power on aquifer properties, but serves to assess the climate history which is the forcing term for the aquifer model. Nevertheless, present day values of groundwater inputs computed from lake surfaces and evaporation rates are valuable pieces of information for comparison with simulations. We showed that this information has a strong constraining power on local aquifer properties (similarity with pumping tests but with larger range) and more limited constraining power on boundary conditions situated at further distances. More field measurements are required in this region to obtain a reliable piezometric head database, analyses of water chemistry and water dating that could help distinguishing between aquifer recharge scenarios.

Acknowledgements
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Concepts for transboundary groundwater management in a region of extensive groundwater use and numerous contaminated sites

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ABSTRACT

The Rhine gravel aquifer in the Basel area (northwestern Switzerland) extends to both France and Germany. Since Basel developed into a major center for the chemical and pharmaceutical industry in the 19th century, vast areas in this region were or were likely to have been contaminated. In addition, there are abandoned sites of small enterprises and numerous areas (fillings of former gravel pits) on adjacent French and German territory which are probably also contaminated. The aquifer is used by numerous municipal and industrial water suppliers. Two case studies are presented that illustrate the need for transboundary groundwater management concepts in the region. Whereas the first case study illustrates short-term impacts on groundwater resources during a major suburban development project, the second case study shows long-term changes of groundwater flow regimes and the regional distribution of contaminants. For both case studies it is shown that river-groundwater interaction along the Rhine is an important element of the regional groundwater flow regime. It further can be demonstrated that considerable risk, with regards to the mobilization of contaminants, can be caused by changes in regional scale groundwater flow regimes together with changed hydraulic boundary conditions. The change in groundwater flow regimes and the reversal of flow lines may lead to the contamination of areas that were formerly not or only weakly polluted. These areas suddenly may lie within the capture zones of municipal or industrial groundwater wells or within the groundwater drainage of construction sites. Such risks of contamination require the development of concepts and methods for groundwater protection and management. A prerequisite for groundwater protection and management is a good knowledge of the spatiotemporal processes of regional scale groundwater flow regimes, which requires appropriate modeling and monitoring. This allows the evaluation of the impacts of planned changes at an early stage and to develop suitable groundwater management systems.

Key words: urban groundwater management; contaminated sites, management concepts

1. INTRODUCTION

Open space in urban areas is very rare and new infrastructures are increasingly extended into the subsurface. However, these areas often had the status of non-productive terrains and were historically used for industry settlements, transport systems and for the deposition of different types of waste. The "Trinational Euro District Basel", including mainly the cities of Basel (CH), Lörrach (DE) and St. Louis (FR), is located at the southern end of the Rhinegraben aquifer system. Here, non-productive areas are becoming increasingly valuable resources for future urban development

However, urban development can impact regional groundwater flow regimes and new constructions (subsurface traffic lines or large buildings) may affect urban groundwater systems temporarily during construction as well as permanently after completion. Potential impacts can include a reduction of the cross-section for groundwater flow and a decrease of aquifer storage volume. Some of these impacts are permanent, while others, such as construction site drainages, only affect the groundwater flow regime temporarily during the construction period.

In order to predict, mitigate or prevent environmental problems across national and legislative borders and to assure the supply of groundwater for municipal and industrial users, integrated multi-disciplinary adaptive groundwater management approaches have to be chosen. An approach is presented which includes the integration of geological and hydrological data, and results in the setup of a groundwater management system comprising (1) groundwater monitoring, (2) the development of a data-base application, facilitating the interpretation of geological and hydrogeological data, (3) geostatistical analyses of the aquifer heterogeneity, as well as (4) regional and local scale high resolution groundwater modeling.

The approach presented is illustrated by two examples. The first case study discusses strategies to understand and predict the cumulative effects of the numerous single impacts on groundwater resources during a major suburban development project. Focus is placed on a construction phase that was associated with considerable changes in groundwater flow regimes resulting in the reversal of flow lines and a shift of groundwater divides. In the second case study the development of groundwater pollution during the last decades in a heavily industrialized groundwater protection area is analyzed. This includes the illustration of long-term changes to a groundwater body due to changed hydraulic boundary conditions.

2. INSTITUTIONAL ASPECTS OF TRINATIONAL COOPERATION

Transboundary cooperation in environmental issues in the Basel area has made considerable progress. Primarily because of the activities of local groups, such as the "Trinational Euro District Basel", whose aim is to cooperate in the three countries in the domain of urban planning, healthcare and traffic infrastructure, as well as the "Regio Basiliensis" (initiation and cooperation in transboundary projects) and the support of international organizations, such as the "Council of Europe", the Upper Rhine Valley and other European border regions have succeeded in voicing their interests in a fairly cohesive manner. However, concerning environmental issues, the continued emphasis of national governments on sovereignty and national interests has prevented international border regions from achieving such basic goals as infrastructure integration and harmonization of environmental policy.

There are several institutions which are in charge of the transboundary cooperation in the Upper Rhine area in the domain of groundwater encompassing politicians and environmental scientists. An important board is the groundwater expert panel of the French-German-Swiss conference of the Upper Rhine. This board supported the several initiatives of INTERREG projects in the groundwater domain ranging from the transboundary compilation of hydrogeological data (Wagner et al., 2001) to the development of tools, that allow to predict the groundwater quality with respect to changes in agriculture policy in the three countries (i.e. MoNit, 2006). The legal aspects are still matter of the three countries, which requires a certain effort of harmonization.

3. CONCEPTS AND METHODS

In order to develop concepts and methods for the sustainable use of groundwater resources in urban areas, environmental impact assessments not only have to incorporate above ground vitiations but also such concerning negative impacts on groundwater flow regimes. Together with various possible sources of groundwater pollution observed in urban environments, urban development may interfere with a previously balanced urban groundwater flow regime and change groundwater quality also across national borders.

Many decisions concerning impacts on urban groundwater flow regimes are typically taken at the level of the individual project. However, it is the sum of all impacts, and their interaction in time and space, that has to be considered. In the context of interferences of subsurface constructions and ancient polluted industrial sites it is of particular interest to know, which hydrogeological data are required to understand the changes in groundwater flow and transport. To accomplish this, it is necessary to develop instruments that facilitate the quantification of the consequences of the cumulative effects of numerous decisions concerning groundwater flow regimes and groundwater quality. At the same time, system profiles must be identified together with the delineation of boundaries and specific targets that lead to defined overall goals for specific groundwater areas. These instruments form part of groundwater management systems, comprising among others, the setup of groundwater observation systems, high resolution numerical groundwater modeling, and the development and evaluation of scenarios. Numerical methods greatly facilitate the consideration of the multitude of impacts in a complex environment. They allow evaluating and comparing changing boundary conditions, constructional alternatives and groundwater management strategies as well as ensuring an adequate protection of groundwater resources (Epting et al., 2008).

4. SETTINGS

The two case studies are located in northwestern Switzerland and extend to both Germany and France (Fig. 1). In both areas the shallow unconfined upper aquifer mainly consists of late Pleistocene gravels deposited by the Rhine. The gravel depositions are intercalated with fine-grained flood-plain sediments that result in variable permeability within the aquifer. The thickness of the aquifer ranges between 15 and 35 m and is underlain by an aquiclude consisting of mud to clay rich sediments, Oligocene in age. In the area illustrated in the second case study the aquifer system is more complex due to a lower karst aquifer.

River-groundwater interactions along the Rhine are an important element in the regional groundwater flow regime. The groundwater table fluctuates phase-delayed and with reduced amplitude in response to the river level fluctuations of the Rhine. Depending on the hydrological constraints, the river can be a source or sink for groundwater.

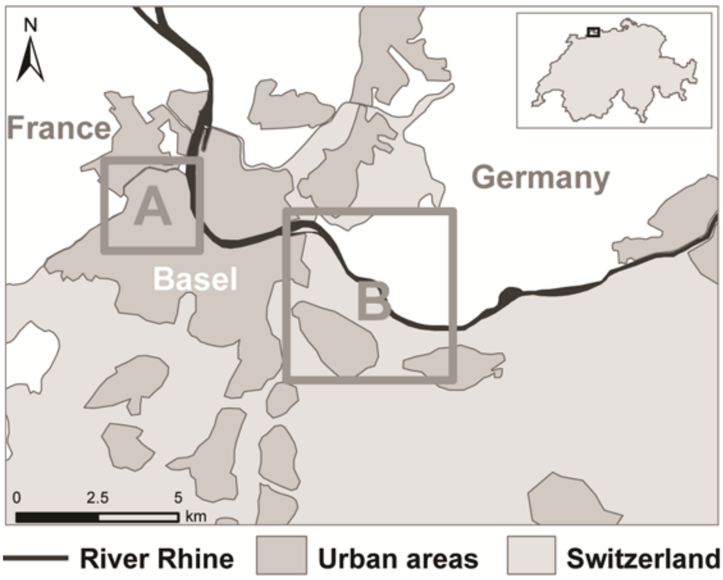

Fig. 1: Location of case studies.

Since Basel developed into a major center for the chemical and pharmaceutical industry in the 19th century, large areas in the region of Basel were or are likely to have been contaminated. In addition, there are abandoned sites of small enterprises and sites with municipal or multicomponent waste (fillings of former gravel pits) on adjacent French and German territory. The aquifer is presently used by numerous municipal and industrial water suppliers. Due to changing activities the groundwater flow regime changed several times, both at the local and the regional scale.

4. EXAMPLES OF TRANSBOUNDARY GROUDWATER ISSUES

To define the specific profiles of groundwater systems, high-resolution groundwater models are applied that have been transiently calibrated with groundwater head data and river stages as well as extraction and recharge rates. In the presented examples, the strongly transient character of groundwater flow regime and/or river-groundwater-interactions in urban areas is illustrated. Scenarios were developed to assess the consequences of decisions and to optimize particular measures such as channel widening and their influence on groundwater quality.

A Transboundary groundwater management during highway construction

The highway construction outlined as the first example is located in the northern part of Basel on the western bank of the river Rhine (Fig. 2). The tunnel highway connection has a total length of 3.2 km. About 87 % of the tunnel construction are situated in the gravel deposits. The remaining 13 % are covered by the bridge across the Rhine and the various tunnel entrances. For the tunnel either methods based on mining techniques or the cover-and-cut construction method were employed. The large scale groundwater model is described in detail by Huggenberger et al. (2004) and Epting et al. (2008). Progressive adaptations were made throughout the various construction phases. In total 44 observation wells were instrumented with automated water-level loggers that continuously measure the hydraulic head, 21 observation wells were regularly sampled for groundwater quality measurements. Furthermore, the extractions to be supplied to the industrial groundwater users and to the settling tanks on the construction sites are sampled at regular intervals.

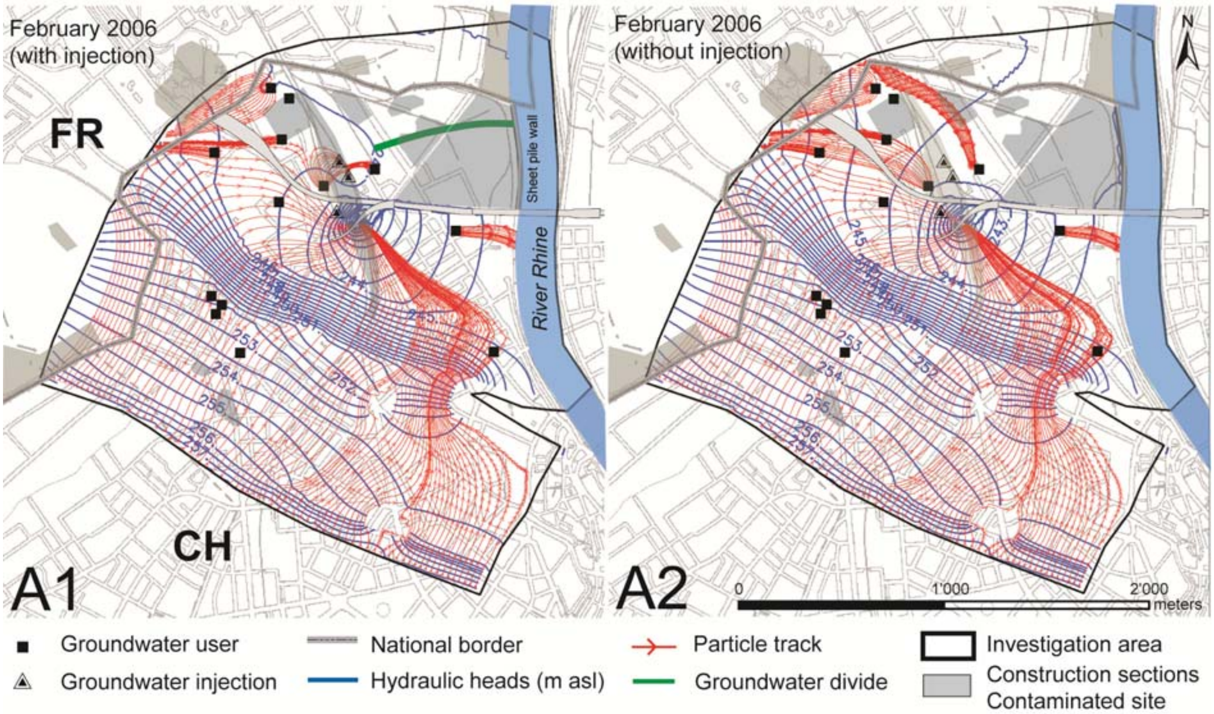

Fig. 2: Groundwater flow regimes for case study A. A1: with groundwater injection. A2 without groundwater injection.

During the entire construction period, the groundwater flow regime was affected by the movement of construction sites requiring different groundwater management systems. Depending on the mining techniques, the degree of complexity for groundwater drainage varied and was either realized as open sump drainage, the dewatering of residual groundwater in areas enclosed by sheet pile walls, or a combination of both. The groundwater extracted from the construction site was generally either discharged into surface waters, into the sewage system or recharged back to the groundwater. In all cases, the discharged water has to satisfy the specific quality standards.

A considerable change in the local groundwater flow regime in the northern industrial area was expected by the open sump drainage in 2006. With the known polluted sites on both sides of the national borders (FR and CH), in the vicinity of the construction site, there was a considerable risk for mobilization of contaminants resulting from groundwater extractions and drawdown of the groundwater table. Contaminated areas may have suddenly lain in the capture zones of the industrial groundwater users or within the groundwater drainage areas on the construction site. As a consequence, positions of groundwater recharge and required recharge rates were evaluated in order to maintain the groundwater flow regime to the north and to minimize remobilization or deviation of contaminated groundwater (Fig. 2).

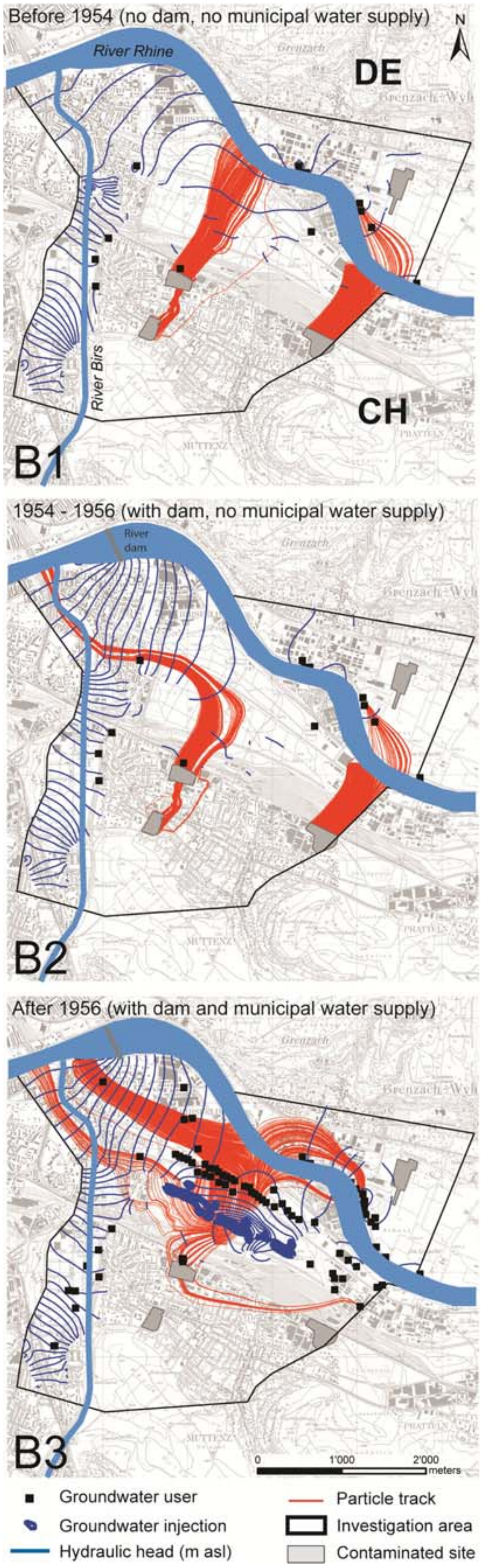

Fig. 3: Groundwater flow regimes for case study B. B1: Situation before construction of the river dam. B2: Situation with river dam and before installation of the water supply. B3: Situation with river dam and water supply.

The management system was continuously adapted, based on the progress achieved on the various construction sections or risk profile in the case of old contaminated sites. The interpretation of changes observed in groundwater quality measurements together with the modeling results allowed an optimal localization of new observation wells. The extended knowledge of groundwater flow regimes could lead to a reduction and minimization of negative effects during the various construction phases and result in a sustainable development concerning use and management the groundwater resource.

B Ancient contaminated industrial sites

In the area of the second case study important drinking water production is located in the vicinity of several contaminated sites. Aware of the risks and due to measurable pollution, the drinking water production was protected by the infiltration of filtrated Rhine water, creating a hydraulic gradient towards the known contaminated sites and towards infiltrating surface waters from the river Rhine.

A total of 72 wells, 30 of them used for industrial use and 42 as drinking water wells were integrated into a 3D numerical groundwater model. Continuous monitoring of the hydraulic head was accomplished by a total of 121 observations wells. The model was used to determine the capture zones of drinking water production wells and downstream of the most important polluted sites for different time periods with changing boundary conditions. Figure 3 shows the development of the groundwater flow regime before construction of the river dam and before the development of the water supply (B1), after construction of the river dam and the hydropower plant in the Rhine resulting in changed hydraulic gradients (B2) and after the development of a municipal water supply in the mid 19th century (B3). For each time period it is likely that part of the contaminants were retained in the subsurface according to the compound specific physico-chemical conditions. This process actually explains the large spreading of contaminants still measurable at many different locations at relatively low concentration, but sometimes with signals above the required quality standards of the drinking water guidelines. In addition the models illustrate the transboundary character of the different groundwater flow regimes over the last fifty years. It also clearly documents the fact, that in future a change of production of one key-player would likely lead to changes in water quality for other groundwater users.

As a consequence groundwater management in this area has to include all the partners across the national borders (DE and CH).

5. CONCLUSIONS

Two case studies of transboundary groundwater projects illustrate the problems of urban groundwater management. As environmental problems generally do not stop at national boundaries, the exchange of information about mayor impacts to the groundwater flow regime requires communication between the neighboring countries.

Extending current protection concepts with process-based approaches that include the consideration of nature and location of contamination in urban areas, as well as the interaction between surface and subsurface waters could enhance the sustainable development of groundwater resources. Knowledge of the composition of groundwater quality, including the consideration of variable hydrologic boundary conditions and fluctuations of contaminant loads in rivers, is therefore of great importance. Key factors in investigating contaminant transport are the relevant boundary conditions as well as their development and origin, in particularly the depth and nature, of relevant substances. Modeling results indicate that flow paths and velocities can vary considerably for the various simulated layers.

Management strategies for groundwater are confronted with enormous implementation barriers. Confidence in their success is often low, and conventional and more expensive approaches, like extensive drillings and analytical programs, are preferred. Applied and problem-oriented fields should fulfill the requirements for a more sustainable management of groundwater resources in a sensitive urban environment. The illustrated approaches can help to meet challenges posed in a sensitive transboundary urban environment. This includes the evaluation of contaminated sites, risk assessment for waste disposal as well as the parameterization of numerical groundwater models. While some of this work may be specific to these case studies, it is expected that the overall conceptual approach and the methodologies will be directly transferable to other urban and transboundary areas. Thus, this is one step towards the application of new findings to complex practical problems.

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The Water Paradox: Is there a sharing crisis?

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ABSTRACT

Water resources management has undergone significant change since the beginning of human civilization. This study investigates water sharing and in particular the impact of the Farakka Barrage in the Ganges River Basin area. This dam has led to conflict between the Ganges states since 1951. A review of the literature shows that one of the best institutional framework solutions is the bilateral agreement between Bangladesh and India. This is encapsulated in the 1977, 1982 and 1985 Memoranda of Understanding (MOU), and also in the historical 1996 treaty. The 1996 water sharing treaty adopted Article IV of the 1966 Helsinki Rules and granted 35,000 cusecs in water releases to Bangladesh. The analysis presented in this paper suggests that availability of flows is crucial during the period March 1 to May 31. Moreover, the average flow availability at Farakka has been gradually declining during the period 1997 to 2007. For 2005 and 2006, we found that the average flow availability had declined by 12% and 25% respectively. We strongly recommend market-based water transfers from Nepal for both Bangladesh and India. We demonstrate that this would provide a better solution to sustainable water resources management in the Ganges River Basin.

Key words: Water sharing, institutional framework.

1 INTRODUCTION

Water is the hub of life and an indispensable part of all terrestrial ecosystems (Vo, 2007). The distribution of these water resources throughout the earth is as follows: Surface water is 0.02%, subsurface water is 0.62%, icecaps and glaciers are 2.15%, and seawater is 97.20% (Bras, 1990). This illustrates the limited availability of fresh water. The quantity issue arising from water sharing is particularly critical. It depends on bilateral agreements among co-riparian states and therefore, water sharing issues often become controversial in water resources management (Haftendorn, 2000). Water sharing is not confined within specific countries, but it has become a transboundary issue as well. Sharing issues between riparian nations may arise through economic development, infrastructural capacity, or political orientation. Indeed, there is already clear evidence of escalating conflicts in different parts of the world concentred on water quantity and quality issues.

In Bangladesh, water flows in the Ganges River impact on human activities in both rural and urban areas. The flow of the Ganges River in Bangladesh is influenced largely by the actions of its neighbouring countries, India and Nepal. The research work presented in this paper aims to quantify how and why the sharing of water resources became a paradox in Bangladesh. This paper analyses the sharing of water in the Ganges River Basin in terms of matching supply and demand.

2 WATER SHARING IN THE GANGES RIVER BASIN

Bangladesh's water resources derive from three main rivers - the Ganges, the Brahmaputra and the Meghna, and their tributaries and distributors. The three river catchments cover approximately 1.75 millions square kilometre areas, only 8% of which lies within Bangladesh (Abbas, 1992). However, these river systems all discharge into the Bay of Bengal through Bangladesh. In general, the problems arise from upstream countries such as India. In particular, in the absence of a treaty, upstream riparian states have a hydrological advantage in a river. In the absence of political constraints, over a number of years these upstream states have occasionally abused this advantage. This is the root of the paradox of water sharing between India and Bangladesh. Bangladesh emerged as a country independent from Pakistan in 1971. After that Bangladesh proposed to build storage facilities in the Ganges River Basin to augment the flow during the dry season (Haftendorn, 2000). As this would involve Nepal, India rejected the plan because of it not being simply a bilateral issue (Khan, 1996). On the other hand, India's proposal of diverting water from the Brahmaputra River to the Ganges River by a link canal was opposed by Bangladesh (Haftendorn, 2000) because diversion of water from the Brahmaputra River during the dry period would cause adverse effects on its downstream reaches.

In 1974, the Indo-Bangladesh Joint River Commission estimated that during the dry season the average minimum flow discharged below the Farakka Barrage was 55,000 cusecs (Adel, 2001). Of this, India claimed 40,000 cusecs to flush the Hooghly River leaving the rest for Bangladesh, which on the other hand demanded the entire 55,000 cusecs for the dry season. Hence a deadlock arose between these two countries (Hossain, 1998). To break the deadlock, the Bangladesh government proposed an interim agreement based around diversions at the Farakka Barrage. The agreement was signed on 18 April 1975 (Hossain, 1998). After the agreement expiry on only 31 May 1975, India unilaterally continued the withdrawal of water at Farakka, adversely affecting a vast area of Bangladesh. Consequently, Bangladesh raised the issue at the thirty-first session of the United Nations General Assembly in September 1976 (Khan, 1996). However, its attempts to internationalize the issue failed and a bilateral solution with India had to be sought.

As the expiry date of the 1977 treaty was looming, Bangladesh urgently needed to find another agreement for the sharing of water in the Ganges River Basin. Then two MOUs were signed on 7 October 1982 and 18 October 1985 for the next two dry seasons and three years respectively following the terms of the original 1977 agreement. After expiration of the second MOU, there was no further agreement until 12 December 1996 (Rahman, 2006), when a thirty year accord was signed by Bangladesh and India (Salman *et al.*, 1999). This will be referred to in this paper as the 1996 Treaty.

3. TREATY OF 1996

The water sharing treaty of 1996 covered a 10-day period in each of the five months from January to May. The water sharing formula presented below (Table 1) granted at least 35,000 cusecs of water to both Bangladesh and India.

Table 1: 1996 Water sharing arrangement between Bangladesh and India for the Ganges River

Availability at Farakka	Share for India	Share for Bangladesh
70,000 cusecs or less	50%	50%
70,000 - 75,000 cusecs	Balance of flow	35,000 cusecs
75,000 cusecs or more	40,000 cusecs	Balance of flow

Table1 shows that accurate estimation of flow availability at the Farakka Barrage in the Ganges River is essential but that it is subject to natural variability. To assess flow variability from 1997 to 2007, we used the median range estimator of standard deviation because it is relatively insensitive to occasional large shifts in the process. The estimated standard deviation ($\tilde{\sigma}$) is calculated from the median of the range multiplied by 1.047. The factor of 1.047 is based on an assumption of a random sample from a normal distribution, although it is irrelevant for calculating the statistical significance. The average flow availability and shifts in the process are shown in Table 2.

Table 2: Assessing the flow variability in the Ganges River Basin from 1997 to 2007 (flow rates in cusecs)

Year	Mean	Median	Standard deviation	Estimator of Std. deviation	Inter-quartile ranges (IQR)
1997	70911	66449	15427	69572	20488
1998	113630	102022	37293	106817	41705
1999	89821	87236	21960	91336	29505
2000	91393	87201	20186	91299	13541
2001	74128	69837	16063	73119	23798
2002	86646	85233	14530	89239	15644
2003	82290	84627	7717	88604	11600
2004	85524	78569	20496	82262	36838
2005	72699	68749	11601	71980	20602
2006	62225	57618	12829	60326	15393
2007	78675	78015	9782	81681	13046

The values of the median range estimator of standard deviation are substantially larger than the standard deviation. Therefore, there is reason to suspect occasional shifts in the mean. Moreover, the interquartile range shifts under the mean process. Figure 1 shows the clear flow variability that occurred from 1997 to 2007. Figure 1 also shows how the seasonal availability of flow at Farakka in the non-monsoonal season continuously declined from 1997 to 2006. Eventually, in 2007, seasonal variation was reduced but the average flow availability in 2007 still only remained close to the 11-year average.

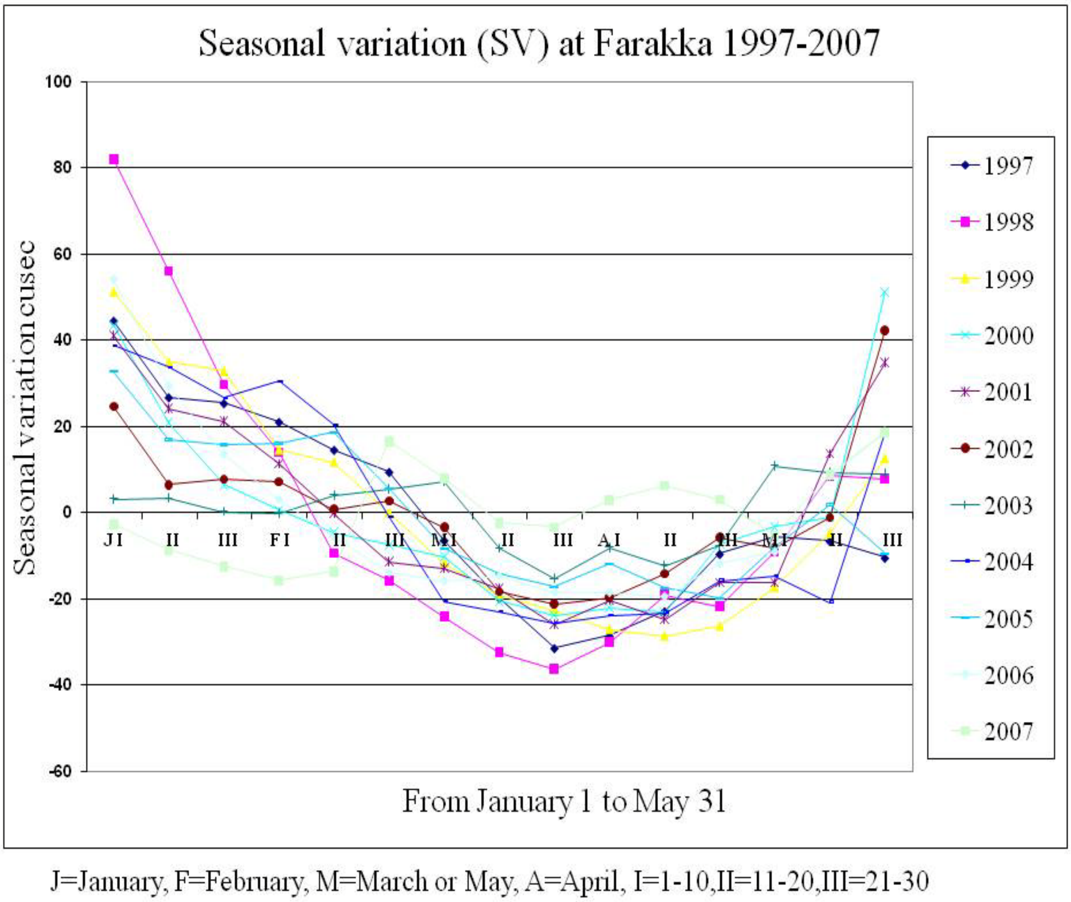

Figure 1: Average seasonal variation (percentage) at Farakka 1997-2007

We may summarise that indeed, flow availability at Farakka is a crucial factor to resolve the water sharing constraints between Bangladesh and India. In order to implement the water sharing formula shown in Table 1, there is a need for flow augmentation of the Ganges River by water transfer from a third upstream country, Nepal.

4. OPTIMISATION OF WATER DIVERSIONS

The strategy is based on water transfer from Nepal to India then for water diversion from India to Bangladesh. Initially, we will consider India's situation without water augmentation. We will presume the additional amount of water transferred by Nepal will affect India's welfare, and we will compare this to the situation without water flow augmentation.

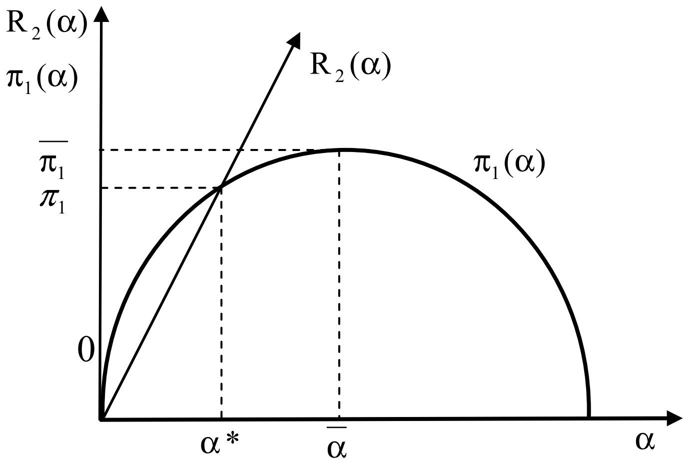

Figure 2: Optimal level of water diversion by India

We will also assume that India's water scarcity is not extreme. It follows that India's profit function is concave in diverting an amount α. We also consider it justified to diminish the marginal productivity of water utilization and to assume a negative second order profit condition, as shown in Figure 2. From Figure 2, the producers in India could maximize their profit up to the net marginal benefit of increasing sharing diversion upstream equal to the marginal cost. Secondly, we will assume that there is no provision for additional water supply from Nepal and there no longer exists a credible threat from Bangladesh in response to India increasing the diversion, α. Then India has a unilateral option to divert water, and the efficient rate of water utilization corresponds to the optimal level of water diverted, α. We define the function, $\omega_1 = f(\alpha)$ to ensure that the net benefit or profit will be at an optimal level $\overline{\pi}_1$ in Figure 2 and profit through choice of α is $\pi_1 = (p-c)p_1(\omega_1, v_1)$. Therefore, the first order condition maximizing the profit is $(p-c)\frac{\partial(p_1)}{\partial(\omega_1)}\frac{\partial(\omega_1)}{\partial(\alpha)} = 0$ which shows that the profit to India will be maximized when the marginal benefit of water diversion equals zero. Since the function $\omega_1 = f(\alpha)$ is convex, the slope of the profit function with respect to the share of water diversion will be positive when $\alpha < \overline{\alpha}$ and conversely is negative when $\alpha > \overline{\alpha}$, where $\overline{\alpha}$ is the optimum level of diversion.

In the above situation we assume that usage of water is a fixed proportion of the availability of water and is a function of α. A lower rate of water utilization would require a lower value of α. This lower value represents an under-utilization condition which generates lower profit for the producer. Similarly, from Figure 2, over-utilization of water will ensure a lower profit $\pi < \overline{\pi}$, because of the diminishing marginal productivity of water and a negative second-order profit condition. If there is no credible threat from Bangladesh, India could maximize its profit $\overline{\pi}$ by diverting a share $\overline{\alpha}$ of water upstream and allocating the rest to flow downstream to Bangladesh. In Figure 2, we can compare the results and see that water transfers from Nepal will reduce the profit to India. When water transfers from Nepal take place, it forces India to face an additional cost to increase the diversion, α. Therefore, if Bangladesh buys water from Nepal then India's optimal share of water diverted upstream, α*, will be less than the optimal level of water diverted by India in the unconstrained case, α. In such a case, India would be better off without a water augmentation treaty. This perhaps better explains why in the past India has strongly resisted efforts by Bangladesh to couple any agreement on water sharing with proposals for augmenting the Ganges' dry season flow with water transfers from Nepal.

5. CONCLUSIONS

Our analysis suggests that India would be strongly motivated to ignore the provisions of the treaty and to decide how much water to divert, as indicated in Figure 2. However, a water augmentation treaty between Bangladesh, India and Nepal not only provides additional water to both downstream countries in times of chronic scarcity but also gives Bangladesh a mechanism for deterring India from violating the Ganges River Treaty and deciding unilaterally to divert more water at the Farakka Barrage. In this regard, a water augmentation treaty is likely to reinforce the existing Ganges River Treaty.

6. ACKNOWLEDGEMENTS

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Transboundary Aquifers of the Fergana Valley: Challenges and Opportunities

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ABSTRACT

Many aquifers of the Fergana Valley have transboundary implications and are linked hydraulically with transboundary small rivers widely spread in the valley. The objective of this paper is to emphasize opportunities and constraints associated with the development of the aquifers of the Fergana Valley. Since 1990, there have been upstream/downstream impacts in the study area which have reduced surface inflow and increased subsurface inflow from the upstream to the downstream. This causes waterlogging and water-quality issues in some downstream locations. This is aggravated by reduction of the groundwater extractions in the downstream causing waterlogging and salinity issues in over 50% of the irrigated land. These issues could be negated by developing the groundwater resources. The zoning of the Fergana Valley on groundwater irrigation potential suggests that the potential area for groundwater irrigation is 32% of the total irrigated land of 900,000 ha while for conjunctive use of groundwater and canal water it is 27%. The system of canals can irrigate the rest of the irrigated area. Aquifer recharge would need to be managed to prevent issues related to groundwater depletion and degradation of groundwater quality. The studies indicated that free capacities of the aquifers exceed 3,000 Mm^3, which could be used in winter for temporary storing of the excessive flow of the Fergana Valley rivers. In spite of the emphasized opportunities, there are low incentives for farmers to practice groundwater irrigation under the state cotton and wheat quota systems supplying subsidized canal water, and high cost of construction and maintenance of wells. This study suggests that under unstable access to the canal or lifted water farmers producing cash crops, such as orchards and vegetables, need to invest in groundwater development, while in many cases shallow bore wells could replace deep wells. The proposed strategy could be a part of the small river basin plans and requires cooperation of the riparian states.

Keywords: Groundwater recharge, groundwater irrigation, upstream/downstream impact, Central Asia

INTRODUCTION

The Fergana Depression is located within a mountain system whose ridges coated with snow and glaciers favored originating the abundance of watercourses. From ancient times, these watercourses have been transporting coarse sediments into the depression creating favorable conditions for generating groundwater aquifers. Many of these aquifers have transboundary implications and are linked hydraulically with a transboundary river. These aquifers can be described by the two main conceptual models: aquifers located completely within the territory of one state but linked hydraulically to a river across an international border; 2) aquifers intersected by an international border and linked hydraulically with a river that is also intersected by the same international border (Eckstein and Eckstein, 2005).

Since 1990, there have been upstream/downstream impacts in the aquifer areas. The shift in the upstream from the rangelands and rain-fed systems to the irrigated cereal production has resulted in reduced surface inflow and increased subsurface inflow from the upstream to the downstream. This causes waterlogging and water-quality issues in some downstream locations. This is further aggravated by reducing the groundwater extractions in the downstream causing waterlogging and salinity issues on over 50% of the irrigated land.

OBJECTIVES

The objectives of this paper are twofold: to emphasize opportunities associated with the development of the Fergana Valley aquifers with transboundary implications; to suggest solutions to constraints for groundwater irrigation.

Studies carried out earlier suggested temporary storage of the small river flow in the subsurface aquifers of the Fergana Valley (Mirzaev, 1974; Akramov, 1991). Raising competition between hydropower and agriculture focuses attention on the groundwater aquifers as the storage for temporarily accumulating the winter hydropower releases on the Naryn River (Karimov et al., 2010). This paper starts with describing the upstream/downstream impacts in the study area. Then the potential of the groundwater development in the downstream is analyzed. Subsurface water storage opportunities in the aquifers are highlighted. This opportunity relates to free subsurface capacities available in the upper part of the river basins. Then potential capacities are emphasized which could be created by intensive groundwater extractions. Then constraints are analyzed for groundwater development. Finally, the study proposes solutions for the constraints and emphasizes the need for conjunctive management of surface water and groundwater.

RESULTS AND DISCUSSIONS

Aquifers of the Fergana Valley

The aquifers of the Fergana Valley having transboundary implications associated with groundwater resources can be described by the two main conceptual models: 1) Aquifers located completely within the territory of one state but linked hydraulically to a river across an international border. Examples of this model are the Sokh and Yarmazar aquifers. In this model the river is international, while the aquifer is geographically domestic. According to Eckstein and Eckstein (2005), this type of river-aquifer system falls within the scope of the Watercourse Convention; 2) Aquifers intersected by an international border and linked hydraulically with a river that is also intersected by the same international border. Examples of this model are the Osh-Aravan and Isfara aquifers. This model also falls within the scope of the Watercourse Convention because of the hydrological connection between the transboundary aquifers and the transboundary river.

Formation of the groundwater resources upstream and downstream of the aquifers with the transboundary implications has distinct features which are to be considered for groundwater management. Since 1990, in the upstream of the aquifers, there has been a trend of increasing water diversions from the small rivers for irrigation purposes. Farmers are moving from rain-fed agriculture and livestock on the rangelands to irrigated cereal production. Thus winter crops, such as winter wheat and oats occupy 40% of the irrigated land upstream of the Shahimardan River Basin. Increasing the area of the irrigated land is indicated in the upstream of the Sokh River and other small river basins. This, in combination with low delivery efficiency of irrigation canals and small-size irrigated fields, creates significant recharge of the groundwater in the upstream. Combined surface and subsurface outflows to the downstream are less than at the previous stage due to increased diversions of the river flow for irrigation and evapotranspiration from the upstream irrigated land. As a consequence, there are upstream/downstream impacts due to reduction of the surface flow and increasing the subsurface flow.

In the downstream, features of the groundwater recharge are as follows:

1) On average, subsurface inflow to the Fergana Valley downstream makes 18% of the total groundwater recharge for the aquifers having transboundary implications. In some cases, it creates waterlogging issue. Moreover, salinity of the groundwater entering the downstream is relatively high due to leaching salts from the upstream irrigated land. This affects the quality of groundwater which is the source of the drinking water supply.
2) The main source of groundwater downstream is losses from canals and irrigation. On average, irrigation contributes 49% of the groundwater recharge of the aquifers of the Fergana Valley, and the corresponding value for Sokh, Isfara and Mailisu exceeds 60%.
3) Groundwater recharge in the downstream is reduced due to several causes. First, since 1990, following the state food independence policy, 40% of the irrigated land was transferred under wheat production. The shift from cotton and alfalfa to winter wheat production has reduced crop water requirements and, as a consequence, water diversions from the Naryn River to the Fergana Valley have been reduced. Second, increasing the upstream water diversions results in seasonal downstream low flow from April to June.
4) In spite of reduction of the groundwater recharge, the current reduced groundwater extraction from 4,400 Mm^3/yr in 1993/94 to 2,700 Mm^3/yr contributes to rising water table and waterlogging issues.

Opportunities

Studies carried out in the Fergana Valley on the territory of Uzbekistan have found significant subsurface capacities which could be used for regulating the river flow, and in particular the winter flow of the Naryn River. Free capacities of the aquifers exceed 3,000 Mm^3, which could be used for banking the excessive winter flow of the small rivers. This capacity is more than the winter flow of small rivers totaling 1,000 Mm^3/yr. This study found that additional capacities can be created at 141 Mm^3/m of drawdown by intensive groundwater extraction in the summer season. This shows that the physical capacities for groundwater banking do exist. However, careful economic analyses and modeling of each aquifer are required to assess to what extent groundwater banking is economically viable. Also, the groundwater banking will need to be seen in connection with groundwater extraction for irrigation purposes. The zoning of the Fergana Valley on groundwater development potential for irrigation suggests that the potential area for groundwater irrigation is 290,000 ha while for conjunctive use of groundwater and canal water it is 243,000 ha. The system of canals can irrigate the rest of the 367,000 ha area. Currently, the groundwater extraction in the Fergana Valley is at 31% of the total recharge on average, while for Chimion-Aval, Sokh and Almaz-Varzyk aquifers it exceeds 50%. Extraction of the annual groundwater recharge in summer may significantly lower the water table. Aquifer recharge would need to be managed to prevent issues related to groundwater depletion, degradation of groundwater quality and high cost of extraction. These data show that there is unused subsurface capacity which could be used for regulating the Naryn and small rivers flows. Extraction of the renewable groundwater resources in summer for agricultural needs will lower the water table. The subsurface inflow causing waterlogging and water quality issues could be extracted for beneficial use. In spite of the indicated opportunities, several constrains to groundwater development are found, some of which are as given below.

Constraints

Low incentives for water saving under the state cotton and wheat quota system. Cotton and wheat cover over 80% of the irrigated land of the Fergana Valley. Farmers producing cotton and wheat receive purposeful state credits, calculated based on planned yield and covering up to 60% of the input costs for the crop production. Farmers have to return the credit after 18 months plus 3% of the state/bank interest rate. Water is delivered free of charge to the farmers except small fees for services of water user associations (WUAs). Under such conditions, these farmers have low incentives to save “free of charge” water and to look for other sources, such as groundwater.

*High cost of construction and maintenance of wells***.** Until the beginning of the 1980s groundwater extraction in the Fergana Valley aquifer was low, mostly for drinking water supply and maintaining the deep water table in the populated areas. Groundwater use for irrigation was practiced only in years with low water. However in 1985, during the severe water shortage, a step was taken to increase the water extraction for irrigation needs. As a consequence, the water extraction increased from 1986 to 1993-1994 from 3,760 Mm^3 to 4,400 Mm^3/yr. By the end of 1992, the number of wells had exceeded 8,000. These wells were drilled to obtain water for drinking, drainage and irrigation needs. Most of the wells for irrigation were 60-100 m deep, with centrifugal pumps and power supply. The deep wells have high yields of 30-50 l/s. These wells were installed under an environment with centralized water management; collective farms had 3,000-10,000 ha area; and the irrigated fields were 15-25 ha in size. Under such conditions, high-yielding wells had the capacity to supply high irrigation demands. Groundwater extraction has become one of the main factors preventing salinization of the topsoil and is an important source of irrigation.

Since 1990, after fragmentation of the farming system into small farms each of 3-10 ha area, there was a lack of a groundwater governance, which could facilitate farmers’ cooperation on operation and maintenance (O&M) of the wells. Most of the private farmers, gaining low incomes from cotton and wheat, are not able to cover O&M costs or to install new wells costing US$15,000-25,000/well, while they have access to free canal water subsidized by the state. Reduction of the state investment in O&M of wells since 1990 has made their centralized exploitation difficult. As a consequence, from 2001 to 2005, groundwater extraction has gradually decreased to 2,700 Mm^3/yr and, moreover, there is a risk that groundwater extraction will further reduce to the levels of the 1980s. The reductions in groundwater extractions were followed by raising the water table and increasing the treating of salinity build-up in the topsoil, especially in the lower part of the basin. For example in 1992, the irrigated area with water table less than 2 m amounted to 38% which made up 74% of the total in 2007. High evaporation from the shallow water table has increased the treating of salinity build-up in the topsoil.

Lack of the groundwater use governance. There are several cases when farmers own deep wells and sell water to the neighboring farmers. The payment share of each farmer getting groundwater is based on operational expenses of the well. Since distribution of groundwater by inter-farm water distribution ditches results in significant losses, farmers are indeed applying these practices, and as soon as possible they try to shift to separate shallow wells.

High power consumption. High power consumption is considered to be one of the limitations of groundwater development. Under these conditions of the Fergana Valley canal irrigation is supplemented by lift irrigation, covering a third part of the irrigated area and requiring high-power supply. Lift irrigation also requires high-power supply due to the great height of the water lift and the old low-effective pumps. Further analysis is required to estimate power consumption for one of the irrigation systems, considering different water supply options.

Opportunities for revitalization

There are several strategies that, at least, bring back groundwater irrigation scales.

The first is often applied in the development projects and based on rehabilitation of old and deep wells and installing new ones. Since the cost of deep wells is high, it is difficult to expect low-income farmers to be able to cover O&M costs of the wells in the very near future. This strategy requires high investment from the state budget.

The second is reducing the area under the subsidized crops, letting farmers themselves select a cropping pattern on the released area to improve access to water. Farmers growing orchards and vegetables do not get purposeful credit in most cases but they can sell the products in the open market. These farmers have higher profits as compared to wheat and cotton producers. In many cases, they pay higher fees for water delivery services of the WUAs. They are interested in guaranteed water and they try to get access to different water sources, including groundwater. The study of farmer practices of the Fergana Valley shows that under unstable access to canal or lifted water they are ready to invest in groundwater extraction, even if it is more expensive than subsidized canal water.

The third is the possibility for coordination of the water users and establishing informal groups that will shoulder responsibility for maintenance of the existing wells and sharing expenses. This practice is already monitored for groups of farmers producing orchards and vegetables in the Sokh River Basin. They apply time-based water distribution for sharing water from the same well. The fee for water delivery is time-based. Relatively rich farmers producing grape and orchards preferring to have own high-yielding wells and are ready to invest in the construction of expensive deep wells.

The fourth strategy is to revert to bore wells and shallow wells. Bore wells or shallow wells yielding less than 1 l/s are widely used for irrigation of home yards and domestic needs in the Fergana Valley. From 2010, some innovative farmers are using similar bore wells yielding 2-3 l/s for irrigation of orchards, vegetables and other cash crops. These bore wells have many advantages as compared to deep wells. Low- yielding wells are much cheaper than deep wells. They are easy to maintain; spares of low-yielding pumps are much cheaper than those of high-yielding ones.

The fifth strategy is to apply managed aquifer recharge. Natural recharge can be enhanced to improve groundwater quality. Adoption of water saving technologies will reduce irrigation water demands, and the saved water could be recharged into the aquifers for temporary storage. There are many other options, requiring further studies, which will permit using opportunities related with management of aquifers of the Fergana Valley.

CONCLUSIONS

Shifts from rangelands and rain-fed systems to irrigated agriculture in the upstream may create upstream/downstreams impacts by reducing the surface flow and increasing the subsurface flow available for the downstream. Low groundwater extraction conditions and poor water use practices in the downstream result in widespread water table and salinity issues in the areas where groundwater aquifers have transboundary implications. These challenges could be shifted to benefits through active management of these aquifers. Groundwater development for agriculture and other purposes will lower the water table and extract the excessive flow for beneficial use. Created by the water table drawdown free capacities of the aquifers could be used for temporary storing of the river's excessive flow. The future of the proposed strategy depends on overcoming constraints to groundwater development. They are as follows: low incentives for farmers to shift from subsidized canal irrigation to groundwater, especially under a state quota system for crop production, and high cost of construction and maintenance of wells. The study suggests that farmers growing cash crops such as orchards and vegetables facing water shortage are ready to invest in groundwater development while, in many cases, shallow bore wells could replace deep wells. The need for management of the transboundary aquifers as a part of the river basin development plan is emphasized which will bring mutual benefits for the riparian states.

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Spatial dynamics and hydro-economic modeling of transboundary aquifers

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ABSTRACT

Extraction from a transboundary aquifer, where no single entity has the authority to control all the pumpage, may result in a divergence between competitive and optimal rates of extraction. This paper develops a hydro-economic model to estimate the size of the payoffs from this divergence under alternative spatial representations. Results show that when an aquifer is heterogeneously distributed spatially, assuming a spatially homogeneous distribution can underestimate the losses with competitive extraction. An application of the model to a sector of the Guarani Aquifer System shows the importance of recognizing spatial heterogeneity in groundwater extraction problems to: (1) provide robust estimates of the costs of sub-optimal extraction and; (2) implement appropriate corrective policies.

Key words: hydro-economic modeling; spatial dynamics; groundwater extraction; transboundary aquifers.

1. INTRODUCTION

Tractable but realistic integrated models are a prerequisite for the sound management of transboundary aquifers. Given the high costs of implementing international regulatory frameworks, careful hydro-economic modeling assessing the need and structure of feasible measures becomes crucial. Indeed, a precise estimate of the size of the loss from competitive (unregulated) extraction is critical to delineate the appropriate size and scope of aquifer management policy.

Although considerable research has been devoted to estimating the magnitude of the welfare loss from competitive extraction of groundwater, studies have neglected to consider the robustness of their results to heterogeneous spatial representations of the aquifer. To address this gap, we build a theoretical model to compare optimal and competitive extraction paths of spatially distributed users yielded by two different spatial representations of the aquifer. The first representation resembles the most commonly used by economic studies. This specification assumes that the aquifer is spatially homogeneous and evolves independently of the history of past extractions. The alternative representation relaxes these standard restrictions and allows for a heterogeneous distribution of groundwater, and lagged effects of past extractions.

Our results show that a homogeneous 'bath-tub' representation of groundwater flow fails to capture well-interference areas, thus underestimating the welfare and hydrological costs from competitive extraction. Overall, our results suggest that assumptions about homogeneity of groundwater distribution are particularly important in terms of the role and scope of corrective policies. The sensitivity of policies to the spatial characteristics of the aquifer is particularly important in a transboundary context where the absence of a single authority increases the likelihood of overexploitation. In these cases, if the benefits of cooperation are derived from spatially simplified models, perverse incentives for noncooperation are likely to result in welfare losses and unsustainable hydrological outcomes.

2. THE CASE STUDY

The Guarani Aquifer System (GAS), or rather the aquifers that form the GAS, are located in the sedimentary Parana Basin located in the subsoil of the east and center-south of South America, underlying parts of Argentina, Brazil, Paraguay and Uruguay. The present paper focuses on a section of the aquifer that was identified by a Global Environment Facility (GEF) project as critical within the GAS: the Concordia-Salto pilot project. Concordia and Salto are two cities located on opposite sides of the Uruguay River, which is a natural boundary between the Argentinean north-eastern province of Entre Rios and western Uruguay. The wells in the area extract thermal groundwater for balneological purposes.

The total number of operating thermal wells on the Concordia-Salto area is six on the Uruguayan side and three on the Argentinean. However, thermal water extraction is likely to rise in accordance to the development of tourism in the coming years. In the area, the notion of common property characterizes exploitation of thermal groundwater reserves. Although access is limited by extraction permits, tourism operators own groundwater as a common property resource subject to the rule of capture and a transboundary legal framework has not been implemented. Thus, the rate of groundwater mining and recycling and the location of new wells are the result of private decision-making.

3. THE MODEL

The hydrologic conceptual model of the local area was developed and parameterized by a study of a Global Environmental Facility (GEF)'s project (Charlesworth, Sangam and Assadi 2008). Following Morel-Seytoux and Daly (1975), the finite difference model is run 50 times by applying different levels of stress at the seven existing and seven potential stress locations. Due to computational constraints, the duration of the study (40 years) is divided in two management/stress periods of 20 years during which extraction rates are held constant.

Let $Q_{k,1}$ and $Q_{k,2}$ be the extraction rates (in m3/h for a 16-hour daily extraction regime) applied at location k during the first and second stress periods respectively. Let $s_{i,1}$ and $s_{i,2}$ be the aquifer's response at location i after 20 and 40 years due to all such stresses. The first spatial representation entails estimating drawdown as:

$$(1)\ s_{i,1} = \beta \sum_{k=1}^{14} \left(Q_{k,1}\right)$$

$$(2)\ s_{i,2} = \beta \sum_{k=1}^{14} \left(Q_{k,1} + Q_{k,2}\right)$$

Note that the drawdown of the water table is uniform throughout the aquifer and the contribution of each well's extraction is constant across time and space (the coefficient β is constant).

The alternative representation is derived by adapting Theis (1946) solution for transient well response to pumping and using the principle of superpositioni to estimate drawdowns $s_{i,1}$ and $s_{i,2}$ as a linear function of $Q_{k,1}$ and $Q_{k,2}$ $\forall k = 1,...,14$ as:

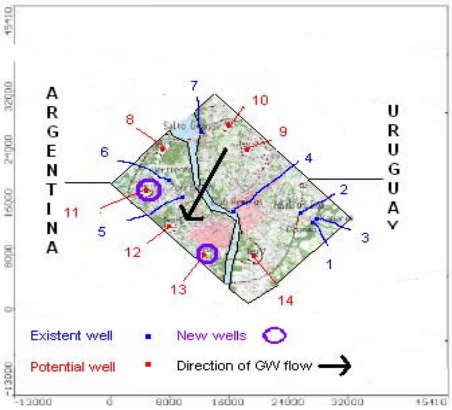
(3) $$s_{i,1} = \sum_{k=1}^{14} Q_{k,1}\beta_{i,k,1}$$

(4) $$s_{i,2} = \sum_{k=1}^{14} \left[Q_{k,1}\beta_{i,k,2} + \left(Q_{k,2} - Q_{k,1}\right)\beta_{i,k,1} \right]$$

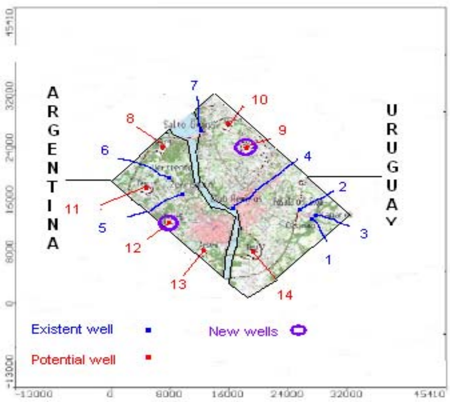
Since users fulfill their demand for water by self-extraction from the aquifer (facing no external price for it), the optimal design policy is derived from a cost-minimization problem. The decision variables are (a) where to install two new wells from a set of potential locationsii, (b) whether to install/de-install a water recycling system at each existent and new location in the first or second period, (c) whether to install/de-install a pumping system at each existent and new location in the first or second period. The constraints are that (a) extraction at each well exceeds a given demand minus the equivalent recycled water (if any), (b) hydraulic heads at all operative well locations must exceed the distance between ground surface and the lower datum of the aquifer by more than 10m if no equipment is installed and more than 3m if water recycling systems but no pumps are installed, and (c) the aquifer's response to extraction patterns represented by equations (1-2) or (3-4).

In the competitive management scenario, one of the locations for the new wells is given by a well that has already been drilled in the area. The other location is assumed to be selected in a 'myopic' fashion based on the largest head excess -expected after the first 20 years- of the distance between ground surface and the lower datum of the aquifer. Two potential sites (one in Argentina and one in Uruguay) are analyzed for the second location.

4.RESULTS AND DISCUSSION



(A) First representation



(B) Alternative representation

Figure 1. Optimal new well locations and technology installed.

The two spatial representations derive different optimal new well locations: under the alternative representation, costs are minimized when the new wells are located at sites #11 and #13 because head and demand constraints are satisfied without the need to invest in any technology in neither the first nor the second management period. Conversely, as figure 1 shows, under the first representation optimal well locations are sites #9 and #12 and no technology is needed given the drawdown predictions of this physical specification.

The location of new wells in the competitive management scenario is the same regardless of the aquifer's representation used. At the start of the first management period, all users expect their hydraulic heads to be sufficient to cover their water needs during the period, and no equipment is installed. During the second 20 years, drawdown in the north-eastern corner of the area increases dramatically if measured with the alternative representation. It is worth noticing that this happens regardless of the position of the second new well. Hence, two users in that area are forced to invest in recycling systems. Since the first representation averages out drawdown throughout the aquifer, it fails to acknowledge the interference area in the north-western corner of the aquifer. As summarized in table 1, the first representation underestimates the welfare losses of a competitive management scheme and calculates an equal difference between initial and final heads for every location irrespective of the positioning of new users and management scheme.

Table 1. Optimal vs. Competitive Groundwater Management.

	Management scheme		Difference
	Competitive	Optimal	
A. NUL representation			
Location of new wells	**8 and 10 or 13**	**11 and 13**	**YES**
Location of recycling systems	**7 and 8**	**None**	**YES**
Location of pumping systems	**None**	**None**	**NO**
Total discounted cost	**US$2,330,554**	**US$2M**	**+16.53%**
Average drawdown after 40 years	**22.41m**	**17.56m**	**+27.62%**
B. UI representation			
Location of new wells	**8 and 10 or 13**	**9 and 12**	**YES**
Location of recycling systems	**None**	**None**	**NO**
Location of pumping systems	**None**	**None**	**NO**
Total discounted cost	**US$2M**	**US$2M**	**0%**
Average drawdown after 40 years	**15.57m**	**15.68m**	**-1%**

In conclusion, our empirical findings show that significant welfare and hydrologic costs from competitive extraction are overlooked if the aquifer is assumed to be a homogeneously distributed resource. This is because such a representation fails to capture well interference areas. Thus, the location of new wells is an irrelevant decision for users in both the optimal and competitive extraction scenarios.

From a policy perspective, the present study raises important issues. An implication, at least in terms of the aquifer studied, is that second-best economically defined spacing regulations are likely to have better efficiency results than uniform taxes or quotas. While policies that vary idiosyncratically across space may, in some transboundary cases, be prohibitively costly to implement, spatially-based policies do offer the potential of higher payoffs than conventional approaches with spatially heterogeneous resources.

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[i] The principle of superposition means that for linear systems, the solution to a problem involving multiple inputs (or stresses) is equal to the sum of the solutions to a set of simpler individual problems that form the composite problem.

[ii] The locations used are the ones proposed by Charlesworth, Sangam and Assidi (2008).

Management Challenges and Opportunities in the Endorheic Basins of the Northern Saharan Transboundary Aquifers

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ABSTRACT

Reasonable utilization of land and water in transboundary aquifer systems requires consideration of the social and ecological dimensions of groundwater use. This paper discusses the experience of local institutions in monitoring and managing the changing groundwater conditions and utilization at the terminal outlets to two major North African transboundary aquifer systems, the Nubian Sandstone Aquifer System (NSAS) and the North West Sandstone Aquifer System (NWSAS).

Results from a multidisciplinary analysis of national research archives, remote sensing, interviews with decision-makers and direct surveys of cultivators in selected oases in both regions are used to examine the impacts of accelerated groundwater extraction from these systems during land reclamation and cultivation for both domestic and international agricultural export markets over the past two decades. Opportunities are identified for international initiatives to improve the management of the aquifer systems by encouraging the engagement of land and water users in local resource monitoring and management.

Key words: Nubian Sandstone Aquifer System (NSAS), North West Sandstone Aquifer System (NWSAS), adaptation to environmental change, groundwater vulnerability databases, management institutions

1. INTRODUCTION

Increasing aridity and climatic variability make groundwater the only reliable source of water for a growing number of land-users (WWAP 2009). At the same time, international demand for agricultural produce is exacerbating overextraction for irrigation (Giordano 2007). The management of transboundary aquifer systems requires thousands of individual land-users to recognize a shared responsibility, assess the effects of their actions, and manage the function of their land and water systems accordingly (Darnault 2008).

This paper draws on the findings of a multidisciplinary assessment of the impacts of environmental change over the past thirty years on groundwater resources in the geomorphological depressions of the North Western Desert of Egypt and the Chotts of the Nefzaoua region in Southern Tunisia. These land and water systems are situated at the terminal outlets of the two major North African transboundary aquifer systems, the Nubian Sandstone Aquifer System (NSAS), shared between Sudan, Chad, Libya and Egypt, and the North West Sandstone Aquifer System (NWSAS), shared between Algeria, Tunisia and Libya (CEDARE 2001, OSS 2003).

The paper begins with a brief review of the management objective of equitable and reasonable utilization, followed by an introduction of the selected land and water systems in the two transboundary aquifers and the changes taking place within them. Methods used to assess the impacts of global changes to groundwater resources are summarised. An overview of results obtained is presented in Section 4. Section 5 focuses on exploring best practices and lessons learned in local management data collection, and opportunities to strengthen collective management systems across the transboundary aquifers through international initiatives based on the findings from the two cases investigated.

2. CONCEPTUAL APPROACH

The UN Resolution (A/RES/63/124) calls on States to manage the `equitable and reasonable utilization` of transboundary aquifer systems. `Equitable and reasonable` utilization is defined in relation to a series of social and ecological factors. In arid environments, where populations depend on groundwater, considerable challenges are apparent in terms of understanding the changing condition and functions of the surrounding socio-ecological systems (Safriel et al. 2005). These information needs are the subject of global efforts to improve the monitoring of land degradation and Sustainable Land Management (SLM).

Challenges encountered at the national level in monitoring groundwater use by both large and small users have led to growing emphasis on the role of socio-ecological or participatory local management approaches (Khater 2003, MWRI 2005, Shah 2005, van Steenbergen 2006, Darnault 2008). These approaches often seek to apply the principles of common pool resource management to address the groundwater management challenge (Ostrom 1990, Pahl-Wostl 2009, Shah 2009). Sharing of information to establish mutual trust and accountability is seen as central to this process (IBRD 2007). This is difficult to achieve where institutions are very decentralized or informal, and without channels for collecting, analyzing and disseminating local management information (Hammani et al. 2009).

Over recent years, international efforts to monitor SLM have explored options to integrate State-led monitoring processes with land-users observations, knowledge and actions. This experience has generated new approaches to monitoring and managing land and water systems where cultivators are depending on transboundary aquifers. Such approaches are investigated in this paper through local scale assessments of groundwater conditions and use within the two transboundary systems.

3. LAND AND WATER USE SYSTEMS CONTEXT AND INVESTIGATION METHODS

The Nefzaoua region is located at the terminal point of the NWSAS, while the Northern Oases of the Western Desert, Siwa and Wadi El Natrun, are underlain by the NSAS. Variable salinity is a natural condition of aquifers in both systems Both the NWSAS and NSAS receive minimal recharge in comparison to extraction, and reserves of fossil water in these deeper aquifers are considered non-renewable (Mamou 1990, CEDARE 2001, OSS 2003). Both regions have supported cultivation for several millennia. Use of naturally emerging spring water and locally recharged drainage water in the local phreatic aquifers does no harm to the transboundary aquifer systems that feed them, or to their associated ecosystems. Indeed, as the soil quality and microclimate are adjusted by the presence of vegetation, the efficiency of water storage and use at the surface increases. This utilization may therefore be considered reasonable according to A/RES/63/124.

Over the past three decades, the number of wells in use in both systems has increased exponentially (Khater 2003, Ould Babasy 2005). While the early wells tapped the overlying local aquifers, land and water management practices have led to the depletion and contamination these shallow renewable sources. Since the 1990s, the middle aquifers at depths of around 100m (the Complex Terminal in the NSAS and the Miocene layers at in the NSAS) have become overexploited, forcing new wells to be drilled deeper into the underlying layers. The Continental Intercalaire (CI) in the NSAS is around 800–2,500m below the Nefzaoua region, and the freshwater Cretaceous layer of the NSAS is at depths of around 1000m beneath the Northern part of the Western Desert.

National research libraries and management databases were used to investigate land and water development patterns in both regions. ERDAS Imagine^{TM} software was used to analyze the Normalized Difference Vegetation Index in multiple Landsat images provided by the USGS in order to detect changes in extent of vegetation cover due to increasing use of groundwater for irrigation. In each location, surveys of cultivators were used to further interrogate these changes, and local efforts to manage the degradation of the land and groundwater resources.

4. RESULTS

4.1. Impacts of changing land uses on groundwater resources

In 1987, Landsat images showed an area of high NDVI covering 10,942 hectares in the Nefzaoua region and a combined total of 6,970 hectares in the two North Western Desert locations of Siwa and Wadi Natrun. By 2003, the Nefzaoua area had undergone a 44% expansion to 15,796 hectares. In the Western Desert areas, a 153% expansion took place. In both cases, the increase can be attributed to the expansion of ground-water irrigation, of which, a significant portion is believed to be unauthorized. In the Tunisian case, decision-makers estimated the level of illicit extractions at around 30% of the total following an investigative field survey (Siegfried 2004). Both official extraction figures and remotely sensed data have continued to show increases in the rates of ground water extraction and the extent of the vegetated area over subsequent years until 2010.

Falling water tables and loss of artesian pressure have been observed in both regions (see eg Mamou and Hlaimi 1999, Khater 2003). These observations were confirmed by groundwater users interviewed during field investigations. As water tables have fallen, the costs for pumping water have risen. Small landholders surveyed either use deep wells provided by the government, or unauthorized shallow wells that remain vulnerable to contamination. In Egypt, electric pumping systems used by large landholders holding permits for groundwater extraction have become cheaper than the diesel pumps used by smaller and informal landusers although their groundwater use is renewable.

Local monitoring over the past decade has shown Total Dissolved Solids rising to above 8g/l in the most exploited parts of the NSAS Complexe Terminal aquifer and to comparable levels in parts of the NSAS (Hossary 1999, Attia et al. 2007). In addition to salinization of aquifers, irrigation causes secondary salinization and sodicity problems where poor drainage leads to waterlogging eg at Siwa in the Western Desert and in low lying areas around the Chott El Djerid in Nefzaoua. Salt deposits on the soil surface can affect surface recharge (Kadri 2002, El Fahem 2003, Gad and Abdel-Baki 2002). Regional models have predicted increasing salinization threats (Zammouri 2007, Attia et al. 2007).

4.2. Responses of land users to changing groundwater conditions

Cultivators in both regions observed the effects of increasing water scarcity and rising salinity on their crops. The two problems interact because salinity weakens the ability of the plants to take up water, making them more prone to water stress and disease. Cultivators adapt their water use and cultivation patterns to cope with productivity losses, either reducing investments in land improvement and cultivation where they will bring diminishing returns, or digging deeper wells to bypass the trend in groundwater degradation. Digging deeper wells solves the immediate problem for individual cultivators, but further exacerbates the threats to the common pool resource, and decreases the overall resilience of the production systems. Both of these outcomes from land users` responses to changing groundwater conditions threaten the function of the cultivated ecosystems and the benefits that they provide to dependent populations. Groundwater uses leading to these outcomes might therefore not be considered reasonable and equitable, as defined in A/RES/63/124.

Different approaches to collective groundwater management associations have been pursued in the two countries. In the case of the Western Desert, where water user associations remain informal, when new wells have been installed either by the State, or increasingly by private water users, the traditional associations have weakened or disappeared altogether. In Tunisia, water user associations are supported by the State, and continue to provide timed water allocations to small cultivators. But these systems are still more vulnerable to water scarcity and degradation than those who have their own private wells. They are therefore considered less efficient in terms of water-productivity than private agricultural producers, which operate outside the collective management associations. In neither case do the water user associations include all groundwater users, nor do they have sufficient capacity to generate effective management data on the shared resource.

5. DISCUSSION:

5.1. The institutional challenge of monitoring and managing the aquifer system's response

Available public data indicates groundwater degradation trends in both regions, but remains incomplete. Public monitoring programmes in Egypt cover a wider area at a relatively coarse resolution when compared to Tunisian groundwater monitoring (DGRE 1979-2006, EEAA 2009). As demonstrated in the previous section, comparable estimates of increases in the irrigated area in the two regions can be generated from remote sensing of NDVI. However, irrigated areas where crops are at early growth stages or have undergone degradation are under-detected using these methods. Nor do they take into consideration groundwater extraction for non-agricultural uses.

Accurate quantitative data on groundwater use by private companies is not available, nor do such companies share hydrogeological information, since this has become a determining factor in the competitiveness of drilling companies, water providers and agricultural export corporations. This constrains the availability of data for management use. States are required to establish expensive parallel data collection infrastructures when a wealth of information already exists in private databases. Regulation through permit systems has taken time to establish, due to the large number of pre-existing unregistered wells and the high transaction costs of controlling use (see Kassah 1996, Khater 2003).

5.2. Best practices in monitoring equitable and reasonable utilization

Groundwater managers interviewed in Egypt indicated that the integration of regulatory systems for land registration with the groundwater permit system was providing increasingly effective incentives for landusers to register their wells. Registration requires users to provide documentation on the hydrogeological conditions. The resulting database is then maintained by the State to enable analysis of the evolving groundwater management situation. This does not address the problem of pre-existing and new unauthorized wells. However, it represents a promising step forward.

Field survey and rapid appraisal techniques directly engaging land-users have been used efficiently to complement official groundwater monitoring statistics in the Nefzaoua region. Further contributions have been made through this investigation, and other local activities by researchers in the field of Sustainable Land Management, generating valuable information concerning the management of groundwater and other inputs by landusers (eg Meddeb 2003, Siegfried 2004, Hammani et al. 2009). In the NSAS, on the other hand, the connection of groundwater management assessments to socioeconomic databases has been explored on a larger regional scale (eg Attia 2002).

5.3 Opportunities to improve management through information sharing

The increasing economic value of groundwater used for high value agricultural exports from both regions could enable improved investments in groundwater management systems, with increased support from the private sector. Whereas, at present, the larger companies run private laboratories in order to analyze the quality of their produce, soil and water supplies, these facilities and data could be used to complement the limited public monitoring systems. While States must coordinate their own institutions for collective management and monitoring, international processes could move this agenda forward more rapidly by requiring data sharing and socially responsible contributions by the larger export corporations to enhance local and transboundary resource management. One new entry point may be through the international environmental certification systems for agricultural export.

Refinements to water use estimates are still needed in order to take into account the efficiency of water uses under different technologies, at different salinities and from different sources – deep, shallow or recycled. For all of these, resource-user information to inform regional scale assessments requires effective processes for local sampling. As described above, the socioeconomic dimensions of groundwater use can be addressed at the local level through SLM surveys and participatory assessments, and at the regional level through connection to national census data. There is an opportunity to meaningfully integrate these different scales of socioeconomic data and to overcome sectoral barriers within ongoing assessments of transboundary aquifer management.

6. CONCLUSIONS

Accelerated groundwater extraction over the past three decades in the Northern Sahara has supported agricultural land reclamation for both domestic and export markets. Sometimes the groundwater use has succeeded in creating benefits and increased productivity. However, there have also been less reasonable and indeed harmful uses where misapplication of technologies and lack of understanding of ecological conditions has led to the depletion and contamination of the transboundary aquifer systems and degradation of productive land.

Best practices in information sharing to better understand and manage the reasonable and equitable use of groundwater dependent ecosystems in the Northern Sahara demonstrate scope for ongoing management improvements. Interactions between monitoring initiatives focusing on groundwater management and Sustainable Land Management more broadly are few at the international level, and at the practical level they are equally rare. International attention to this gap could enable a timely response to global change processes affecting transboundary aquifer systems and the people who depend on them.

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Modeling Surface Water Depletions Due to Groundwater Pumping in a Transboundary Basin

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ABSTRACT

The present study quantifies surface water depletions due to groundwater pumping in the Lower Colorado River Delta, motivated by the desire to conjunctively manage surface and groundwater and restore riparian habitats. Surface water depletions are a form of surface water capture by pumping. Capture can only be calculated by running a hydrologic model of the system under two conditions: (a) simulate the historical record of hydrologic measurements, and (b) simulate a base case that represents the hydrologic records under limited or no groundwater development. Surface water capture is the sum of increased stream losses in loosing reaches and decreased stream gains in gaining reaches. The seasonal capture estimates presented in this publication is water removed from the river by groundwater pumping.

Key words: surface water capture, groundwater pumping, riparian system, hydrologic modeling

INTRODUCTION

The current paper is a demonstration analysis of the depletion of surface water due to groundwater pumping on a transboundary system: the Colorado River Delta (CRD) between the US and Mexico's Sea of Cortez. The desire to conjunctively manage surface and ground waters, to restore the severely impacted riparian habitat along the river, and to test newly developed software motivated the current study.

The Colorado River crosses the border between the United States and Mexico with limited surface water. The amount of water flowing into Mexico is restricted by a complex set of water management policies throughout the Colorado River Basin, and by construction of the Colorado River Dam system which includes six dams within the United States. These policies and dams have reduced surface water flows to Mexico by approximately 75 percent during the last century (Luecke et al, 1999). Altogether, the regulation and divvying up of water within the Colorado River Basin is carried out according to the complex set of laws, international treaties, and agreements known as the Law of the River (see website of U.S. Bureau of Reclamation)

The CRD covers over 8,600 km^2 extending across the international border between the United States and Mexico. Characterized by a desert climate dominated by high temperatures and arid conditions (18mm in summer and 44mm in winter), the persistent hot dry conditions in the CRD result in a moisture deficit where evaporation potentials far exceed the input of precipitation. During pre-development of the delta for irrigated agriculture, widespread wetlands provided essential habitat for resident and migratory bird and animal species, some of them endangered. Nowadays, the remaining 5% of the original wetlands survive due to agricultural return flows and other unplanned flows resulting from human activities.

Modern day Colorado River flows crossing the international boundary are regulated in accordance with the 1944 U.S-Mexico treaty which states that no less 1,850,234,000 m^3 of Colorado River water is to be released into Mexico each year (the US-Mexico Joint Projects 1944 treaty). The surface water flow from the Colorado River into Mexico is used extensively for large scale irrigation. At present, there are over a 200,000 hectares of irrigated farm land within the CRD of Mexico (Olmsted et al, 1973). The surface water is inadequate to support the level of irrigated agriculture, which has led to development of groundwater resources to augment the surface flow. By 1965 there were over 400 large capacity irrigation wells withdrawing approximately 160,000,000 m^3 per year. Agriculture is the largest single user of water in the CRD region. Farms depend on a system of canals the bring a prescribed combination of surface water from the Colorado River and groundwater pumped from the region to their fields, and a series of drains that move irrigation runoff away (Cohen and Henges-Jeck, 2001)

Surface water and groundwater are not separated sources of water and interact through surface water/ groundwater interactions. The large scale pumping of groundwater from an aquifer system hydraulically connected to a surface water system will deplete the surface water system. This depletion is a form of surface water capture. To properly manage the available waters in the CRD region, it is imperative that the water managers understand the capture process and estimate its affect on the water supply.

METHODOLOGY

When a well is pumped a cone of depression is formed and continues to expand until a source of capture is encountered. There are two sources of capture from streambeds are: 1) decrease in groundwater discharge to gaining streams (interception of baseflow), 2) increase in groundwater recharge from losing streams (increased infiltration).

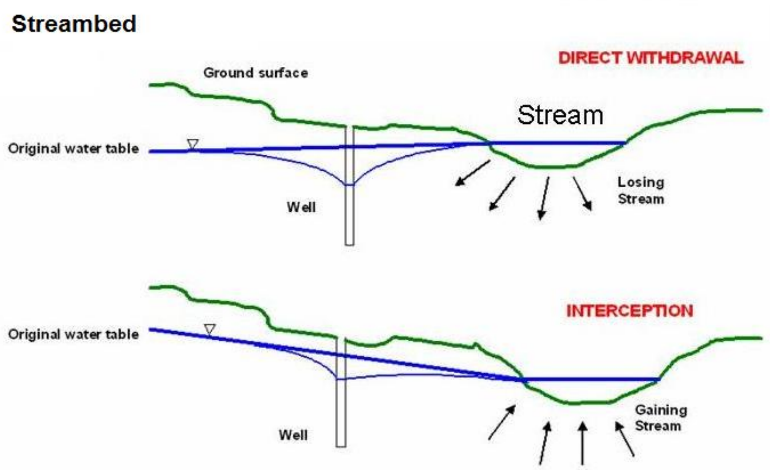

Figure 1: Sources of capture from streambeds.

If drains are present within the irrigation system, the cones of depression will likely encounter them first. If the drain water is to be returned to the river and used again, these cones of depression will reduce streamflow by the capture of the drain water.

Capture can only be calculated by hydrological modeling, it cannot be measured directly in the field. There is no capture meter. The hydrologic model of the system is run under two conditions: 1) simulate the historical record of hydrologic measurements, and 2) simulate a base case that represents the hydrologic records under limited or no groundwater development. The historical run and the base-case run simulate the system over the same distributions in time. For example, if the historical run simulation the systems groundwater and surface water system annually for a 25 year period, then the base-case run simulates the system annually for the same 25 years.

Surface water capture is the sum of the absolute values of two terms. The first term is the base-case time series of recharge from losing stream portions subtracted from the historical time series of recharge for the same stream segment. The second term is the historical time series of discharge from the gaining stream portion subtracted from the base-case time series of discharge for the same stream segment.

The historical run seeks to match the historical spatial and temporal data sets, thus the historical run is a calibrated run. The base-case may be fictional or artificial in nature, and based on little or no data. It is a hypothetical system that represents how the system would have been operated under limited or no groundwater pumping. The form or structure of the base-case may be the result of a negotiation process, or administratively or Court imposed.

The base-case run uses the same parameters and time steps as the historical run. Because capture cannot be measured in the field directly, there will be no capture data values to compare or calibrate with the calculated values.

The U.S. Geological Survey numerical model MODFLOW 2000 was used to simulate the groundwater flow and groundwater/surface water interactions in the CRD portion shown in Figure 2.

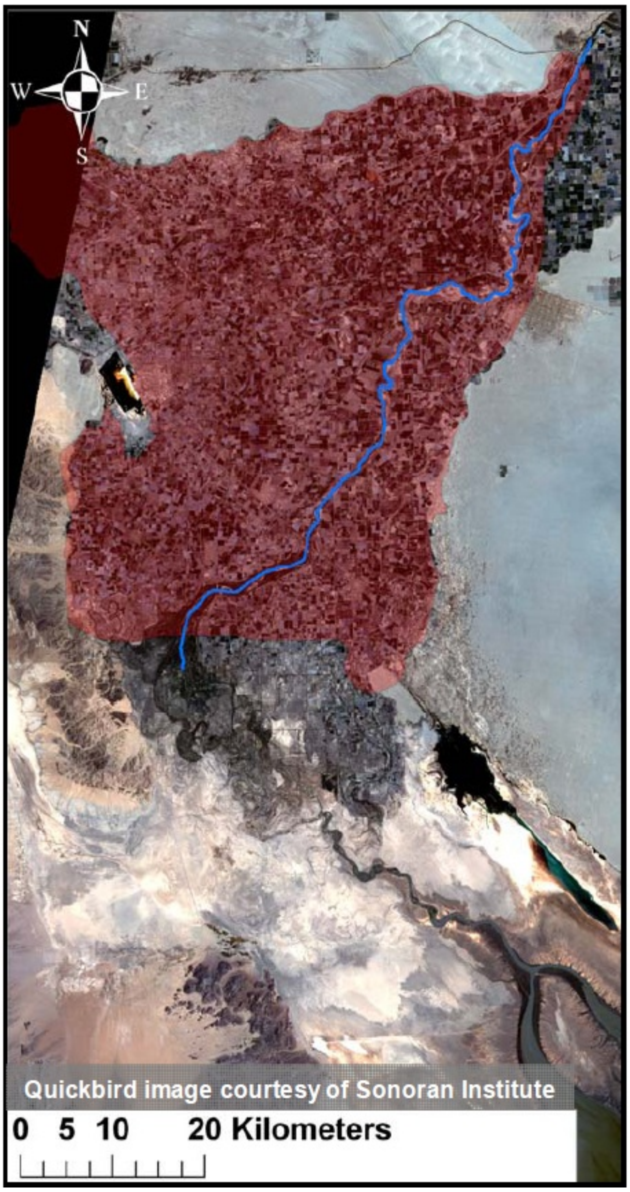

Figure 2, Colorado River Delta model area is shown in red with Colorado River shown in blue.

Streamflow in the CRD model was simulated using the stream package in MODFLOW developed by D. Prudic (1989). The stream-aquifer package, referred to as the STR package, routes flow through one or more rivers, streams, drains or ditches and computes leakage between these surface water features (commonly referred to as streams) and the aquifer beneath it simulating both gaining and losing portions

(Prudic, 1989). The STR package also calculates the water depth in the streams. Therefore, streamflow data at gage sites are additional calibration variables. The Mexican surface water allotment and any flood waters enters in at the northeast boundary of the model, and are routed through the system where losses associated with groundwater pumping are accounted for.

The CRD historical model includes 639 groundwater extraction wells, of these 418 are Federal and 221 are private (Figure 3). These wells are monitored by CONAGUA which maintains records of monthly volume pumped from each well, and takes a water level measurement from many of the wells once a year.

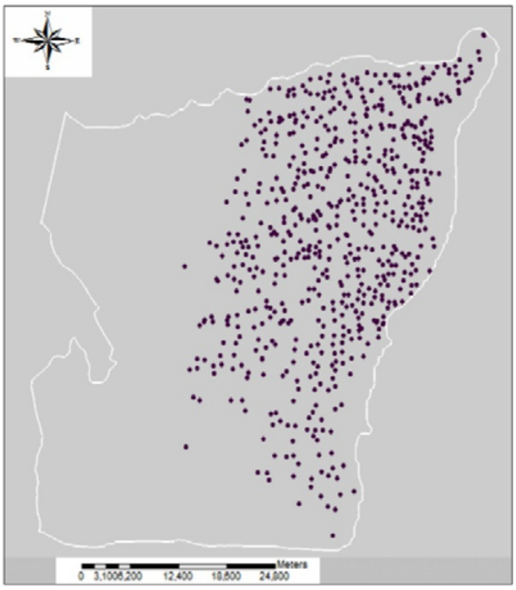

Figure 3, Distribution of 639 large production wells within the CRD model domain.

The historical model was calibrated for the years between 1957 and 2000 using data from CONAGUA (regional office Mexicali), the Autonomous University of Baja California, Dr. Jorge Ramirez, and the ITESM-Campus Guaymas. The model was calibrated for two seasons: 1) season 1 (winter) consisted of October – December of the previous year and January – March of the following year, and 2) season 2 (summer) April – September for the same year as the second half of season 1. Agriculture is the main water user within the CRD and recharge to the aquifer associated with agriculture, mainly irrigation, may be considered a primary source of recharge to the CRD aquifer.

Calibration was conducted by comparing model generated water levels to observed levels. Calibration was achieved through iterations of a process during which the model was run, computed vs. observed water levels were compared, and hydraulic parameters and boundary conditions were manually adjusted.

The base case model had the following properties. The 1957 through 2000 time frame and associated seasons were the same as the historical model. There was no groundwater pumping. The same quantity of water in flowed at the northeast boundary as with the historical model. The agricultural recharge was adjusted to reflect only surface water availability.

In a previous study of the CDR, capture was calculated using spreadsheet analysis (Feirstein et al, 2008). For this study, the capture was recalculated using a software called CAPT_CALC (see Figure 4). CAPT_CALC automates the capture calculations for MODFLOW historical and base model runs from the STR package.

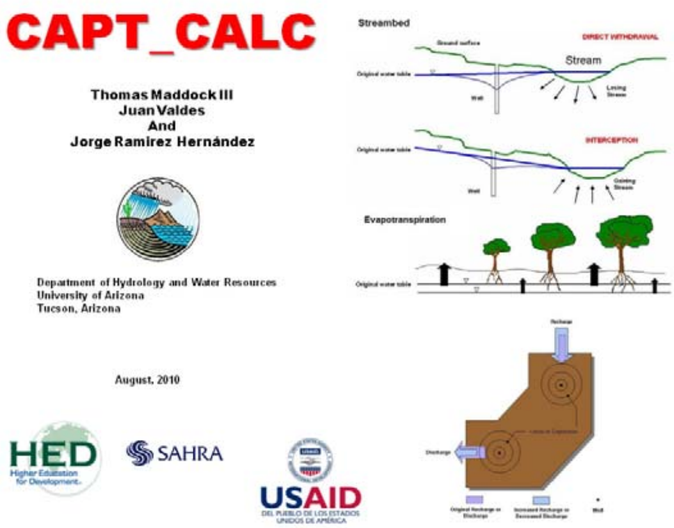

Figure 4, CAPT_CALC, a software that calculates capture from MODFLOW outputs.

CAPT_CALC can calculate capture from MODFLOW outputs from streams (STR, SFR, RIV), evapotranspiration (EVT, RIP-ET), head dependent boundaries (GHB), and specified head boundaries (CHB) packages. CAPT_CALC was funded in part by a Ties Grant (HED and USAID) between the University of Arizona in the United States and the Autonomous University of Baja California in Mexico, and SAHRA, a NSF Science and Technology Center.

RESULTS

The following results show the impacts of pumping on the stream system. Figure 5 shows the impacts of pumping on surface water in the CRD and differentiates the capture due to increased stream losses in loosing reaches, and the capture due to decreased stream gains in gaining reaches. In both cases, the capture shown is water that has been removed from the river flows by groundwater pumping.

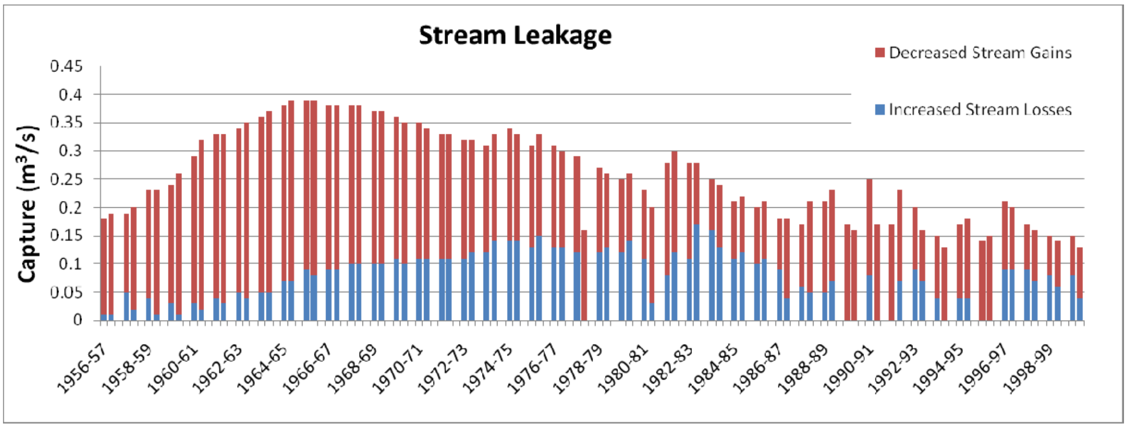

Figure 5: Capture from stream leakage through decreased stream gains (red) and increased stream losses (blue) for seasons 1 and 2 of each year.

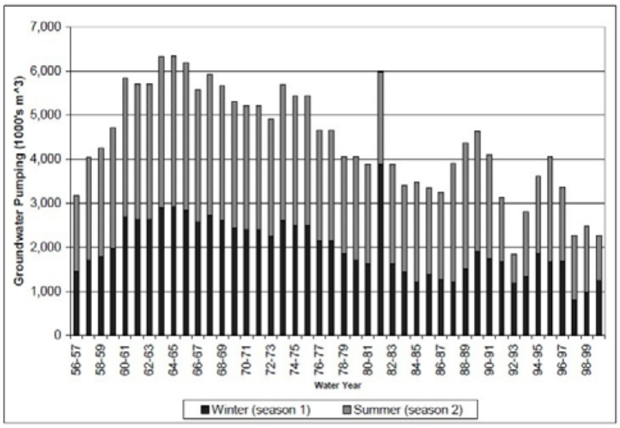

Figure 6, Total groundwater pumping rates for the CRD groundwater flow model

Figure 6 shows the groundwater pumping that produced the surface water depletions, and Figure 7 show the streamflow of the Colorado River for the same time frame. A casual comparison of the streamflow capture (Figure 5), the total pumping (Figure 6) and the stream inflow into the CRD (Figure 7) over time indicate that for periods of flooding where there is less groundwater pumping there is less capture. This is because of the dependence of Colorado River water for agricultural irrigation. When river flows are high, less groundwater is withdrawn to supplement irrigation, and there will be less depletion of streamflow.

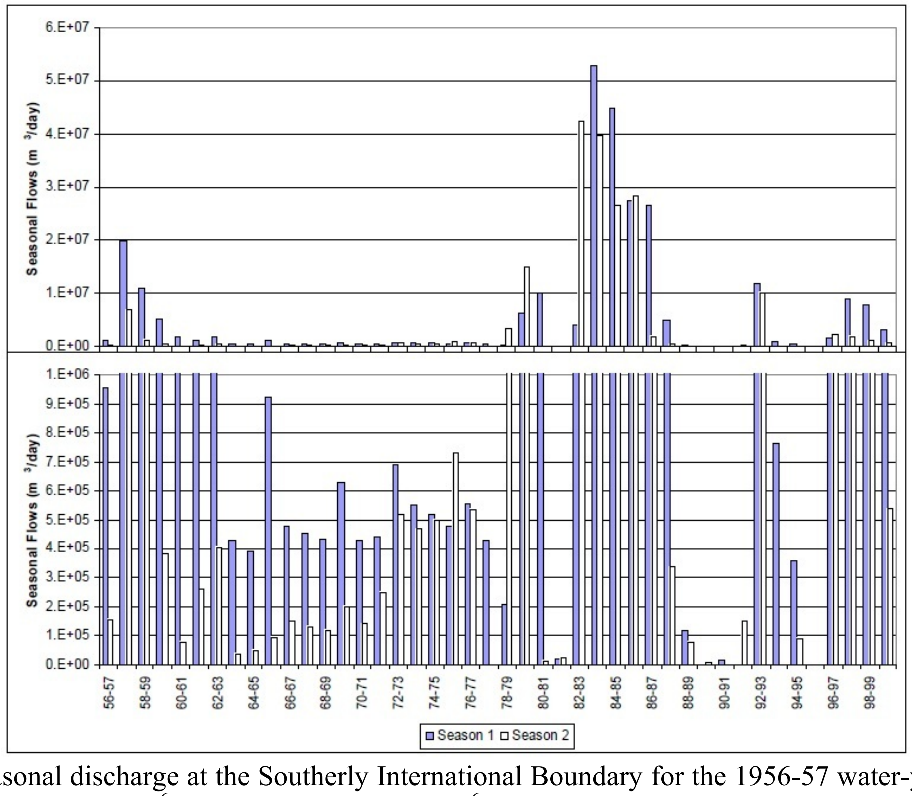

Figure 7, Seasonal discharge at the Southerly International Boundary for the 1956-57 water-year to 1999-00. (Top) scale 0 to 60×10^6, (bottom) scale 0 to 1×10^6.

Although the surface water capture estimated in this study provide a useful indication of the CRD's natural response to stresses such as groundwater pumping, the reader should keep in mind the limitations in any modeling processes such as those associated with conceptualization of the system, data availability, and data quality.

FUTURE WORK

The completed Colorado River Delta model will form the parent model for the use of a modeling technique called Local Grid Refinement (LGR). The LGR technique will be used produce a grid refinement of the selected regions of the Colorado River Delta. The grid refinement produces a child model that is a localized model of higher grid density that interacts with the parent model. These child models may be used to analyze potential sites for riparian restoration, local drawdowns in specified regions, and local stream/aquifer interaction with its associated capture.

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Transboundary Aquifers in Karst - Source of Water Management and Political Problems
Case Study, SE Dinarides

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ABSTRACT

One of the most deeply karstified regions in the world is the area of the South-Eastern Dinarides situated between the Neretva River in the West, Kotor Bay in the East and the Adriatic Sea in the South-West. This area has the largest resources of natural fresh water in the Mediterranean region, and experiences the highest precipitation in Europe (up to 8,000 mm). Surface flows are rare and generally short-lived. Between 70% and 80% of water in this region flow through the well developed network of underground karst conduits. The subterranean karst is, also, world famous for the large number of different endemic species.
In this region, three countries (Croatia, Bosnia and Herzegovina, and Montenegro) now exist where a short time ago there was only one country, Yugoslavia. The transboundary relationships are sensitive and complex, and are further complicated by the existence of separate entities within Bosnia and Herzegovina. Infrastructure such as large hydropower systems, which previously served a single country, now needs to be shared between multiple interested partners. There are many examples where such engineering complexes now cross the newly defined international boundaries. The groundwater conditions are particularly complex. Main karst aquifers discharge from massive springs. In a few cases, serious problems have arisen as a result of aquifers crossing the new boundaries. In these cases, parts of catchment areas (and aquifers) do not fall into the same political entity as the springs. The main questions which have arisen are: who has the exclusive rights to use water potential for power production if the water occurs within a transboundary aquifer; how to control locations of concentrated infiltration into the transboundary aquifer to provide proper groundwater quality protection; how to control floods in closed karst depressions (karst poljes) if the boundary crosses the polje; and how to protect the environment, including underground endemic species, in the case of transboundary aquifer disturbance.
The groundwater resources of this region are excellent and have important potential for improved water usage, not only for local purposes. In the near future, this potential could be of significant interest to a large part of the greater Mediterranean region. The South-Eastern Dinaric karst region could potentially be declared a Mediterranean “Water Treasure”. Presently, a large part of the water flows through underground channels or through power plant structures directly to the sea. Because of this, problems caused by transboundary aquifers have to be overcome and the entire region should be treated as a unique hydrogeological and hydrological entity. It is the only way to achieve optimal management and proper groundwater resource utilization.

Key words: transboundary aquifer, karst, South-Eastern Dinarides, hydro power, endemic species.

1. OBJECTIVE

The purpose of this article is to illustrate the very complex problem of transboundary aquifers located in the extremely karstified carbonates of the Dinaric Karst, with its deep and concentrated underground flows. Newly established state boundaries cross these aquifers. As a consequence, the main springs and parts of their catchment areas are divided and situated within different political units. The large hydropower system that exist in the region has a considerable influence on the underground water regime including the artificial transboundary transfer of a huge amount of water. The power system was constructed when the entire region was part of one state, hence, without transboundary concerns. Presently, questions appear regarding potential water power rights and the influence of transboundary aquifers on the environment (acceptable ecological flows, nature parks and endemic spices). Criteria for groundwater zoning to protect public supply, including proposals and restrictions which are acceptable for parties on both sides of boundaries are very important. However, very complex professional and (sometimes) political questions arise. Some of these questions are discussed in this article.

2. GENERAL HYDROGEOLOGICAL AND HYDROLOGICAL PROPERTIES OF THE REGION

The South-Eastern Dinarides situated between Neretva River on the West, Kotor Bay on the East and Adriatic Sea on the South-West is one of the most karstified regions in the world. The watershed between the Black Sea and Adriatic (Mediterranean) catchments is located along the mountain chain on the North (el. 1000 - 1300 m). In the recent past this region belonged to one country - Yugoslavia. Recently, region was separated between three countries (Croatia, Bosnia and Herzegovina and Montenegro). Bosnia and Herzegovina also consists, of two political entities.

The South-eastern Dinarides is the richest precipitation region in this part of Europe. Average annual precipitation varies from 1500 to 2500 mm/a, locally to more than 5000 mm/a. More than 70% of precipitation occurs during the wet season (October - March). Because this region is extremely karstified, surface flows are very rare. Infiltration exceeds 80%. Rain water percolates immediately through thousands of ponors (swallow holes) into the underground. The swallowing capacities of some individual ponors exceed 100 m^3/s. Only sinking rivers exist. Surface flows are temporary. Length of some underground flow systems is more than 30 km. Depth of underground flows is between 100 and 200 m, locally even deeper. Average velocity of underground flows range between 1 and 7 cm/s, sometimes between 20 and 30 cm/s. After heavy precipitation events, when aquifers are fully saturated, underground flows are much faster than during the dry period of year. Maximal registered fluctuation of groundwater levels exceed 300 m, up to 80 m/24 h. Discharges of underground flows are mostly concentrated at large karst springs. A common characteristic of these springs, whether permanent or temporary, is the strong dependence between precipitation and discharge. As a consequence, difference between minimum and maximum discharge is enormous (1 : 60, or more). The largest difference was registered at Bunica Spring, between 0.72 and 207 m^3/s. More than 150 m^3/s, average annually, are being discharged in the Adriatic Sea through only four huge permanent springs (Buna, Bunica, Bregava and Ombla) and few large but temporary springs at Kotor Bay.

Water stored at highly elevated reservoirs influence the water regime in springs at lower elevations. During construction of the first phase of Trebisnjica Hydrosystem project, karst aquifers were starved of about 4 billion cubic meters of water annually as a result of surface water re-routing through a number of tunnels, reservoirs, bored channels for power production and due to the plugging of many swallow holes (ponors). Resolving water resource conflicts between power plant owners (from one side of the border) and spring consumers (on the other side of the border) required common sense and an understanding of the karst systems involved. To prevent conflict issues, 8 years before the project became operational, a total of 120 springs that could potentially be affected by the Hydrosystem were cataloged, and carefully monitored, along a 100 km length of the Adriatic Sea coast, and along 50 km of the eastern border of Neretva River valley.

Changes of underground and surface water regimes locally have, also, a very distinct negative effect on the fauna of subterranean karst. Realization for the need to increase environmental protection appears as a very important issue. Ecological and environmental protection is more difficult when deterioration of an aquifer is unexpected, occurs rapidly, the source of problem is located some distance from the impacted area, and on the other side of an international border.

The karst environment is unusually sensitive to any change in natural conditions because its reactions to such disturbances are fast and often drastic. For such complex natural hydrogeologic conditions, newly established state boundaries additionally complicate the situation by provoking a number of very important professional and political questions.

3. SIMPLIFIED MODEL OF TRANSBOUNDARY AQUIFERS IN KARST

As it was stated above, hydrogeological properties of karst are quite different than for nonkarstified rock masses. The term transbounday aquifer in karst does not mean only zones located close to both sides of a state boundary - borderland zone. In many cases transboundary problems appear as a consequence of water sinking into ponors located far from the state boundary i.e. close to watersheds with other catchments, at distances of 10, 20 or 30 km from the borderland. As a result, the entire catchment area can be declared as potentially dangerous for groundwater regime and properties of water within borderland areas. In general the transboundary problem in karst appears at any case where the border is located between the recharging zone inside the catchment area and areas of discharge along the erosion base levels (sea coast and deep valleys).

Two simplified models of transboundary aquifers (better say transboundary concentrated flows) are presented in figures 1 and 2. A number of expensive investigation works have to be done to define exact connections between sinking and discharging points. Particularly complicated is knowing the location of the main channels and monitoring of groundwater regime and water quality in the borderland. The groundwater regime in the dry period of the year (flows with free surface) is quite different from that of the wet period of year. After periods of heavy precipitation, karst aquifers are fully saturated and water within the main channels is under pressure (hydraulic system under pressure). The groundwater regime is very dynamic and permanently changes in space and time. Within some parts of an aquifer, bifurcation of the regime can occur further complicating the hydrogeological model.

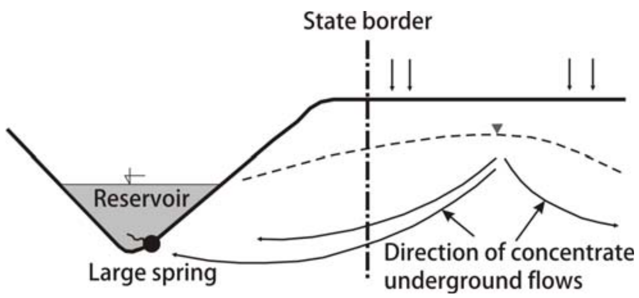

Fig. 1 Transboundary flow crossing state border.

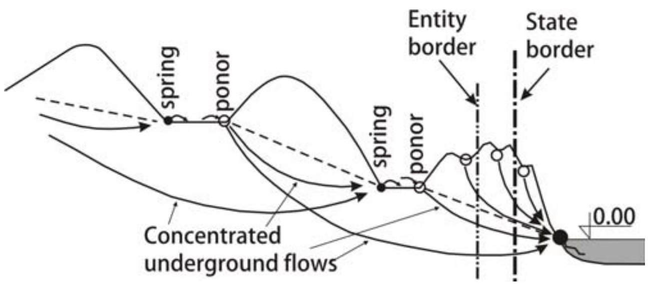

Fig. 2 Transboundary flows crossing entity and state border.

4. QUESTIONS APPEAR

Before new state boundaries were established, the concentrated infiltration points and springs were located entirely within one country. Boundaries between republics had no role or posed no serious obstacle. Problem of defining exclusive rights to underground water was not a very important task. Water needs for power production and water supply were analyzed as part of integral projects on the bases of their hydrogeological and hydrological properties. Competent boundaries only were the natural boundaries that defined the physical limits of watersheds. Projects were focused on multipurpose utility to obtain the greatest water potential for development of the entire region.

Immediately after new boundaries were established (boundaries between republics became state boundaries, see figure 3) a number of very important questions appeared that need to be solved. Newly established regulations for each country were not harmonized. Criteria for determining the environmental protection, as well as, regulatory procedures that are applicable for nonkarst regions are generally not suitable for karst terrains. Velocities of concentrated underground flows in karst are a basic problem. In some cases (dry period) velocity of labeled tracer is 1.13 cm/s, however for the saturated aquifer case (wet period) velocity increase up to 7.53 cm/s.

4.1. Example 1

One of the largest spring zones in the entire region are Trebisnjica Springs that discharge between 2 and >300 m^3/s. Majority of its catchment area presently is situated on one side of the border (in Bosnia and Herzegovina) but a minor part of its catchment is situated on the other side of the border (in Montenegro). However, the part of catchment area in Montenegro has not been exactly determined. Due to construction of the 123 m high dam and reservoir in Herzegovina, this spring zone was exposed to a water head of 75 m. The newly established state border locally enter along a small part of the reservoir. The average discharge of the spring has been estimated at 80 m^3/s. This part of the aquifer can be determined as a transboundary aquifer. The problem of transboundary flows did not exist when this was included in one state. Immediately after the new state border had been established, question of exclusive rights of spring water appeared. Groundwater governed by rights in one state now crosses the border and discharges at the springs in the other state. Request for rights for part of this discharging water because part of its cattchment is located on the other side of border for power production is a topic of very tough negotiations.

4.2. Example 2

At the western border of the region, along the Neretva River valley, the largest springs are Buna (2.95 - 380 m^3/s), Bunica (0.75 - 207 m^3/s) and Bregava spring (0.45 - 58.7 m^3/s). Buna and Bunica springs including their entire catchment area are situated in one country (Bosnia and Herzegovina), however, both springs are situated in one political entity but almost their entire catchment area is located within another political entity (approximately 90%) . By construction of the large hydropower system, part of spring waters would be re-routed in the direction of the already operational part of hydro-system. Bunica Spring (el. 36 m) is directly connected with Biograd ponor at el. 800 m and distance 20 km. Underground flows cross the entity border at depths of 600 - 700 m. The entire Zalomka River sinks into the Biograd ponor (about 110 m^3/s at maximum). During summer time this river does not exist. The river bed is totally dry. However, minimal flow of Bunica Spring also depends on catchment by its own aquifer (not only due to sinking water in Biograd ponor).

Consequences of water re-routing on the regime of the Buna Spring is negligible in periods of minimal as well as in maximal discharge. Discharge of the Bunica Spring however, is considerably disturbed but only during periods of high discharge. For discharges less than 4 m^3/s, influence of any man-made structure within catchment area is not possible. This is confirmed by two independent mathematical models.

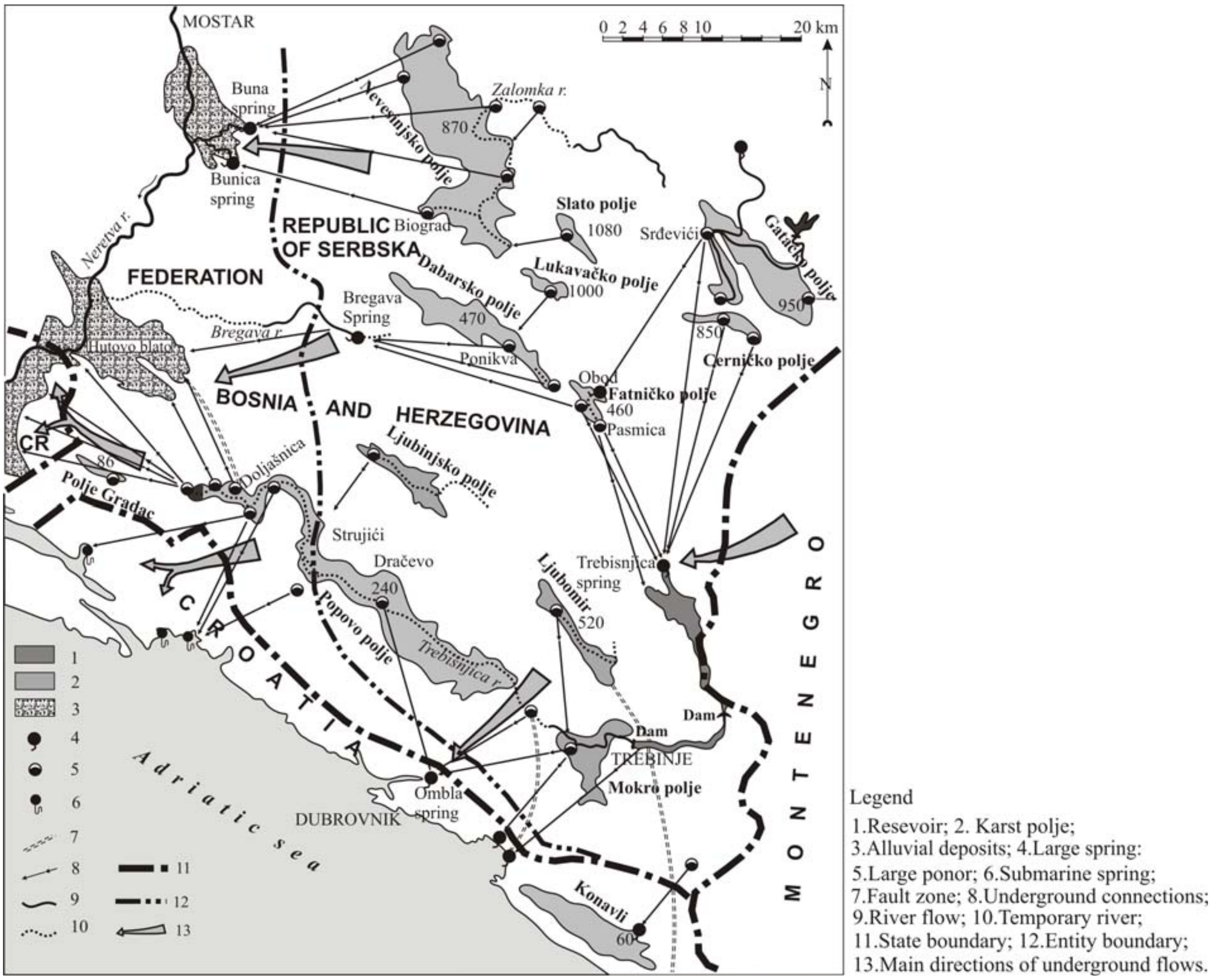

Fig. 3 SE Dinarides. Boundaries between Bosnia and Herzegovina, Croatia and Montenegro.

4.3. Example 3

Protection zones for public water supply in karst cannot be based on the same criteria as for nonkarstic aquifers. The important difference between karst aquifers and aquifers in intergranular or low permeable rocks is a consequently shorter contact of the contaminant with the rock matrix because of the fast circulation through karst conduits. Contaminated water masses quickly spread through the karst aquifer, that is, the time available for autopurification process is very short.

All waters discharging at a number of springs near the sea coast (Croatia) are derived from sinking water through thousands of ponors in Bosnia and Herzegovina. When this transboundary aquifer is fully saturated, the groundwater needs about 70 hours to travel a distance of 16 to 18 km, from sinking to discharging point. If the aquifer is not completely saturated (dry period), underground flows are 2 to 3 times slower. For both cases, underground water flows are very fast when compared to non karst aquifers.

Zoning concepts on both sides of state borders are based on the same parameters: groundwater velocity, groundwater residence time and distance between source of pollution and intake structure. However, an important question appears. Is it possible to apply a general rule for zoning (i.e., same rules for all hydrogeological formations) or do karst aquifers need separated rules adjusted to the specific hydrogeological and hydrological properties of karstified rock masses? It is sure that in karst the parameter of groundwater velocity cannot be applied automatically. Also, optimal zoning concept in karst depends on many other factors: saturation of aquifer, necessary time of water replacement, locations of ponors and their swallowing capacities, protective measures at sinking zones, discharge capacity and similar other concerns. In many cases the zone of immediate protection, requiring very severe protection and restrictions, crosses state borders and encompasses large areas on the other side of the border. Because of this, proposed criteria should be applied with flexibility and should allow for changes to be made when local hydrogeological conditions require it.

Crucial question in this particular example is how to harmonize optimal criteria and how to monitor efficiency of accepted criteria on the other side of border. Trust between both parties, professional approach and verification are the only possible way to provide efficient protection of transboundary aquifers.

5. IMPORTANCE OF WATER POTENTIAL OF SE DINARIDES

It is obvious that the Eastern Herzegovina and Kotor Bay areas are the most important water resource area of this part of Europe. In the near future, because of the global water shortage importance of this water will increase. This region will serve as a source of "water treasure" for surrounding parts of the Mediterranean. The estimated average annual discharge potential of the entire region, from elevation 1800 m to the sea coast, is Qav = 300 m^3/s of excellent quality water.

Presently only one part of this enormous water potential is used for power production and negligibly for water supply or irrigation. Almost all this water is lost into the sea. Surrounding Mediterranean regions, including the African coast suffer because their needs for water are much higher than their own surface and underground water potential.

As previously stated, this region is presently dissected by state borders and optimal management with huge water potential has become very complicated. However, rapidly increasing water shortages impose the necessity for acceptance of the entire region as one unique water resource. Importance of this region is much beyond its border. Because of its potential, water quality has to be under severe control. Proposals for regional water quality protection, monitoring and optimal water management have to be important goals of all parties in region.

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Managing Transboundary Aquifers for Climate Change: Challenges and Opportunities
UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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The paper focuses on managing transboundary aquifers and aquifer systems for climate change, in recognition of the challenges and opportunities that will be presented by climate change. The first part is understanding the complex impacts of climate change on transboundary aquifers. The second part is managing affected aquifers and aquifer systems to minimize adverse implications of climate change. The third part is the exploration of opportunities for aquifer management to adapt to climate change and mitigate greenhouse gas emissions.

Key words: aquifers, climate change, salination, adaptation, mitigation

1. INTRODUCTION

Managing transboundary aquifers for climate change provides significant challenges and opportunities. This topic is divided into three aspects, with the first part being understanding the impacts of climate change on aquifers. The second part is managing aquifers to minimize adverse climate impacts and to take advantage of positive impacts. The third part is exploring opportunities for states to use aquifer management to adapt to and mitigate climate change

In recent decades, use of deep and shallow aquifers has increased dramatically. Aquifers are essential to human life and agriculture in many regions, sustaining streams, wetlands, and ecosystems, and resisting land subsidence and salt water intrusion into fresh water. Water is never lost to the hydrologic cycle, so it is not possible to experience global peak water. If water is extracted from aquifers and rivers faster than nature can replenish it, there is the potential for regional peak water. Water from some aquifers and lakes and glaciers can be thought of as non-renewable, and subject to peak and decline when they are depleted faster than the natural recharge rate. There is also the concept of peak ecological water, or when a water supply is depleted to the point of causing irreversible damage to local ecosystems that depend on it (Palaniappan, 2009).

These considerations of aquifer use and scarcity contribute to the complexity of transboundary aquifer management. Some key climate impacts for water quantity and quality are saline intrusion and contamination of aquifers. Changes in seasonal and annual precipitation, flooding, temperature and extreme weather events also affect the recharge and discharge of aquifers, and could lead to contamination of aquifers even where there is no water scarcity. Last, climate impacts for aquifers may be greater for coastal aquifers, or in arid and semi-arid regions, such as the Mediterranean, Middle East and northern Africa.

Management of transboundary aquifers may minimize the adverse implications of climate change. There are also opportunities for aquifers to assist in adaptation and mitigation of climate change. Appropriate aquifer management could alleviate surface water scarcity and contamination, reduce seasonal, annual and inter-jurisdictional flood risks, and help sustain aquatic and terrestrial ecosystems dependent on aquifers. For example, water could be abstracted from transboundary aquifers when necessary, and re-injected when beneficial, so the aquifer functions as managed water storage system for all aquifer states.

Transboundary aquifers could also have a beneficial role for climate mitigation. For example, aquifer states could individually or jointly sequester greenhouse gases in deep saline aquifers, which provide the greatest global potential for the storage of greenhouse gases. Further, these aquifers have a key role in facilitating future energy development, such as natural gas in shale rock formations. If appropriately done, this development would not adversely affect aquifers, and could result in lower carbon energy sources.

2. IMPACTS OF CLIMATE CHANGE ON TRANSBOUNDARY AQUIFERS

2.1 Changes in Water Quantity and Quality

Due to the importance of aquifers, changes in water quantity and quality will affect food availability, stability, and access and use, particularly in arid, semi-arid and coastal regions, as well as function and operation of water infrastructure, such as hydro facilities, flood defences and irrigation systems. Climate change can heighten and change extremes in temperature and precipitation, whether flood or droughts, and can affect the severity of pollution and contamination. Changes in water quantity due to climate change are already the subject of much concern and debate, as there are significant gaps in understanding aquifers even in the absence of climate change.

It is not altogether clear globally if whether climate change will result in an increase or a decrease in water quantity. For example the Mediterranean, research suggests that despite local variations, for the region as a whole, precipitation will decrease seasonally and annually, while the level and frequency of extreme temperatures increase, adversely affecting aquifer exploitation and recharge. If greenhouse gas levels double within this century as many climate models predict, other areas of the globe could experience increases in the rate of groundwater recharge, permitting additional exploitation. This necessitates carefully monitoring and modeling at a local and regional level in order to understand aquifer impacts.

For example, Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) found that the rate of aquifer recharge could be increased by the changes in precipitation and temperature caused by elevated greenhouse gases. The scientists developed a method for simulating the effects of elevated greenhouse gas levels, then applied that method to a subtropical and Mediterranean locales within Australia. The Mediterranean location responded more to temperature changes, while the subtropical location was more influenced by the frequency and volume of precipitation. In both locations, changes caused to soil, precipitation and plant transpiration by simulated climates led to significant increases in the rate of groundwater recharge (Green, 2007).

Contamination of aquifer can occur by diffuse loading, such as from agriculture, flooding or storm water runoff; or from point sources, such as industry and hydrocarbon development. Contamination of aquifers is a risk even in areas when the waters contained in those aquifers are not being depleted, and is the main risk to aquifers that are not significantly exploited or over exploited. Consider the example of the Po River in northern Italy, and related contamination between the aquifers and river. The main aquifer for the region's groundwater supply is the top of four sandy aquifers. This aquifer is separated at the top, through a clay layer, from an unconfined aquifer. Recharge to the main aquifer occurs partly by leakage from the upper shallow aquifer, and mainly by lateral recharge from the Po river, which is in contact with the confined aquifer. Groundwater contamination from land fill sites within the river basin areas has been detected in the shallow and in the main confined aquifer. (Zavatti, 1995)

2.2 Saline Infiltration

Salination of coastal aquifers is a global phenomenon that places at risk the present and future uses of aquifers. It causes health problems, decreases agricultural yields and profits and can destroy agricultural lands. It also affects livelihoods, increases costs of infrastructure maintenance and industrial processes, and can modify eco-systems. Saline intrusion of coastal aquifers may occur due to sea level rise, flooding or storm surges, and can extend significantly inland, impacting other aquifers and surface waters (IGRAC, 2009). Salination of aquifers can also result from over exploitation of deep aquifers for agriculture, human and industrial uses, or from natural gas or oil extraction. Where drilling or exploitation has occurred for water or hydrocarbons, a deeper saline aquifer may contaminate a shallower fresh water aquifer.

Saline intrusion is an important concern in the Mediterranean region where high seasonal water demand, primarily for tourism, has resulted in aquifers being over exploited (Inglesias, 2007). Saline intrusion is also very important in regions that are already below sea level such as the Netherlands, which a relies on ground waters to meet much of their domestic supply, due to the contamination of surface waters from transboundary rivers such as the Meuse and Rhine Rivers which originate in Belgium, France and Germany. It is costly for the Dutch to sanitize contaminated surface waters or to desalinate the ground waters.

2.3 Contribution of Groundwater to Sea Level Rise

The possible contribution of groundwater to sea level rise was mentioned in the IPCC Third Assessment Report. However, it was noted that the uncertainty was large and that the positive contribution of groundwater depletion may be offset by impoundment in reservoirs and associated recharge of surrounding aquifers. For this reason, anthropogenic contributions to sea level rise are not quantified in IPCC Fourth Assessment Report, although they are mentioned as the possible cause for the discrepancy between observed sea-level rise and the sum of the known sources. Global groundwater depletion has been increasing since the 1960s and is likely to increase further in the near future, while the increase of impoundment by dams has been decreasing since the 1990s. Recent research suggests that the contribution of groundwater depletion to sea-level rise may become increasingly important in the coming decades, and could contribute as to much as one quarter of the overall sea level rise (Wada, 2010). This research illustrates the complex and coupled interactions between ground water use and impacts of climate change.

2.4 Coastal Aquifers and Aquifers in Arid and Semi-Arid Regions

The vulnerabilities of coastal aquifers to salination have already been discussed. Coastal aquifers, and aquifers in arid and semi-arid regions, can be viewed as overlapping categories of aquifers, with shared vulnerabilities. This is particularly true for the Mediterranean, which is defined here to include the Middle East and northern Africa. For example, climate change projections for the Mediterranean, driven by socio-economic scenarios, result in temperature increases and precipitation decreases in most of the region. The projections indicate an increased likelihood of drought and variability of precipitation seasonally and in intensity. The combination of long term change and greater extremes will increase water demand, with further impacts on ecosystems. Under all scenarios, available water decreases while irrigation demand increases. Ground water is used extensively in arid and semi-arid regions, including the Mediterranean region, for agriculture. While technology and need are resulting in desalination becoming affordable for domestic water uses, it is too costly for the large water demands of agriculture in the Mediterranean (Inglesias, 2007).

3. MANAGING TRANSBOUNADARY AQUIFERS TO MINIMIZE ADVERSE CLIM ATE IMPACTS

3.1 Management Frameworks for Aquifers and Climate Impacts

Climate change may alter the reliability of current water management practises, due to future changes in hydrological characteristics, so this management will have to be adaptive, and based on accurate and ongoing scientific measurements. Management responses to climate change for aquifers need to be closely linked to different sectoral policies (agriculture, energy, food security, health, nature conservation etc.). Non-confined aquifers require linkages with the management of and connecting river basins, lakes and seas. For all aquifers, whether confined or non-confined, management will need to consider those aquatic and terrestrial ecosystems where waters may be discharged.

Transboundary aquifer management requires monitoring, data collection and modelling for those aquifers and within their recharge and discharge zones to understand how these aquifers are impacted by both gradual climatic changes and extreme events. For example, a global, coastal database is being investigated in a model based on a simple, unconfined, coastal aquifer to explore the impacts of climate change on saline intrusion. A basic database provided temperature, precipitation, population density and evapotranspiration. Because evapotranspiration is not forecast in climate models, a value will be predicted from a linear correlation with the temperature data. When fully developed, these calculations could be incorporated into the Dynamic Interactive Vulnerability Assessment model and used to investigate salt water intrusion into estuaries, beach erosion, land-loss and other parameters.

Management may also require the development of appropriate tools and processes, including legal and institutional frameworks. This concept will be explored further in the final paper and presentation. For example, though it may not be essential, it could be useful to have explicit references to climate and ground water issues in bilateral, regional and international agreements concerning aquifers, and related river basins, watersheds, and coasts.

3.2 United Nation Approaches and Projects

Relevant United Nation (UN) agreements for aquifers include the UN International Law Commission's Law of Transboundary Aquifers, and the UN Economic Commission for Europe's Water Convention and Guidelines on Water and Adaptation to Climate Change. The UN Economic Commission for Europe is working on climate change and transboundary aquifers, and in the past had limited activities on groundwaters. Assessments currently under preparation include groundwaters, and a study on the applicability of the Water Convention to transboundary aquifers is currently underway with a workshop on transboundary aquifers tentatively being scheduled for 2011.

The UNESCO International Hydrological Programme, and particularly its UNESCO Cairo office, is actively engaged on aquifers and climate impacts. Water scarcity is noted as constraint on social development in the Arab world, and population growth and expansion of agriculture exacerbates these impacts. For example, Egypt experiences climate impacts of changing precipitation in the Nile basin, challenges of drought, flooding and sea water intrusion. The UNESCO-sponsored GRAPHIC project promotes and advances sustainable groundwater management considering climate change and linked human effects. In does this by providing a platform for exchange of information, and through providing scientific and policy recommendations.

The Kampala Statement on Groundwater and Climate in Africa addresses ground water and climate issues, including developing water policies at national and regional levels that strike balance between renewable ground water and demand, and recognizing the role of ground water storage and importance of ground water discharge to dependent ecosystems. The eighth point of this statement notes that management of Africa's transboundary aquifers requires a regional approach involving technical cooperation and joint monitoring among nations, and recommends strengthening of institutional structures at continental and regional scales, and development of legal and institutional frameworks.

3.3 European Union Approaches and Projects

The European Union's Water Framework Directive (WFD) and the EU Groundwater Directive are based on principles of river basin management planning and designing programmes of measures to achieve good status objectives. The WFD does not contain an explicit reference to climate change, but requires monitoring at regular intervals and the achievement and maintenance of the objectives. The Groundwater Directive similarly includes risk assessments, achievement of good status, programmes of measures and ongoing monitoring. The EU Flood Directive and the Communication on water scarcity and droughts address some of anticipated impacts of climate change, including impacts on ground waters. There is a significant consideration of water and climate within the White Paper on Adaptation to Climate Change of 2009, and extensive EU projects. The Genesis project may be the most relevant for groundwater, as it considers aquifers and associated aquatic and terrestrial ecosystems. It will include case studies of important geologic formations and aquifers; different climate regions; ecosystems including lagoons, oasis, springs, streams, wetlands; and economic developments and drivers of climate change (Quevaviller, 2010).

4. UTILIZING TRANSBOUNDARY AQUIFERS TO ADAPT TO AND MITIGATE CLIMATE CHANGE

4.1 Aquifer Storage and Recovery

Aquifer storage and recovery is being investigated by the United States Environmental Protection Agency Water Resources Adaptation Program. The focus is to evaluate the potential of aquifer storage and recovery as a practical climate change adaptation tool. Investigations have focused on technical feasibility, regulatory implications, and engineering techniques for field applications considering the need to mitigate water budget imbalance; environmental impacts and potential regulatory implications; and adaptation techniques and engineering guidelines for sustainable development. Preliminary research supports the feasibility aquifer storage and recovery in adaptation to climate changes, and provides the basis for developing engineering techniques with managed environmental impacts.

In many countries, including Australia, the potential to store harvested storm water using managed aquifer recharge is significant. Within Australia, concepts of aquifer storage and recovery are being developed further, as constructed wetlands are being used to provide the initial water treatment for managed aquifer recharge and recovery schemes. For example, in Sydney, Perth, Brisbane, and Cairns, the volume of urban storm water runoff is larger than the volume of water supplied by the water system. Managed aquifer recharge is a cost effective solution where suitable urban aquifers are present, and research is underway to map the potential for managed aquifer recharge and recovery in Australia. Urban aquifers in Perth, Adelaide and Melbourne show significant potential storage capacity.

4.2 Desalination,Water and Energy Research

Desalination research is being conducted on the production of fresh water from brackish water using such technologies as reverse osmosis membranes, and on the prevention of saltwater infiltration through modification of aquifer field and pumping design. To prevent aquifer salination, one technique applied in developed countries is to construct hydraulic barrier and inject it with water from aquifers further inland, or to use purified, recycled wastewater. This technology can not be applied in developing countries due to cost. So instead of constructing hydraulic walls as a preventive measure, adaptation techniques create commercial, community and individual desalination plants using solar energy. Research into water and energy conservation and efficiencies are also being explored, and offer significant possibilities for decreasing water demand and the associated carbon footprint of the extraction of groundwater.

4.3 Carbon Sequestration in Saline Aquifers

Carbon sequestration in saline aquifers provides significant mitigation opportunities for greenhouse gases. In the sequestration process, CO_2 captured from industrial emissions are pumped into deep-saline aquifers. The depths of these aquifers provide pressures high enough to keep the CO_2 supercritical in a single fluid phase with physical properties similar to those of a liquid rather than a gas. Some CO_2 will become dissolved in the aquifer and react with other dissolved salts in the brines and rocks to form carbonate minerals that will permanently fix part of the CO_2 as a rock. These aquifers are unsuitable as resources for drinking water, so there are no adverse consequences for fresh water aquifers. The best industrial facilities are coal-fired power plants where as much as 90 per cent of the CO2 emissions could be captured, or other large emitters such as oil refineries, cement plants and oil sands facilities.

4.4 Natural Gas Development and Aquifers

Shale gas development is occurring on a global scale, and can result in a lower carbon form of energy development. There is some dispute as to the impact of hydraulic fracturing on adjacent aquifers. The best way to protect groundwater during shale gas development is with high quality casing, good cement, and proper water-handling procedures. Provided shale gas development occurs in consistent regulatory framework, this natural gas development can assist in the mitigation of climate change.

5. CONCLUSIONS

This paper briefly touches upon the managing transboundary aquifers for climate change, and the challenges and opportunities that will arise. More detailed discussion and case studies will occur at the ISARM 2010 conference.

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Regulating transboundary groundwater: big challenges for Brazil

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ABSTRACT

Brazil is considered to be a very wealthy country in terms of fresh water resources. It owns two of the largest river basins: the Amazon and La Plata. It shares with Argentina, Paraguay and Uruguay one of the hugest aquifers: the Guarani Aquifer. All this wealth brings up legal e political challenges, such as the following questions: How is the management of water resources in Brazil? What are its instruments? Is the management of surface and groundwater integrated? Is it possible to manage jointly transboundary waters? This paper intends to face these questions by studying the case of the Guarani Aquifer. At first, describing and analyzing the Brazilian domestic laws that apply to it and to general water management. Secondly, by the comparison of the recent treaty on the Guarani signed by Brazil, Argentina, Paraguay and Uruguay and the United Nations General Assembly Resolution 63/124 (2009) on the Law of Transboundary Aquifers. The gap between domestic law and international soft law is still impressive, but analysis of the Guarani Aquifer case leads to the conclusion that Brazil is beginning to face the issues of transboundary groundwaters.

Key words: Transboundary Groundwater, Brazilian Legal Framework, Guarani Aquifer, International Law.

1. INTRODUCTION

Brazil owns approximately 13% of the world's fresh water, two of the biggest river basins in the world lay in Brazil's territory and both cross the border: the Amazon and La Plata. One of the biggest aquifers in the world, the Guarani Aquifer covers a total area of almost 1,2 million squared kilometers; most of it is in Brazil, but also in Argentina, Paraguay and Uruguay. The Brazilian part of the aquifer extends through 8 States of the Federation: Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, Mato Grosso, Mato Grosso do Sul, Goiás and Minhas Gerais. Besides the Guarani, Brazil shares another 10 aquifers, according to ISARM studies. All this wealth, however, demands political decisions, made according to a clear legal framework, strong institutions and an up-to-date water management system.

This article aims introducing the Guarani aquifer case, in two parts. First, there must be an overall view and evaluation of the Brazilian framework for water, including one of its weaknesses, the fact that it doesn't integrate groundwater. In the second Part, the international law applicable to the Guarani, in other words, the treaty on the Guarani Aquifer, recently signed by Argentina, Brazil, Paraguay and Uruguay must be analyzed. The method will be to compare the treaty with the United Nations Resolution on the Law of Transboundary Aquifers, to make it visible how comprehensive are the commitments accepted by the members of Mercosur, not failing in making a good profit of the UN disposal.

2. THE GUARANI AQUIFER

Since the Guarani Aquifer was discovered, in 1996, it became the focus of a variety of agents from the economic, political and social fields, whether or not from the Mercosur region. It was first the object of study or research in public universities (Taks, 2009).

There was a concern to investigate the actual conditions of the aquifer: its extension, the continuity of the geological formation beneath the borders and the movement of ground water. It was also necessary to think about a common framework between Argentina, Brazil, Paraguay and Uruguay for the management of groundwater. The political connotations of the Guarani were soon proeminent: questions about sovereignty and regional integration. The universities involved in the study of the Guarani proposed a research project and sought support of the States, which was denied. Then the World Bank through the Global Environmental Fund - GEF decided to give a loan, being given the coordination to the Organization of American States (OAS). The Guarani Aquifer System Project had a total cost of 26 million dollars, with 12 million dollars counterpart supplied by Argentina, Brazil, Paraguay and Uruguay (Caubet, 2006).

The issue was soon brought to the Mercosur. In July 2004 an *ad hoc* High Level Group was formed in order to study the possibilities of an agreement on the management of the aquifer. The draft agreement prepared by the *ad hoc* High Level Group has been delivered to the Common Market Council of Mercosur in December 2004, but only recently signed, in August 2010 (Taks, 2009).

It is known today that the Guarani Aquifer System constitutes "a vast rock strata (geological formations) with aquifer characteristics, forming a vast groundwater reservoir (hydro geological basin)". Its area is calculated in 1,087,879 km^2. The aquifer is present in the subsoil of Argentina (20,98%), Brazil (61,65%), Paraguay (8,05%) and Uruguay (3,32%), and its geological formation is a continuous structure in the four countries. The water is renewable but its circulation is slow and hampered by hydraulic barriers and natural compartments. The groundwater presents heterogeneities and its characteristics vary from one region to another, including: chemical and hydraulic differences, and some others of accessibility and temperature (OAS, 2009).

3. AN OVERVIEW AND EVALUATION OF THE LEGAL FRAMEWORK OF WATER RESOURCES MANAGEMENT IN BRAZIL

The first legal document that deserves mention, when studying water issues in Brazil, is the 1988 Brazilian's Constitution. Before 1988, it was possible to meet "private water" as a legal category, according to real practice. Under the Constitution's precepts, the surface water (rivers and lakes) that exists in the territory of two or more States, is under the jurisdiction and control of the Federal government: the Union. The same occurs with: a) waters that constitutes border with other countries, b) water which comes from or goes to another country's territory; c) the reservoirs built with federal funds (art. 20, III), and d) all mineral resources, including those of the underground (art. 20, IX and art. 176). On the other hand, surface water that does not belong to the Union (according to the above mentioned criteria) is under States jurisdiction. Likewise, groundwater in general belongs to the States (art. 26, I) (Brasil, 1988).

Under the Constitution, the Federal government has the competence to legislate on water resources. It is thereby allowed to establish a National Water Resources Management System and to define criteria to authorize its uses (art. 21, XIX). Therefore, in 1997 was enacted the Federal Law n. 9.433 that creates the National Policy of Water Resources and establishes the National Water Resources Management System. The Law's first article gives the grounds of the national policy for water: water is a public good; a limited natural resource with economic value; in the case of scarcity, priority of use is for human consumption and animal thirst-quenching; management should favor multiple uses; hydrographic basin is the territorial unit to implement the policy; water resources management should be decentralized and take into account the participation of the government, users and communities (Brasil, 1997).

The goals of the national policy of water resources are (according to art. 2): the guaranty, for the present and future generations, of water resources in adequate quality for its use; the achievement of sustainable development, rational and integrated use of water resources; the prevention of and reaction against "hydrological critical events" due to natural causes or inadequate use of natural resources. The law creates instruments that are supposed to achieve these goals. The instruments are, first of all, charging a price for the use of water resources. The use of bulk water depends on an administrative act of authorization called grant (*outorga*). Other instruments are: the development of plans of water resources, the classification of water bodies according to its uses and the establishment of a data system (art. 5). One of the main critics that can be made on this law is fact that it is based only on the idea of water as a limited natural resource with economic value, with no regard whatsoever to social, environmental, cultural and religious values of fresh water. The intention is to rationalize the use of water, by granting it a price. This option has been implemented in 4 river basins, 13 years after the law was enacted. Another problem in the policy implementation is the fact that water grants have been given before the existence of a management plan and the classification of water bodies (which should include the priority of uses): both instruments should precede the grants, according to art. 13 of the Law (Brasil, 1997).

The biggest flaw of the Law is the fact it has no regard to integrate the management of surface water with groundwater. In fact, the law barely mentions groundwater, except to prescribe that groundwater exploitation depends on an official grant (art. 12), the same one needed for surface water. Besides that, drilling wells to extract underground water or to operate these wells without proper authorization is against the Law (art. 49, IV) and one of the penalties is the order to stop the operation, revoke the license and plug the well (art. 50, IV). Even though the Law mentions the idea of "integrated management", it provides no instruments to do so, consecrating an idea of hydrologic circle disconnected from the groundwater (Rebouças, 1999). But the integration is being made *infralegis* through the Resolutions of the National Council of the Environment (*Conselho Nacional de Meio Ambiente – CONAMA*) and the National Council of Water Resources (*Conselho Nacional de Recursos Hídricos – CNRH*). The documents on groundwater enacted by these institutions are: Resolution of the National Council for the Environment n. 396, from 3 April 2001 and Resolution of the National Council of Water Resources n. 15, from 11 January 2001; n. 22 from 22 May 2002; n. 91 and n. 92, from 5 November 2008 and Resolution n. 107, from 13 April 2010.

It has to be emphasized that Brazil has two different legal regimes for groundwater. As mentioned above, the Brazilian Constitution establishes that groundwater belongs to the States, but mineral water (all mineral resources, including those in the underground) is under federal domain. So there are two different legal regimes for groundwater and mineral water and two different administrative acts to allow the use of one or another. The groundwater considered to be mineral is subject to the Mining Code (*Decreto-lei* n. 227/67) and the Mineral Water Code (*Decreto-lei* n. 7841/45); its exploitation depends on authorization from the National Department of Mine Production (*DNPM*). Groundwater in general is subject to the license of the State, according to its own state policy (the guidelines of which are given by the National Policy) (Camargo, Ribeiro, 2009).

Besides it is weak in terms of groundwater, the National Policy for Water Resources Law is almost silent about transboundary waters: the single legal provision on the subject is the one on art. 39 § 2º of the Law n. 9433/1997, saying that in case of a transboundary basin, the Foreign Affairs Ministry (*Ministério das Relações Exteriores*) must have a chair in the River Basin Committee (Brasil, 1997). But the issue is much more delicate. It was said that the Constitution prescribes that groundwater belongs to the States. But the federal government argues that, by analogy with surface water of federal concern, all other waters should be legally added to the federal dominium. Since 2000, there's a proposal to emend the Constitution (*PEC* n. 45/2000) on that issue, placing all transboundary groundwater under federal jurisdiction. This would boost the main concern of the federal government in order to extend its control over the Guarani Aquifer (Coimbra, 2009).

4. OVERVIEW AND EVALUATION OF THE GUARANI AQUIFER TREATY

The United Nation's General Assembly adopted in 2009 the Resolution on the "Law of Transboundary Aquifers" (Resolution 63/124), based on the works of the International Law Comission and UNESCO'S IHP/ISARM programs. It encourages States to adopt agreements regarding principles (like equitative and reasonable utilization, sovereignty of the States, the obligation not to cause significant harm, obligation to cooperate) and the need to take measures for the protection and management of the aquifers. The four countries of Mercosur signed a treaty on the Guarani Aquifer, in August the 2nd 2010, which contemplates some of the provisions elaborated by the UN Commission on International Law. A comparison between the two documents gives in-puts to understand what the abstract UN Text gives as a Standard and what Argentina, Brazil, Paraguay and Uruguay assumed as effective compromises.

In the preamble of the two documents appear the first differences. Both texts assert the importance of cooperation; they reaffirm the resolution on permanent sovereignty over natural resources (Resolution AG/UN 1803 of 1962); and the principles enshrined in the Rio Declaration (1992). But there is no express quotation of UN GA Resolution when it recognizes, e.g.: the increasing demands for freshwater and the need to protect groundwater resources; the need to ensure the development, utilization, conservation, management and protection of groundwater in the context of sustainable development; the need to take into account the special situation of developing countries. The Agreement on the Guarani, on the other hand, apart from the considerations already mentioned, recalls the statements of Stockholm (1972) and Johannesburg (2002); notes the progress made on the harmonious development of water resources and physical integration, according to the Plata Basin Treaty (1969); notes the Mercosur's Framework Agreement on the Environment and the desire of States to expand the levels of cooperation to a higher scientific knowledge of the Guarani Aquifer System and responsible management of water resources.

Other differences between the Guarani Agreement and the UN Resolution should be mentioned. For the UN General Assembly, an aquifer is a geological formation that contains water; the use of the aquifer means the extraction of water, heat and minerals, as well as storage and disposal of any substance. A system of aquifers in this context is a series of two or more aquifers hydrologically connected. For the countries of Mercosur, the definition of the Guarani Aquifer System is different: the Guarani Aquifer System is a transboundary water resource that integrates the sovereign territorial area of Argentina, Brazil, Paraguay and Uruguay (art. 1). To make clearer what's the "sovereign domain" of each State, art. 2 provides that each State "shall exercise the sovereign territorial domain over their respective portions of the Guarani Aquifer System in accordance with its constitutional and legal dispositions and in compliance with international law." While the UN Resolution uses the notion of the aquifer as a geological formation containing water (thus, admitting the exercise of sovereignty over portion of the aquifer), the Agreement on the Guarani define the aquifer as a "transboundary water resource", i.e.: something that by its characteristic of fluidity cannot be submitted to territorial sovereignty, although the assertion of sovereignty seems to be the main objective of the Agreement. This means that the Agreement looks for a formula in which only the States concerned will be able to deal with these waters and its users, on the basis of normal traditional rights of the four covenant States.

The UN Resolution on the Law of Transboundary Aquifers establishes six principles: sovereignty of aquifer States; equitable and reasonable utilization (as well as relevant issues to determine what is equitable and reasonable, including the basic human needs); obligation not to cause significant harm to another State; obligation to cooperate; and an obligation to promote a regular exchange of information. At last, the Resolution encourages States to adopt regional or bilateral agreements, which Brazil, Argentina, Paraguay and Uruguay just did.

Four principles were established by the Agreement on the Guarani Aquifer: sovereignty (art. 2); "sovereign right to promote the management, monitoring and sustainable use of water resources of the Guarani Aquifer System", on the basis of "criteria for rational and sustainable use and respecting the obligation not to cause appreciable harm to other parties or the environment" (art. 3); duty of protection and preservation of the Guarani Aquifer System "in order to ensure the multiple, rational, sustainable and equitable use of water resources" (art. 4); compliance of International Law Rules and adoption of measures to avoid damage to other Parties or to the environment, when activities or studies related to the aquifer are undertook (arts. 5 and 6). It's therefore established that management, monitoring and sustainable exploitation of the aquifer are rights of the States; though the Agreement emphasizes the obligation not to cause sensitive damage too.

The Resolution on the Law of the Transboundary Aquifers establishes 5 obligations related to the protection and conservations of aquifers or an aquifer system. They are: the duty to adopt measures to protect and preserve the ecosystems within a transboundary aquifer or his dependent; duty to identify and protect recharge and discharge zones of an aquifer; duty to prevent, reduce and control pollution, adopting a precautionary approach; and the duty to monitor the aquifer, if possible jointly with other aquifer States concerned; the duty to establish and implement plans for the proper management of the aquifer and to establish mechanisms for joint management (art. 10-14). The States of Mercosur made an agreement on promoting the protection and preservation of the Guarani Aquifer System to ensure the multiple, rational, sustainable and equitable use of water resources (according to art. 4 of the Treaty on the Guarani). They also set their commitment to cooperate for technical and scientific knowledge; cooperate to exchange information about the aquifer and on management practices, possibly to promote "joint projects" (art. 12) - without prejudice to the projects each State wishes to engage in its own territory (art. 13) -; and also cooperate in identifying critical areas that require specific treatment (art. 14). A committee will be created, within the framework of the La Plata Treaty, and will be in charge of the coordination of cooperation between the States (art. 15). These provisions mean an advance, because nothing like this existed in the regional context. Now the four States are committed to cooperate for various purposes and obliged to ensure sustainable, rational and equitable use of water resources.

Finally, procedures for "planned activities" are mentioned in both documents. The Guarani Agreement establishes that a State shall inform the others about activities that may have an effect on the Guarani Aquifer System, or beyond its borders (art. 9), along with technical studies available. If a State considers that an activity undertaken by another Party may cause harm, it has the right to request information (art. 10, 1). If the notified State concludes that it might suffer harm as a result of an activity authorized or undertook by another State, both Parties must negotiate in good faith to achieve the most equitable solution possible. According to art. 11 of the Guarani Agreement, if the notified State offer strong evidences that harm will be caused, the planed activity must be suspended and cannot be initiated or continued during the negotiations, which should be completed within six months (art. 11). If the dispute persists, it should be settled through direct negotiation or consultation with the Commission [to be created], which will have 60 days to make recommendations (art. 16-18). In case of failure of these proceedings, the States shall appeal to arbitrage; the Agreement says that the procedure of arbitrage will be set in the Additional Protocol to the Agreement (art. 19). On this point, the Mercosur Agreement on the Guarani Aquifer is more detailed than UN Resolution on the Law of Transboundary Aquifers. The procedure for planned activities of art. 15 of the UN/AG Resolution is very similar, but it doesn't specify delays for negotiations, nor the possibility of suspending the activity during the procedure. The States proceed to consultations or negotiations and they may use an independent fact-finding body to make an impartial assessment of the effect of the planned activity.

5. CONCLUSIONS

It has been said that Brazil is a wealthy freshwater resources country. The Brazilian State is begging to deal with water issues, trying to deploy the best management practices recommended. The Constitution of 1988 was very important in this field, because it divided clearly the domain and jurisdiction within the Federation. In 1997 was enacted the Law 9433 that created the National Policy for Water Resources and the Water Management National System, with valuable principles, goals and instruments. But it's not immune to criticism: the integrated management of surface and groundwater was not predicted and the institutions of the management system had to develop a framework for that; and the public participation on the decision making process is only implemented as the river basin committees are created. The biggest problem seems to be the fact that the federal government and the

States of the Federation are fighting over the control of some groundwater reservoirs, even tough the Constitution is very clear on that matter.

On the regional level, Brazil and its neighbours made progress on regulating transboundary groundwater. The Agreement on the Guarani Aquifer, signed in San Juan (Argentina) on August the 2nd, 2010, contains provisions never seen before. First of all, the main concern is to proclaim the sovereignty over the Guarani or, in other words, tell the rest of the world who owns the aquifer. Besides that, Argentina, Brazil, Paraguay and Uruguay agree on the need to assure the sustainable use of the aquifer, as well as to avoid activities that could harm another State or the environment. This provision goes further than the UN Resolution on the Law of Transboundary Aquifers, which establishes the obligation not cause damage to another State, but doesn't mention the environment. It is worth to mention also that the articles on planed activities and the procedure created by the Agreement on the Guarani is a huge advance for the relationship of the four States. They are also obliged to cooperate to various purposes, including joint projects, and to exchange technical and scientific information on the aquifer. Even though there aren't provisions specific on pollution, discharge and recharge zones – as the UN/GA Resolution recommended - the Agreement mentions the duties to promote the conservancy and protection of the Guarani Aquifer System, to exchange data and information, to identify critical zones that demand special treatment, and to use water on a sustainable and rational way. It seems that an important step was taken.

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Transboundary Groundwater Aspect in the Past Water Management Practices and in the New Water Policies of Turkey
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ABSTRACT

So far, groundwater exploitation has not well managed or controlled in many cases, and groundwater sources have been exploited intensively without considering their recharge rates. In many cases, an intensive use caused drawdowns of water tables that were associated with other environmental problems such as land subsidence, saltwater intrusion, water pollution. The problems were often irreversible or have not been remedied up to now.

In this paper, technical, administrative and legislative challenges of a successful groundwater management is analized in the light of data and information obtained from some previous case studies. Furthermore, challenges and opportunities introduced into surface and groundwater management context by means of new water policy of Turkey will be discussed.

Key words: exploitation, policy, pollution, transboundary aspects.

1. INTRODUCTION

Technically and economiacally available water potential of Turkey is 112 bcm. About 14 bcm of this potential is from groundwaters. Average annual water consumption of Turkey (620 m^3/cap) is highly below the OECD average (890 m^3/cap). Moreover, per capita available water resources have been decreasing as a result of population increase, as well as climate change. As of 2010 per capita available water resources is 1 550 m^3, which is quite below the world average (7 600 m^3). Hence, Turkey is not a country rich in water resources but a country expected to be a water-stressed by 2030 (DSİ, 2007).

Most of Turkey's territory is situated in a semi-arid region, and precipitation is limited to five to six months per year. In addition, areal and spatial distribution of precipitation is not homogeneous. Herewith, in order to meet increasing water demand, Turkey has to construct dams, hydropower plants and irrigation networks throughout the country (DSİ, 2007).

Although most of the large water development projects have realized on surface water resources so far, groundwater resources are expected to be more charming in the near future because of the increasing stress on water resources. Already started explorations for deep groundwater aquifers especially in the west parts of Turkey can be considered as signals of this attraction (Simsek *et.al.*, 2009).

2. LEGAL AND INSTITUTIONAL SETUP

According to Turkish Civil Law, spring waters in the privately owned lands are subject to land registry. All other surface and groundwaters are under the public sovereignity. State Planning

Organization prepares five year development plans, which specify the general principles and priorities of the implementation of medium and long term economic, technical, environmental, social and cultural policies.

General Directorate of State Hydraulic Works (DSI) under the Ministry of Environment and Forestry has the responsibility for designating amount of groundwater available and the extent to which boreholes may be drilled. It also gives licences and controls implementation with the aim of damage prevention.

Bank of Provinces, Special Provincial Administrations under the auspices of Governorships, Municipalities, Ministry of Agriculture and Rural Affairs (MARA), and General Directorate of Environmental Management affiliated to Ministry of Environment and Forestry are other organizations, which have responsibilities on water supply for different purposes, as well as pollution prevention and control. The Ministry of Health determines quality standards for drinking waters, and follows efficiency in compliance with the standards.

Any direct discharge of wastewaters or treated wastewaters to groundwater bodies is forbidden according to the Turkish Environment Law, with the exception of geothermal waters. As geothermal waters are of concern, all responsibilities about research, licences, as well as control of discharge and reinjection procedure are given to the General Directorate of Mineral Research and Exploration (MTA) under the Ministry of Energy and Natural Resources.

Within the catchments of groundwater resources used for domestic purposes, all the activities, which use substances given in the Turkish Dangerous Substances Decree-Law are forbidden. Any material, which may seep to the groundwaters via wastewaters or rain water can not be stored directly within the groundwater drainage area. In these areas, agricutural activities are carried out in the way that possible negative impacts to groundwater quality are minimized. Similarly, use of treated wastewaters in irrigation, as well as mining activities are carried out only with special permissions.

Environmental Impact Assessment Decree-Law, first enacted in 1993 and finally amended in 2008, is one of the main milestones of water protection. In this regard, activities such as solid waste disposal, mining or groundwater abstraction are subject to detailed investigation in order to take necessary measures. Execution of the by-law is under the responsibility of the Ministry of Environment and Forestry.

3. TRANSBOUNDARY GROUNDWATER RESOURCES OF TURKEY

3.1. Quantity of Groundwater Resources in Turkey

Plain and valley alluvium deposits and carbonate formations constitute the most productive aquifers in Turkey. Mostly karstified carbonate formations cover one third of the country. Large limestone aquifers with more than 1000 m thickness have considerable groundwater potential for local and regional demands, and they are mainly located in the Taurus Belt, which lies in the south of Turkey from Antalya City to Syrian border (Apaydın, 2009).

Although there is not an exact figure about the groundwater potential with transboundary nature, 3,8 bcm of the already designated potential is in the locations adjacent to a neighbour country. Among these, about 1,6 bcm potential at Şanlıurfa city at the border of Syria particularly takes attention because of its high volume of transboundary nature (Hirch, 1959).

The aquifer lies between the Ceylanpınar village in Turkey and Res-ul Ayn village in Syria. The general groundwater movement is towards the springs, and there is well developed porosity in the area near to springs due to groundwater circulation. There are 18 springs, 5 of which are in Turkey, and remaining 13 are in Syria. All of the springs are in the streambed of the Habur (Khabur) river. Habur river with 7000 km^2 drainage area is one of the four seasonal creeks, which born at the Karacadag mountains and flows to the south more or less parallel to each other. Every creek has up to 50-70 m depth and they are becoming shallower as they flows to the south. They are all dry during June-October period. The groundwater surface intersects with the land surface over a larger area in Syria. So, Habur river flows throughout the year in Syrian land (Atuk, 1995; TUMAS, 1995).

3.2. Quality of Groundwater Resources in Turkey

DSİ has around 200 regular groundwater quality measurement stations in nationwide scale. According to the DSI data, nitrates concentration slightly increases from urban to rural areas, and from the west to the east of the country (OECD, 2008).

MARA has started to monitor water quality at 550 wells within the scope of a project for adoption of EC Nitrates Directive. Results of the measurements showed that Nitrates concentrations were below 50 mg/l, which is the maximum drinking water treshold level in corresponding Turkish regulations. However, Nitrates concentrations were slightly above the EC suggested drinking water treshold level of 10 mg/l at Burdur, Antalya, Konya-Aksaray, Erzurum, Adana-Osmaniye, Şanlıurfa and Mardin. Among the cities, last two are at the Turkish south-east border (Ulger, 2008; OECD, 2008).

3.3. Present and Planed Uses of Groundwater Resources

Until now, total water extracted from surface and ground waters for various reasons was around 46 bcm, and nearly 12 bcm of this amount was exploited from groundwater. 8 bcm of the groundwaters was used for irrigation, and remaining part was directed for domestic and industrial water supply (DSI, 2007).

Groundwater is especially used in areas where the usage of surface water is not possible or not convenient. İzmir, Elazığ, Antalya, Kahramanmaraş, Konya and Diyarbakır are the cities at which domestic water is supplied by means of groundwater resources. Konya, İsparta, Eskişehir, Kayseri, Edirne, Samsun and İzmir, situated in the mid, west and north-west of the country are the locations with higher density of groundwater irrigation (OECD, 2008).

Ninth Development Plan period of 2007-2013, energy and transportation infrastructure development, environmental protection and urban infrastructure development are among the basic development axles. It is also aimed that the percentage of irrigated areas will be increased as investment opportunities are favorable (DPT, 2006).

Groundwater irrigations as part of Southern Anatolian Project (GAP) have particular importance from transboundary aspect, since they are very close to Turkish Syrian border. Within the context of the project, Akcakale, Ceylanpınar and Suruc irrigation projects under operation currently aims at irrigation of 10 255 ha, 9 000 ha and 7 000 ha area respectively. Transition to pressurized systems in irrigation, as well as initialization of farmer education programs for best agricultural practices are main efforts spent for water conservation and protection in the area (TUMAS, 1995; Ulger, 2008).

According to the hydrogeological investigations carried out in the area, it is possible to abstract upto 1,2 bcm/year water from Harran and Ceylanpınar aquifers in Şanlıurfa. This amount can be met with the irrigation water requirement of more than 150 000 ha area (TUMAS, 1995).

4. MAJOR CHALLENGES AND OPPORTUNITIES OF GROUNDWATER MANAGEMENT IN TURKEY

4.1. Decline in Grounwater Levels

The major threats on the aquifers in Turkey are overexploitation, contamination, urbanization and removal by excavations. The problem related to water shortage is a part of the nationwide agenda, which in turn contributes overexploitation.

Groundwater level declined and well yields were reduced, moreover water quality was spoiled in some large plains of Turkey particularly for the last 15−20 years because of uncontrolled excessive consumption. For example, in the Konya closed basin with average precipitation of 378 mm, which is extremely below the Turkey average (643 mm), groundwater levels declined as a result of both drought faced in the last 8 dry years and overexploitation. Unfortunately, about half of the 60 000 wells active in the area have not licences (OECD, 2008).

One of the most dangerous threat is removal of the aquifers via excavations in quarries and mines. Alluvial aquifers in the plains and valleys are destructed by sand-gravel quarries, and limestone aquifers are removed by stone quarries and mines.

4.2. Contamination

Mostly limestone aquifers have clean fresh waters since they are located on uncontaminated high regions. Groundwaters in the low-gradient areas, on the other hand, has been subject to increasing stress in terms of quantity and quality. Contamination increases with the increase of population, the use of agricultural chemicals and fertilizers, urbanization and industrialization, as well as seapages through several other sources such as inaccurate site selection or mismanagement of waste disposal sites.

4.3. Legislative and Administrative Challenges

Carefull assessment of the legal framework of Turkey shows that there is a significant paucity in legislation on groundwater management and transboundary aquifers. National legislation concerning groundwater management is embedded in other (Turkish Water Pollution Control Decree-Law) water resource or environmental management regulations. And, there is no provision or arrangement concerning transboundary issues.

Turkey has transposed and adopted most of the EU legislation so far. However, there are some overlapping issues in legislation, as well as shared responsibilities among competitive bodies, which in turn, cause failures in implementation, especially in "control issues". Although potable water resources have been protected better, pollution treat on surface and groundwaters has been increasing in national level.

4.4. Challenges in Implementation

There is a growing awareness of effective supply optimization and demand management. Build up of a nationwide water database, as well as shifting closed systems and transfer of operations to water user associations in irrigation are main dimensions of progress. So far, a number of capacity building projects have been implemented jointly by Turkey and various European partners in an effort to closing the gaps in transposition, implementation and control of legislations between Turkey and the EU. However, applicable river basin management plans relating surface and groundwater resources, strategy reports or action plans have not been prepared, mostly due to the lack of data, unsuccessful data share, and lack of coordination among the stakeholders.

4.5. Overriding Issues Related to Policies of Turkey and Its Neighbours

When transboundary water use is of concern, regional and country-specific challenges come forward. For example, in the Euphrates-Tigris basin, large parts of the region face the problem of climate change, drought and salinity. Moreover, Turkey's lower riparians, who are strongly dependent on the surface and groundwaters incoming from Turkish border for their development projects, are strongly opposed to its investments on transboundary water bodies (Attahaki, 2009, Dellapenna 1996). This situation sometimes causes Turkey to delay its projects even though it fulfills the necessary prerequisites to commence construction.

5. TURKISH POLICIES ON TRANSBOUNDARY WATER ISSUES

The challenges Turkey faced in water sector call for a new approach to water resources management. Its central objective is to promote efficient, equitable, and sustainable development through coordinated development and water resources management. In line with these policy principles and objective, a number of european community legislation has been transposed and adopted so far.

From Turkey's point of view, transboundary waters should be utilized in an equitable, reasonable and optimal manner in the interest of all riparian countries. Long lasting solutions to transboundary water issues can be reached through confidence building measures and genuine cooperation among riparian states. The riparian countries should mutually abstain from causing any significant harm to each other while utilising transboundary waters. And, natural meteorological and hydrological conditions should be considered in allocating the transboundary waters.

With this intention, Turkey continues bilateral and trilateral cooperation activities with its neighbours concerning transboundary water courses. Number of memorandum of understandings on many fields including water were signed with Iraq and Syria in October and December 2009 respectively. In this regard, across examination of the relations linked to the water issues would provide better understanding of the status of the conflicts in the transboundary water basins. Furthermore, cooperation via lateral and multilateral meetings, seminars, workshops and courses have great help in building better understanding and confidence atmosphere.

6. CONCLUSIONS AND RECOMMENDATIONS

Conflicts related to transboundary water issues seems to be hidden under the more protective policies. Power, trust, political will, and incentives lie at the basis of all attempts at cooperation. This reflects the modernist convinction that strong government agencies staffed by scientifically trained experts should be delegated responsibilities for policy design and implementation in water resources management.

Concerning the policy, management, and technological aspects, the transboundary surface and groundwater basin management needs to make environmentally sustainable increases in agricultural and hydroelectrical productivity with better management. Careful examination of international dynamics, establishment of a functional legislative and administrative infrastructure, better governance including stakeholder participation, preperation of an inventory, determination of methodologies, dissemination of knowledge, experience and research findings, improvements in technologies (modernization), integration of better control mechanisms will prepare a strong base supporting decisions in national and transboundary basins.

In the semi arid region Turkey lies, the water conservation issue should be made prominent in the management of water resources, especially in the planning stage, and more importance should be attached to demand management, as well as use of green, grey and black waters (treated wastewaters). By and large, efforts that promote more economically efficient use of surface waters also alleviate stress on groundwater resources. Moreover, countries should put more effort to find new methods apart from conventionally used ones. In this regard, water transmission between basins, artificial recharge and potential improvement of aquifers, as well as use of non-renewable groundwater resources should be (re)considered within the management concept. Last but not least, national and international donor organizations should be encouraged to fund investments necessary for better demand management and pollution prevention.

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Transboundary Aquifers: Challenges and New Directions
Beyond 'transboundary' Aquifers: *Australia's Great Artesian Basin*
UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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ABSTRACT

Australian's Great Artesian Basin (GAB) lies beneath one-fifth of the Australian continent and is estimated to be the largest supply of groundwater in the world. The groundwater from the GAB plays a major role in meeting domestic, farming and irrigation demands and remains a vital 'life line' for rural Australia. The recent UN General Assembly Resolution on the 'Law of Transboundary Aquifers' attests to the need to regulate groundwater resources appropriately. It calls for an international instrument to provide a framework for bilateral or regional aquifer management. While, the GAB is not a transboundary aquifer it is a shared groundwater resource. The domestic legal regime regulating the GAB operates under a 'cooperative federalism' model spanning four Australian jurisdictions. The important standards set out in the UN Resolution need to be recognised for other types of aquifers, namely the ones that are not transboundary but do have multiple jurisdictional management issues. This paper will explore the commonalities between transboundary and domestically shared aquifer systems – the threats and pressures, sustainable utilisation and governance issues. Finally the paper will demonstrate the greater standard setting role that an international instrument on transboundary aquifers could play in facilitating good governance, capacity building and sharing best practice of all shared groundwater resources.

Keywords: groundwater, shared aquifer, cooperative federalism

1. THE GREAT ARTESIAN BASIN

1.1 Introduction

The Great Artesian Basin (GAB) is regarded as one of the largest underground collections of artesian water supply in the world. The Basin underlies approximately one fifth of the Australian continent, extending beneath the arid and semi-arid regions of four Australian jurisdictions, namely the Northern Territory (NT), Queensland, New South Wales (NSW) and South Australia (SA). However, the most important source of water is found in western Queensland, parts of regional NSW, SA and the NT and supports rural and mining industries (Welsh et al., 2005). The GAB is a confined multi-layered groundwater system which consists of highly permeable sediments mainly continental sandstones and non-water bearing siltstones and mudstones (Radke., 2000). The groundwater contained in the aquifers is generally of good quality and can be used for stock and in most areas is under sufficient pressure to provide a naturally flowing water resource when tapped by water-bores (Welsh et al., 2005).

However, a number of bores have been allowed to flow 'uncontrolled' into open bore drains, which has led to a unnecessary waste of this precious resource (Welsh et al., 2005). In addition, the constant discharge of water through bore drains is reducing groundwater pressures in parts of the Basin and in some naturally occurring artesian springs (Welsh et al., 2005). Lastly, groundwater contamination is a very real problem, particularly when the hydraulic pressure in one aquifer falls below the pressure of an adjacent aquifer. In this instance, cross-contamination due to excess salinity can occur and remediation of contaminated groundwater can be generally difficult (Welsh., 2000 ; Hardisty et al., 2005). Under the Australian Constitution, primary responsibility for water and water resources rests with the state governments.[1] However, 'cooperative federalism' can prove difficult when it has been necessary for each state to legislate to manage its water and provide adequate mechanisms towards both the control and fair distribution of Australia's subterranean water system.

This paper will explore the commonalities between transboundary and domestically shared aquifer systems – the threats and pressures, sustainable utilisation and governance issues. Finally the paper will demonstrate the greater standard setting role that an international instrument on transboundary aquifers could play in facilitating good governance, capacity building and best practice of all shared groundwater resources.

2. A BRIEF HISTORY OF GROUNDWATER IN AUSTRALIA

2.1 The background

The 1880s marked the discovery of the artesian water supply in Australia. From that point on, groundwater became a raw resource that could be drilled, piped and exploited (Cathcart., 2009). For instance, artesian water would allow marginal grazing to extend thousand of kilometers into what was previously hostile country (Cathcart., 2009). In addition, the building of pipelines and great water projects became the means by which the new settlers sought to bring progress to the land they colonized and bring life and prosperity to this arid country (Cathcart., 2009). In other words, hydro-engineering was though to 'triumph over the shortcomings of nature' (Cathcart., 2009).

However, the discovery of a 'new found' water supply would prove devastating for Aboriginal people, who had relied on the access to healthy freshwater for their survival since they first arrived in Australia thousands of years ago. Artesian water attracted a flood of colonial squatters into the inland of Queensland, NSW and SA and as the pastoral industry rapidly expanded the fragile ecosystems soon became trampled into dust by the herds of sheep and cattle (Cathcart., 2009). More importantly, however, Aboriginal people base most of their culture, identity and spirituality on their close association with the land and with groundwater and they have a profound understanding about the fate of the water systems in Australia (Yu., 2009 ; Craig., 2007). In a dry land where water is scarce, Aboriginal people value their own water resources 'to the last drop'(Cathcart., 2009).

As the colonial period was slowly drawing to a close, the bores kept gushing water from the earth but they did not open the country to more intensive settlements nor create new cities in the middle of the wilderness (Cathcart., 2009). However, the constant discharge of artesian water would point out to a lack of water conservation practices in a country where fresh- water can be hard to find.

[1] Section 100 of the Constitution provides that: 'The Commonwealth shall not, by any law or regulation of trade or commerce, abridge the right of a State or of the residents therein to the reasonable use of the waters or rivers for conservation or irrigation'.

2.2 The current governance

The GAB underlies four different jurisdictions, each of which operates under different legislation frameworks, policy and resources management approaches. Therefore, the implementation of consistent policy and water management practices between jurisdictions has proved difficult. In addition, the pastoral industry is regarded as central to the improvement of the management of the GAB, as pastoralists are the main - and often the most inefficient - users of its groundwater (Postel., 1999).[2]

In 1994, the Council of Australian Governments[3] (CoAG) set out to adopt a new agenda to introduce significant changes to the way in which Australia's water resources were managed. One such change recognised the need for cooperative action by all Australian Governments in order to achieve consistent best practice management across water resources. In addition, under the Great Artesian Basin Sustainability Initiative (GABSI), the Commonwealth (that is, the federal government) has committed in excess of A$140 million over the next fifteen years (1999-2014) to accelerate the repairs and replacement of open bores with piped water reticulation systems and to stop the wasteful use of GAB's water. The GABIS initiative is being delivered through state agencies and the Commonwealth Government makes its contribution jointly with state governments and pastoral bore owners.

The Great Artesian Basin Coordinating Committee (GABCC) was established in 2004 to replace the Great Artesian Basin Consultative Council, which had ceased operation in December 2002. The GABCC provides advice between community representatives and agencies to key Ministers on how to encourage a strong commitment from governments and industry leaders to a sustainable management of the resources across the basin.

Lastly, the Great Artesian Basin Strategic Management plan was released by the GAB Consultative Council in 2000 and marks a significant stage in the history of the GAB. The Strategic Management 15 year plan provides the first comprehensive framework within which States, Territory and the Commonwealth Government can coordinate the management of the Basin's groundwater resources (Papas., 2007). However, the plan and what it can achieve remains confined by the constitutional limits, within which each state government and the Commonwealth must operate. Even the introduction of the Commonwealth *Water Act 2007* does not adequately promote an integrated approach to water management in Australia, let alone in the subterranean aquatic ecosystems.[4] Therefore, there still remains scope for much improvement.

3. TRANSBOUNDARY AND DOMESTICALLY SHARED AQUIFER: LOOKING AT COMMONALITIES

3.1 Characteristics

[2] In most countries, farmers who can afford to sink a well can extract groundwater unrestrained. In addition, traditionally ownership of the land typically implies the right to access the water on the surface and beneath the land.

[3] CoAG is an entity comprising the nine heads of federal, state and territory jurisdictions. The role of the CoAG is to initiate, develop, monitor and implement policy reforms that are of national significance. Water is one such area.

[4] The Commonwealth *Water Act 2007* is said to implement key reforms to water management in Australia. However, the Commonwealth government has taken a more proactive role in water law and governance in relation to one river system in Australia - the Murray-Darling system.

Whether an aquifer lies within a country and is domestically shared, internationally shared or transboundary does not diminish the value of its resources as a significant reservoir of freshwater storage. Today, groundwater is the most extracted raw material in the world. Worldwide, a number of large cities and medium-sized towns depend on groundwater for everyday use. For people living in arid and semi arid regions, groundwater is the most important and safest source of drinking water. Although groundwater storage varies between regions, a number of countries rely to a greater degree on their groundwater resources for irrigation than their surface water.[5]

3.2 Challenges: Political and legal environmental context

Groundwater characteristics vary with each 'type' of aquifer. Aquifers are generally classified as 'confined' or 'unconfined'; however, their rate of recharge[6] may lie within the territory of one state (country) or may be situated within the territory of a different state (country) (Barberis., 1991).[7] It is crucial therefore that the recharge zone, which primarily captures water at the surface, is protected so that the quantity and quality of water flowing into the ground is neither diminished nor polluted. In addition, an aquifer with a consistent source of recharge can be drawn upon sustainably, whereas any continuous withdraws from a non-recharging aquifer will result in the exhaustion of the resources (Eckstein., 2005). Postel (1999) suggests therefore that the rate of recharge for each type of aquifer should be assessed to provide a clear indication to scientists, irrigators and government agencies of how much groundwater can be safely extracted without exceeding sustainable limits.

Barberis (1991) points out that aquifers that are lying wholly within one state (country) are regarded as "state-owned" and subject to the domestic law of the state (country) concerned. However, aquifers that lie between or across countries are regarded as transboundary or internationally shared and subject to two or more domestic regulatory regimes (Mc Caffrey., 2003). Nonetheless, under a Federal system, groundwater is also a resource that often extends across jurisdictions where comprehensive regulation can prove difficult even when such regulation may be seen to be in the national interest.

Another issue worthy of concern is the threat of climate change to groundwater resources. Prolonged higher temperatures are forecast to increase evaporation, reduce surface water and therefore reduce the amount of groundwater available in recharge rates (Ludwig et al., 2009). More recently, progress in hydrological research has greatly influenced the treatment of shared resources (Barbaris., 1991) and an hydrogeological perspective - the science dealing with groundwater - has been a strong focus for Special Rapporteur Yamada in formulating the draft articles on transboundary aquifers (Eckstein., 2005). However, there seems to remain some ambiguity whether all aquifers can be bound by the same rules for the purpose of regulating their resources (Eckstein., 2005).

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[5] United Nations World Water Development Report (UNWWDR) points to countries such as India, Bangladesh, Iran and Saudi Arabia in particular.

[6] Recharge is the process by which water is allowed to replenish an aquifer.

[7] There are four cases in which the hydrological system of one aquifer is shared between different countries: (i) where a confined aquifer is divided by an international boundary (ii) where an aquifer lies entirely within the territory of one state (country) but is hydraulically linked with an international river (iii) where an aquifer is situated entirely in the territory of one state (country) and is linked hydraulically with another aquifer in a neighbouring state (country) and (iv) where an aquifer is situated entirely within the territory of one state (country) but has its recharge zone in another state (country).

4. THE LAW OF TRANSBOUNDARY AQUIFERS: STANDARD SETTING ROLE

4.1 What are the standards?

The UN Resolution on *the Law of Transboundary Aquifers* marks a very important stage in the development of international law to the particular requirements of groundwater resources. However, one shortcoming for the purpose of the protection of groundwater generally, and transboundary aquifers in particular, is that the proposed legal instrument does not clearly address those aquifers that are not international and not transboundary, but rather are domestically shared. A lack of clear international standard for all shared aquifers would imply that transboundary systems are worthy of protection whereas other types of aquifers do not warrant the same attention. And yet, a UN Resolution, by definition, would be expected to focus on international and transboundary issues. Therefore if the proposed UN Resolution actually provides a world's best practice regime for the management of aquifers, it would be expected that the same Resolution would state international standards which are capable of domestic application.

4.2 Standards in Australia

In Australia, primary responsibility for water and environment management rests with state governments. Since 1994, the Commonwealth and the states governments have agreed to a system of co-ordinative federalism in which planning and decision making are made so that progress can be made to implement reforms for effective water management. However, progress has been mixed (Papas., 2008). In addition, the recent political and popular debate about the desirability of a 'bigger Australia' suggests that the demand for water will increase in the future.[8] Declining surface-water resources due to over-allocation for irrigation purposes, coupled with prolonged periods of drought and the impact of climate change also means that there will be increasing demand from supplements from groundwater resources. However, the long term impacts of increasing extraction of groundwater Australia wide are not well understood.

More recently, the Australian Government has shown some level of engagement with and commitment to these issues, by launching the 'National Groundwater Centre' in Western Australia, which suggests a very real prospect for reform in this area. While the new centre is regarded as "an important investment" to help secure and improve groundwater management and knowledge for Australia's future water supplies, it remains too early to tell what the outcomes will be. In the meantime, the long term political commitment to the protection of groundwater nationwide is paramount, given that groundwater has become such an integral component of life in Australia. Capping the GAB has also been strongly suggested by some, although no governments to date have made a clear commitment as to how this would be implemented (Cullen et al., 2002).

5. CONCLUSION

Groundwater constitutes the only reliable reserve and resource of fresh-water in arid and semi-arid regions. In Australia, the GAB underlies one fifth of the continent across four different jurisdictions each operating different legislation frameworks, policy and resources management

[8] Former Australian Prime Minister Kevin Rudd announced during his time in office a strategy for a 'big Australia', in which he suggested a population target of 36 million by 2050 - representing a 60 per cent growth in population over the next four decades.

approaches. In the early 1990's, CoAG agreed that reform was required to address the economic, social and environmental implications of water use. In addition, the release of the recent Great Artesian Basin Strategic Management Plan offers the hope of effective national governance structures and adequate guideline of groundwater usage. However, the long term impact of groundwater over-extraction across the GAB is not well understood and the rate of recharge poorly evaluated.

The recent UN General Assembly Resolution on the 'Law of Transboundary Aquifers' sets out to fill a considerable gap in the law in relation to a certain type of aquifer. Nevertheless, the scope of the instrument needs to encompass adequate protection for groundwater systems that are beyond 'transboundary' and are located in arid and semi-arid regions which is where the GAB is situated. However, it provides an important starting point and it would be expected that the UN Resolution would state international standards which are capable of domestic application.

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Mathematical modeling is the main instrument for assessment of transboundary groundwater flows

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ABSTRACT

The results of studying of transboundary groundwater interaction in Russian-Kazakhstan and Russian-Ukraine boundary area are given. The direction of undisturbed groundwater flows is determined, and changes caused by the exploitation of the aquifers are assessed. The methodological approaches for solving transboundary problems applied to groundwater are determined as a result of mathematical modelling.

Key words: transboundary ground water flows, mathematical modelling

1. INTRODUCTION

Research and forecasting of hydro-geological processes in transboundary aquifers of neighboring countries demands an exact quantitative estimation, especially in case of technogenic load increasing on groundwater. The decision of this problem is provided to the full by creation of the regional mathematical models with borders that are natural borders of a hydrodynamic flow of the groundwater. These borders are probably location on adjacent territories. Monitoring data on groundwater from the territory of neighboring states is necessary for an adequacy of model estimation therefore one of the primary goals is to get agreement on granting of all monitoring data for modelling at interstate level. Information on allocation of existed or planned sources of possible groundwater pollution is of critical importance. Thorough analysis of the hydrogeological situation in the near-boundary zone is necessary, in which experts from both countries can take part. Only such analysis can show which of the bordering countries overpumps the natural transboundary groundwater flow and inflicts damage to the neighbor.

2. METHODOLOGY AND INSTRUMENT

The basic equation describing of a geofiltration process is reduced to a kind having simple physical sense - the sum of flow rates in each point ***i*** of aquifer ***n*** equals to 0 in natural conditions or time difference in capacity in the broken:

$$\sum_i Q^n_{xi} + \sum_i Q^n_{yi} + \sum_i Q^{n-1}_{zi} + \sum_i Q^{n+1}_{zi} + \sum_i Q^n_{IIi} + \sum Q^n_{IIIi} + \sum_i Q^n_{wi} = \sum_i Q^n_{ci} \quad (1)$$

where $Q^n_{xi} = \frac{\partial}{\partial x}(T^n_{xi}\frac{\partial H^n_i}{\partial x})$ is the plain flow along axis X (m/day), Q^n_{yi} is the same along axis Y, Q^{n-1}_{zi}, Q^{n+1}_{zi} are vertical flows between neighboring aquifers, Q^n_{wi} is an infiltration,

Q^n_{IIi} is an intensity of groundwater extraction, $Q^n_{IIIi} = (H^n_{si} - H^n_i)G^n_{IIIi}$ is groundwater exchange with surface water, H^n_{si} is surface water level, G^n_{IIIi} is conductivity of river-bed deposits, $Q^n_{ci} = S^n_i \frac{\partial H^n_i}{\partial t}$ is change in the capacity for non-stationary filtration regime, H^n_i is required function of water pressure head in point i of aquifer n. First four members of this equation describe a configuration and a condition of water containing thickness other three reflect external sources of disturbance.

This approach shows an important peculiarity of mathematical modeling that new information on regional groundwater flow conditions can be obtained due to the possibility of separate components of the total water balance calculation in accordance with equation (1). These possibilities provide studying and predicting the development pressure influence on underground hydrosphere.

The following problems should be solved by modeling for these purposes:

- to estimate and predict the degree of an admissible exploitation of groundwater,
- to estimate and predict an admissible size of a damage to an underground component of river runoff which is a result of long groundwater extraction in comparison with natural conditions,
- to forecast the contaminated areas extended in groundwater flow from possible pollution sources, and also to track their relative dynamics.

To provide optimal schemes of joint groundwater use in accordance with suggested criteria as a result of modeling the following data are output from the model database:

- *assessment of groundwater depletion*

1. maps of hydroisopiese and maps of water head position relative to the top of aquifer on check time steps that allows to give quantitative assessment of direction, velocity and time of depression cones spreading towards administrative boundaries;
2. graph of groundwater level lowering in inner points of hydrodynamic flow values corresponding to administrative boundaries;
3. graph of the full amount of plane groundwater flow in the case of depression cone spreading on the territory of the neighboring state;

- *assessment of surface water depletion* (Polshkova,2009)

4. graph of value variations in water exchange between surface and groundwaters relative to natural conditions;
5. values of damage to groundwater component of river runoff for all surface water sources;

- *assessment of groundwater contamination*

6. maps of time and areas of contaminated groundwater distribution from the surface sources of pollution which provide determining of sanitary zones of exploited or planned well-fields;
7. discovering of a probable pollution source location if the contaminants in groundwater samples taken from aquifers are detected.

In a number of cases, a major factor defining character and rate of migrant movement in groundwater flow is convectional masstransport which develops according to geofiltration process. Modelling of groundwater pollution in accordance to the piston replacement scheme in comparison with others, demands the least quantity of additional information. In each point of modelled area speeds of migrant movement VX, VY, VZ according to groundwater flow gradient are calculated. Time of pollution front movement to the given node point is the minim of possible time of advancement of the migrant getting out from initial pollution area. This time is calculated by the analysis of all transition times between adjacent node points in 10 directions along each of possible routes of the migrant movement according to a speed vector direction. Calculated flow times in days are input in the model database and are output in the form of an isochrone map. This map depends on the chosen mode and can be a map of front pollution location or a map of sanitary protection zones of water intakes. Such approximation is enough for an extreme estimation of groundwater deterioration rates.

Cartographical database is one of necessary conditions for creation and functioning of mathematical models. Initial information as well as model results should be represented in a form that can be adapted for formats of standard GIS-packages. Thus this possibility should be one of software functions used at modelling. The isochrones map is represented in figure 1 as an example of described scheme.

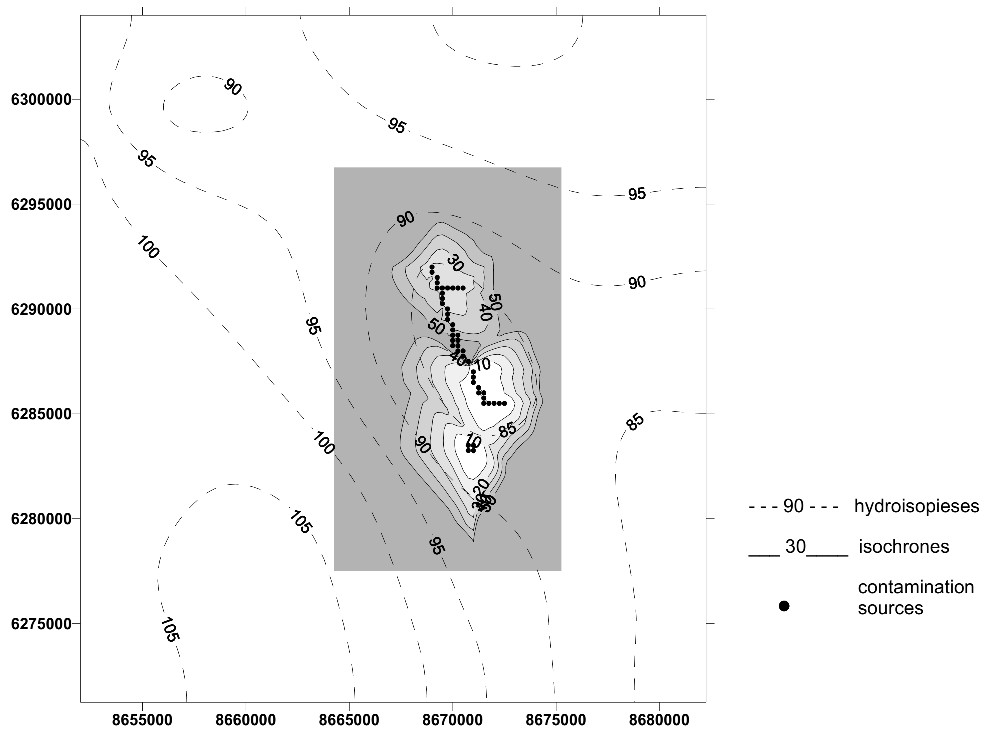

Fig.1 Map of isochrones and areas spreading from contamination sources

3. NUMERICAL MODELS

Now transboundary problems become especially acute for bordering territories of former soviet republics. But all studies were focused mostly at hydrological objects. The first quantitative estimation of the mutual hydrodynamics influence in the process of simultaneous exploitation of aquifers of near-border zones was made for the zone near Russian-Estonian boundary (Mironova *et al*. 2006).

Concerning this article described methodology was approved for calculation of transboundary groundwater flows between Russia and Kazakhstan and Russia and Ukraine.

The modeling area of Russia-Kazakhstan bordering zone is a part of West-Siberian artesian basin and has the size of 800×550 km in plane. The three-layer hydrogeological schematization including first from surface atlym aquifer and two aquifers of chalk deposits was accepted for mathematical model with dimension of 170 × 140 node points. The aquifer's borders are natural borders of aquifer outcrop on an earth surface. At modelling the calculation scheme for not rectangular (quadrangular) blocks was accepted. Node points have an exact geographical coordinates. Natural conditions are reproduced on the beginning of 50-th years. Broken conditions reflect the exploitation of chalk aquifers for 50 years. Coincidence of model results and observed data was satisfactory.

In figure 2 model result for variant of the broken mode is represented.

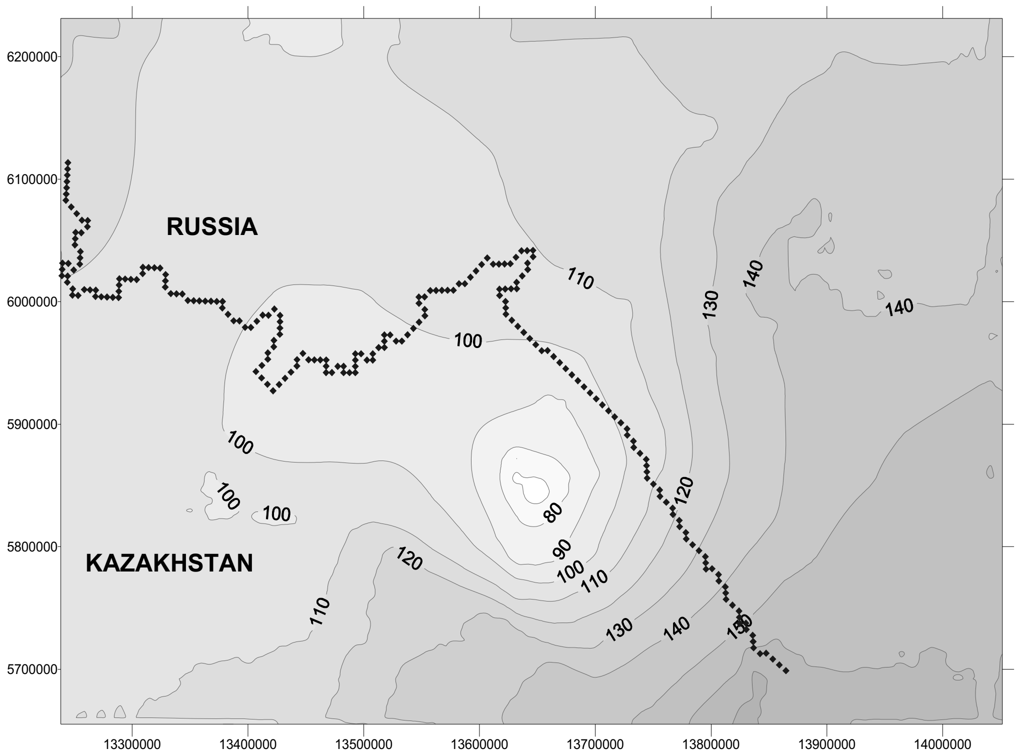

Fig. 2 Map of model water heads for broken groundwater flow conditions
in the Russia-Kazakhstan border area

Thus the sum groundwater extraction in Pavlodar city (Kazakhstan republic) from 2 aquifers with value of 530 000m^3/day creates depression cone which extends abroad on Russian territory. Lowering of groundwater level gradually distributes along the administrative boundary on an extent of 300 km and increases up to 40 m for 40-year water intakes exploitation (fig. 3). The plane groundwater, which is grasped by the depression cone along border, increases from 60 up to 135 thousands m^3/day.

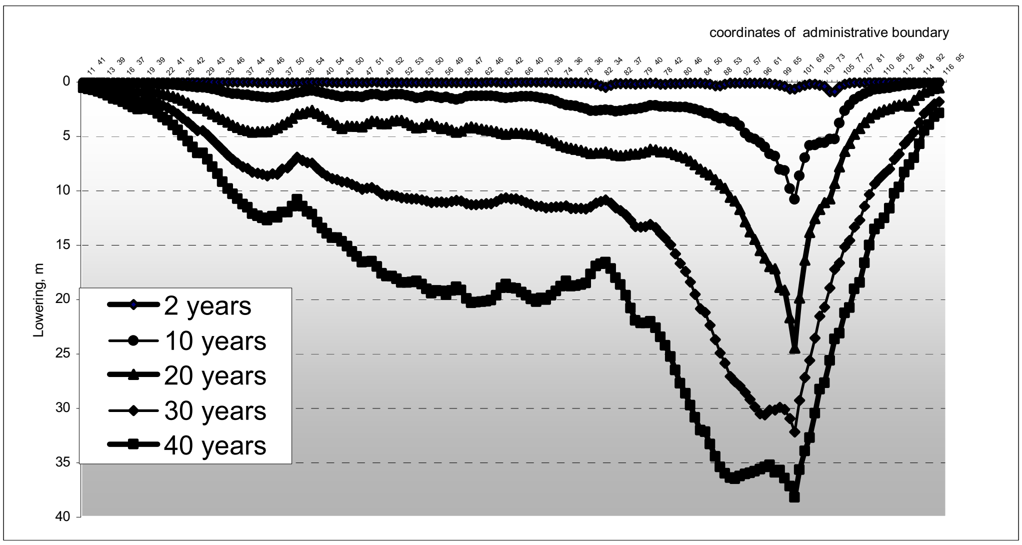

Fig. 3 Lowering in the points along administrative boundary for some time steps

Russian-Ukraine model is extended on territory of 248×276 km of Belgorod and Harkov regions. It reproduces the general groundwater flow for 1 km step as well as four aquifers on depth. Natural conditions were modeled on 1970 year and broken ones from 1970 up to 2009 year. The results for most exploited aquifer are presented on figure 4-5. The maximum lowering of groundwater head in depression cone areas is 55 m for Belgorod city and 80 m for Harkov city in 1980-1982 years.

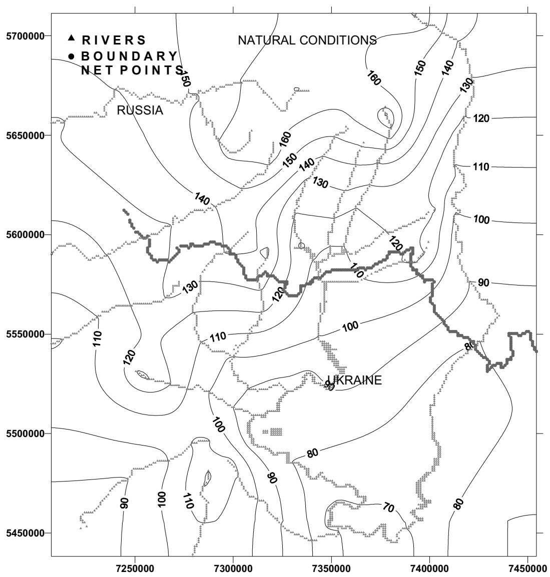

Fig. 4 Maps of model water heads for natural groundwater flow conditions in the Russia-Ukraine border area

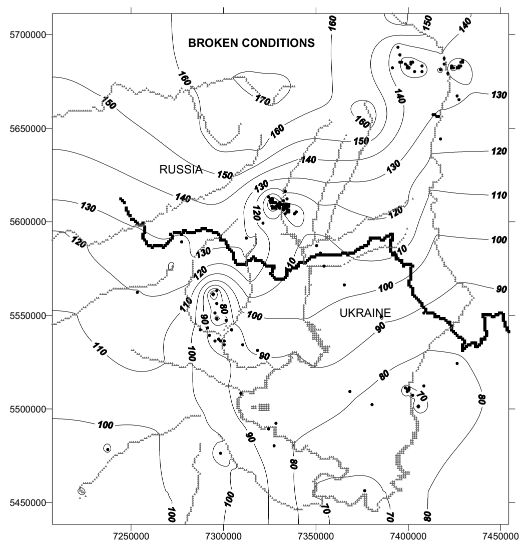

Fig. 5 Maps of model water heads for broken groundwater flow conditions in the Russia-Ukraine border area

Comprising the groundwater head maps it's possible to conclude that the flow character does not change. That is confirmed by quantitative estimation of plane flows across administrative boundary on the model. It increases approximately on 7-8 thousands m/day near Harkov city. Assessment of surface water depletion was made on 2009 in comparison with 1970. Recharge groundwater from surface one increased from 300000 up to 380000 m^3/day and release of groundwater decreased from 3 200 000 up to 2 600 000 m^3/day.

Reduction of water extraction to the middle of 90-th years almost restores the natural condition of groundwater flow near Harkov city.

But excess of water extraction can cause an association of depression cone on Russia-Ukraine transboundary groundwater flow and considerable depletion of aquifer (fig.6).

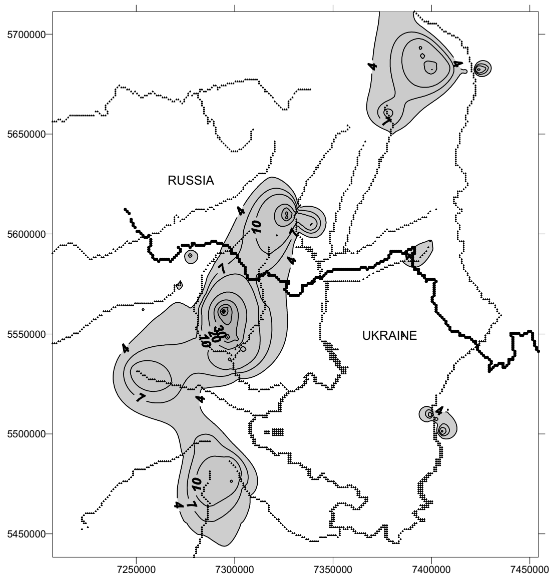

Fig. 6 Contours of generated depression cones in transboundary groundwater flow in the Russian-Ukraine area in 1980-1982

4. CONCLUSIONS

The mathematical models, as an instrument for hydrogeological forecasting, have to be the part of total interior monitoring subsystem. Using such approach, both geological service and government authorities meet the real instrument for assessing present-day and predicted conditions of underground hydrosphere and efficient regulating of the anthropogenic pressure load. All technogenic load on groundwater should be preliminarily estimated with a help of models before possible damages can happen.

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Challenges Facing the Management of Shared Aquifers

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ABSTRACT

Libya enjoys a wide experience in dealing with shared aquifer systems and has cooperated in good faith with neighboring countries, regional and international organizations in this domain long before the UN General Assembly's resolution 63/124 on the Law of Transboundary Aquifers has been enacted. Since the early seventies of last century, bilateral and multilateral committees have been formed mostly with Libyan initiatives to exchange acquired information on the geometry, extent, and properties of the Transboundary aquifer systems as well as the level of development, water abstraction, water quality, type of use and rates of depletion. Such dialogues were later developed into permanent bodies in the form of joint commissions and consultation mechanisms whose duties were clearly defined by the countries aiming at achieving an acceptable level of sustainable development.

These concerted efforts made by all concerned parties and their continuous cooperation have led to the implementation of regional hydrogeological studies and the establishment of shared data bases and monitoring networks with the support and guidance of several international organizations. These efforts did not always proceed smoothly, however; several challenges were faced throughout this evolutionary period, although they were never serious enough to interrupt or stop the coordination process among countries. Among these challenges was the lack of a defined legal framework that specifies the relationship between sharing states when action is needed to overcome negative phenomena resulting from overexploitation and/or contamination, the effect of which propagates beyond national boundaries. Other difficulties/challenges are closely related to financial, administrative and technical inputs by the parties.

This paper is intended to identify the major challenges facing the management of shared aquifer systems with a special focus on those states depending on groundwater as the main source of water supply for all fields of their socioeconomic development. To this end, recommendations are made to overcome these challenges individually by each state and collectively by all sharing states with the ultimate objective of achieving sustainable management of the shared aquifers.

BACKGROUND

Libya is one of very few countries in the world that depend almost entirely on groundwater for their agricultural, industrial and domestic supply. The country encompasses large sedimentary basins of multi aquifer systems characterized by relatively good quality waters. Due to its uneven population distribution, over exploitation is taking place in the coastal aquifers which led in recent decades to the evolution of serious problems in the form of a continuous drop in the water table and increasing salinity. Although coastal aquifers are receiving annual recharge, their water budget deficit is becoming wider every year, threatening national development schemes. The coastal aquifers are mostly local in nature with negligible effect beyond national borders.

In the north-central and south-eastern parts of Libya, two major groundwater systems exist, namely the Hamada basin, regionally known as the North Sahara Aquifer System and the Kufra – Sarir basin regionally known as the Nubian Sandstone Aquifer System. Both aquifer systems are transboundary in nature with considerable storage capacity. Apart from being the source of fresh water supply for local use, they represent the primary source for an inter-basin water conveyance system to the north known as the Great Man-made River Project (GMRP). In the south western part of Libya, a major aquifer system known as the Murzuq basin is classified as a local inland basin and is extensively tapped for water supply to local communities as well as the second phase of the GMRP.

Since the early sixties of the last century, bilateral and multi-lateral cooperation with neighboring states was initiated. Accordingly, joint technical committees were formed aiming at the realization of an efficient exchange of information on the conditions of the shared aquifers with emphasis on the rate of groundwater extraction, aquifer geometry, water levels, water quality and hydraulic parameters.

Financial and technical assistance from international organizations resulted in the realization of regional hydrogeological studies for the entire basins with data bases and mathematical models being produced.

INSTITUTIONAL ARRANGEMENTS

A joint authority for the study and management of the Nubian Sandstone Aquifer System (NSAS) was formed in Tripoli in 1989 between Libya and Egypt and was later extended to include Sudan and Chad. The mandate of this Joint Authority was initially defined to include the following duties;

- Collection, analysis, integration and dissemination of data
- Conducting complementary hydrogeological studies
- Planning and implementing water resources development schemes at national and regional levels.
- Training and capacity building
- Rational use of water
- Assessing the environmental impact of water development
- Organization of workshops
- Coordination with regional and international organizations

On the other hand, a trilateral committee between Libya, Algeria and Tunisia was formed in 1999 to coordinate efforts during the early stages of the regional hydrogeological study of the North Sahara Aquifer System *(Systeme Aquifere du Sahara Septentrional)* (SASS). In 2002 a permanent body known as the "the consultation mechanism" was created to undertake the following tasks:

- Manage the data base and mathematical model developed under the regional hydrogeological study
- Develop and follow up a reference observation network
- Process, analyze, and validate data
- Develop data bases on socio-economic activities
- Develop and publish indicators on the resource and its use

- Promote and facilitate joint studies and research
- Formulate and implement training programmes
- Update the regional model on a regular basis

Both the Joint Commission of the NSAS and the Consultation Mechanism of the SASS are chaired on a rotational basis and are jointly financed by the member countries.

CHALLENGES AND SETBACKS

The technical aspects of the management exercise of the shared groundwater aquifer systems have to a certain extent been addressed despite the scarcity and irregularity of information. Enormous extensions of these aquifers under barren deserts within the riparian states render them inaccessible without appropriate and often costly means. Desert storms and moving sand dunes could halt movement and activities for days. Such conditions have serious implications on the drilling activities and data collection campaigns .

The areal distribution of the water extraction zones and observation wells is often limited to very few scattered plots or oases. For economic and technical reasons, the bulk of water withdrawal comes from the shallow and intermediate aquifers. Deeper aquifers are rarely tapped or monitored which minimizes the value and validity of groundwater models. However, results generated from oil exploration campaigns are invaluable in providing geological, geophysical and hydrogeological data.

These problems reflect the magnitude of uncertainty encountered during the development of groundwater models for the two transboundary aquifer systems.

Other challenges that still need to be properly addressed include the securing of necessary funds needed to carry out technical tasks by the established mechanisms and the training of competent individuals to enable them to plan, execute and implement the pre-defined duties.

An equally important challenge is the lack of a legal and institutional framework. National water legislation defines priorities for water use in view of available alternatives. In Libya, for example, water scarcity led to the adoption of the mining process as a transitory solution to close the gap between supply and demand. The Tripoli statement issued at the end of the International Conference on Regional Aquifer Systems in Arid Zones – Managing Non-Renewable Resources held in Tripoli in November 1999 indicated that *"In many arid countries, however, the mining of non-renewable groundwater resources could provide an opportunity and a challenge, and allow water supply sustainability within foreseeable time-frames that can be progressively modified as water related technology advances."*

This approach implies that whenever water demand grows much beyond any country's supply capabilities, groundwater mining can be accepted at least on a short term basis.

It is therefore imperative to account for the possible transboundary effect of groundwater extraction, a matter that is not properly addressed under the existing coordination mechanisms.

The growing rate of groundwater use, particularly in arid and semi-arid regions, and the possible harmful effects that could propagate beyond national borders have motivated the issuing of the law of transboundary aquifers.

This law, subject of the UN General Assembly Resolution No. 63/124, could form a solid base for cooperation between countries. It is suitable of addressing practically all issues that may emanate as a result of over use or misuse of the resource. It urges countries to cooperate in good faith through an agreed mechanism and calls for equitable and reasonable utilization of water taking into account present and future needs and alternative water sources for the aquifer states with special regard given to vital human needs.

Libya and its partners are in an advanced stage of cooperation in managing their shared aquifer systems both technically and institutionally. The newly introduced law will complement the on-going process by adding a legal dimension. This dimension may or may not be utilized in the near future but it forms a set of principles that can realize the preservation and protection of this scarce and vital resource.

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Towards Joint Management of Transboundary Aquifer Systems: Methodological Guide

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ABSTRACT

Aquifer systems, which represent an important part and sometimes the only source of a country's available water resources, are unequally known.

Much more frequently than transboundary rivers, transboundary aquifers are shared between various countries which generally use them independently, partially for drinking water supply and for industrial uses, but mainly for irrigated agriculture. This leads more and more to cases of overexploitation and pollution which create tensions at all levels, with a risk of crises and conflicts between countries sharing the same aquifer.

For all these reasons, it is today important to improve knowledge and promote a reasonable and sustainable integrated management of transboundary aquifer systems.

To reach this objective, the present document firstly recalls the main challenges of transboundary aquifers, their specificities, and the need for integrated water resources management (IWRM) (Chapter I). It then describes the different tools available to improve knowledge and the development of this precious resource: technical, legal, institutional and economic, but also educational and co-operation instruments (Chapter II). Finally, it proposes a progressive and multiform approach for joint, equitable and sustainable transboundary aquifer management and it describes the mechanisms required to create the proper institutional structure for the management of shared ground (and possibly surface) water resources.

Key words: challenges, tools, joint management methodology,

1. WHY THIS METHODOLOGICAL APPROACH?

Currently more than half of the world population and a great number of socio-economic activities, particularly agriculture, depend on groundwater, which is now under increasing pressures. In fact, groundwater is more and more seen as a heritage to preserve, both for our present needs and for the future generations. This strategic resource should be given special attention and sustainable management, as sound as possible, in order to make the necessary economic and societal changes, while maintaining or improving at the same time the living conditions of the users.

This is especially necessary when the aquifer systems are transboundary, i.e. crossed by political boundaries, and therefore shared between two or more sovereign States. This issue, dealt with inappropriately or partially, may lead to a loss of opportunity in terms of human and economic developments, to a degradation of the living conditions in the areas concerned, and can generate tensions and even open conflicts.

To date, many efforts have focused on the management of transboundary surface waters. However, still little action on transboundary aquifer systems has been made, except for a restricted number of projects involving some shared aquifer systems, and only taking into account some aspects of the issue.

Yet, to date, over 270 transboundary aquifer systems have already been identified worldwide by the ISARM (Internationally Shared Aquifer Resources Management) programme of UNESCO. These aquifer systems are, quantitatively and qualitatively, very affected by the development of human activities, mainly agriculture, and by increasing urbanisation. Moreover, in many arid and semi-arid regions, groundwater resources are not or little renewed. Their sound use is even more crucial and climate change may worsen the situation in the decades to come.

To avoid irreversible degradation of these shared aquifer systems, not penalise future generations and prevent possible conflicts between States on the use of these critical resources, it is essential to establish a dialogue and constructive collaboration among the stakeholders. This involves the definition of common objectives and adapted strategies as well as the design and implementation of some mechanisms for transboundary management. Good knowledge of the characteristics and operation of aquifer systems is a prerequisite without which no informed decision can be made.

In order to contribute to the establishment of appropriate management of shared groundwater, the French Development Agency has launched a study carried out by a partnership between BRGM, UNESCO, the International Office for Water and the Water Academy, which led to the development of a methodological guide for the joint management of transboundary aquifers. The goal is to help the political and administrative authorities concerned to gradually implement collaborative, balanced and sustainable management of their groundwater and shared aquifer systems.

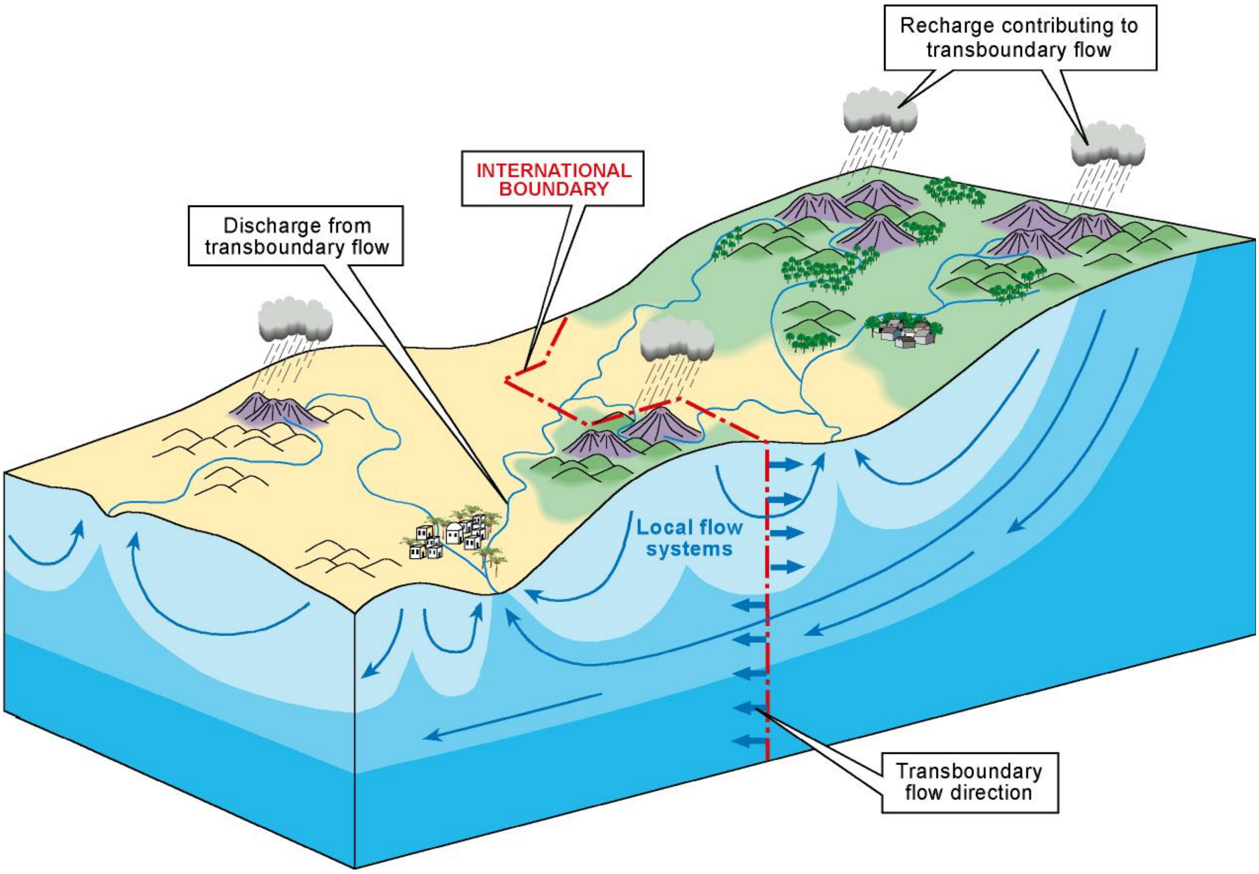
2. CHALLENGES AND SPECIFICITIES OF INTEGRATED MANAGEMENT OF TRANSBOUNDARY AQUIFER SYSTEMS

Groundwaters play a major role in the socio-economic development of our societies. More than half the global human population relies on groundwater, for various economic activities and for drinking purposes. Furthermore, groundwaters contribute to maintaining ecosystems and feed numerous humid zones which are the habitat of a rich biodiversity. Today groundwaters are under more and more pressure due to increased pumping, urban development and socio-economic development, and climate change. They are also under severe threat and often affected by pollution due to human activities.

Aquifer systems whether transboundary or not, are still unequally known on the scientific and technical level. Their characteristics, their functioning, their capacities and their limits are often ignored. Aquifers have a more complex functioning than surface waters: in aquifers water flows in a three dimensional space. Human activities can have a very negative impact on aquifers, and due to their inertia (often ignored) such an impact is visible only some years later. These characteristics are still not well considered by water managers.

Aquifers are also of two categories: renewable and not. Different management considerations are affected to each category.

Transboundary aquifers are not different from any other aquifer system. The difference is that they span the territory of two or more States. The political boundaries add more constraints to the knowledge and the management of this shared resource.



(Source: UNESCO, ISARM 2001)

3. RECOMMENDED TOOLS AND APPROACH

3.1. Available tools

To establish effective and sustainable water resources management, the practice around the world shows that it is necessary to implement a package of complementary and consistent means for action in accordance with the concepts of Sustainable Development and Integrated Water Resources Management, namely:

- scientific, technical and technological means, to improve knowledge of transboundary groundwater and aquifer systems regarding its geological structure, its three dimensional physical limits, its recharge and discharge zones, its vulnerability

- organisational and institutional means to effectively implement Integrated Water Resources Management (IWRM) with the involvement of stakeholders

- legal and administrative means to ensure the framework and the necessary regulatory functions of water resources in a harmonious manner on both sides of the borders. While international law for groundwater is still at a premature stage, the UN General Assembly adopted in December 2008 a Resolution on the law of transboundary aquifers, offering guidelines for States for their agreements on transboundary aquifers.

- economic, financial and fiscal resources, to mobilise the necessary capital and encourage the achievement of common objectives, such as fixing water tariffs, applying the polluter pays principle and mobilising cooperation funds;

- means for training and professional development to improve the skills of political decision makers, managers and technical and administrative staffs. Multi-disciplinary training courses on transboundary aquifers at the intention of water managers and decision makers are under development

- means for participation and co-operation, to exchange information in a transparent manner and to develop long-term co-operation, such as the establishment of cooperation mechanisms, or joint commissions, as it is widely spread for transboundary surface water bodies, and benefiting from the exchange of experience within specific networks, and from the catalytical role of international and regional organisations.

None of these six categories of means is, in itself, sufficient. Their combination enables progress and the achievement of satisfactory and sustainable results.

These tools must be gradually implemented at the same time and at the different levels necessary for shared aquifer systems: local, national, transboundary and international, while working according to the natural geographical units, the hydrogeological basins.

3.2. Proposed methodological approach and mechanisms for a concerted management of transboundary aquifers

Joint management of transboundary aquifer systems is an extremely complex and very sensitive issue. Therefore, the recommended approach and proposed mechanisms for joint management of transboundary aquifer systems are pragmatic, multifaceted and progressive.
Joint, equitable and sustainable management of transboundary aquifer systems requires not only technical skills and financial resources, a clear legal and technical organisations but also a political involvement from the countries concerned. The commitment of all concerned parties (non-governmental stakeholders, international organisations, etc.) is also necessary for the implementation of the management methods. Indeed, the actions to be carried out, using the available tools presented above, should be conducted both at the national, local and transboundary levels and in some cases or for some aspects, at the international level.

The recommended methodological approach proposes actions that can be consistently, successively or, if possible, simultaneously carried out:

1. At the local and national level:
   - Clarification of roles and responsabilities of institutions with the elaboration of a legal framework for groundwater management, and the definition of the roles and responsibilities of the national institutions involved in groundwater management.

   - Improving the knowledge of the transboundary aquifer systems: Data is collected at the national level. However, in the case of transboundary aquifers the exchange of data among the riparian countries is a first step, in the cooperation, allowing the apprehension of the system as a whole, and not limited to part of it.

   - Information and involvement of the various stakeholders and users, as well as the local authorities

2. At the transboundary level

- Preliminary technical contacts: these contacts, which could be facilitated by international organisations, appear as important first steps, identifying the needs and issues at stake, and preparing for the official meetings
- Holding official meetings with the participation of high level representatives from the riparian States, representatives from regional or international UN organisations, development agencies and banks
- Collecting, organising and sharing data in a harmonised framework
- Establishing common tools for management, such as conceptual and mathematical models including the various aspects: physical, environmental and socioeconomical

4. CONCLUSION

The equitable share of benefit deriving from the use of transboundary aquifers is a goal to be achieved, taking into consideration the importance of this resource and the issues at stake. After the first step raising awareness and improving the scientific knowledge, the second step is for the concerned steps to establish relations at the technical and diplomatic levels. International organisations can facilitate and assist such actions. Existing commissions and organisations for the management of transboundary surface water bodies have here a role to play by extending their scope of action to aquifer systems in their territory of competence. Pilot projects can already develop the tools and the know-how presented in the guide book, and create lessons learnt to be exchanged in other basins.

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Transboundary Aquifers and Groundwater Resources Management between Provinces of Japan: In Case of Kumamoto Prefecture, Kyusyu Island, Japan

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ABSTRACT

The paper describes one of typical groundwater management systems called "Transboundary Groundwater Resources Management" which is proceeding in the Kumamoto region, Kyusyu island, Japan. The system was introduced in 2004 and prefectural and city governments have created a unique funding system to encourage artificial groundwater recharge through abandoned rice paddy fields which exist in neighboring towns outside of the city boundary for the sustainable use and management of the regional groundwater resources. This groundwater management system is regulated by the Kumamoto City, local governments and the large groundwater users in the city areas for supporting the funding system. This may be a good example for assessing the impacts of human activities to groundwater resources and managing aquifer systems which cross boundaries between different provinces/prefectures.

Key words: Transboundary GW resources management, artificial GW recharge, abandoned rice paddy fields, funding system, Kumamoto region

1. INTRODUCTION

In addition to aquifers that continental countries share with other countries, there are aquifers within Japan which cross boundaries between different Japanese provinces/prefectures as shown in fig. 1. These aquifers are distributed in a wide range and over whole of Japan as can be seen in fig.1. The monitoring and management of such aquifers shall need at least the same amount attention as those of transboundary aquifers.

Under Japanese law condition at the present time, there is no unified national law to manage the groundwater resources except for preservation of the land subsidence and, therefore, right of groundwater resources belong to the landowners. In Japan, excessive development of groundwater resources in the past decades, especially in the high economic growth period from 1955 to 1972, in mostly of the 1960s, has caused serious social problems such as water level decline, land subsidence, groundwater salinization and oxygen-deficient air accident. The maximum cumulative land subsidence in the Tokyo area, for example, has reached over 4.5 m from 1918, but mostly in the 1960s to the present. Because of such serious problems related to the excessive groundwater use, the National Government has introduced laws to restrict the extraction of groundwater for industrial use by the Industrial Water Law in 1956, and for air-conditioning use by the Law on Regulating the Extraction of Groundwater for Use in Buildings in 1962. In addition, local governments such as Tokyo Metropolitan's have been applying their ordinances to restrict the drilling of new wells in the area where is not covered by the national laws.

Two groundwater laws are effective in whole Japan, but practical application of these laws to a specific area has been decided by the local government. For example, the Tokyo Metropolitan Government has succeeded in reduce the rate of land subsidence by converting water resources from groundwater to surface water and by making legislative guidance in order to save groundwater resources in factories and buildings depending on these two laws. However, bordering prefectures in the similar plain are still suffering from the land subsidence.

Beside for preservation of the land subsidence, however, it is now growing up a new concept in Japanese local governments, communities and citizens that the groundwater resource is a shared natural resource for practice the groundwater management in the region. One of typical groundwater management systems called "Transboundary Groundwater Resources Management" is proceeding in the Kumamoto region, Kyusyu island, Japan. The artificial groundwater recharge proposed by this

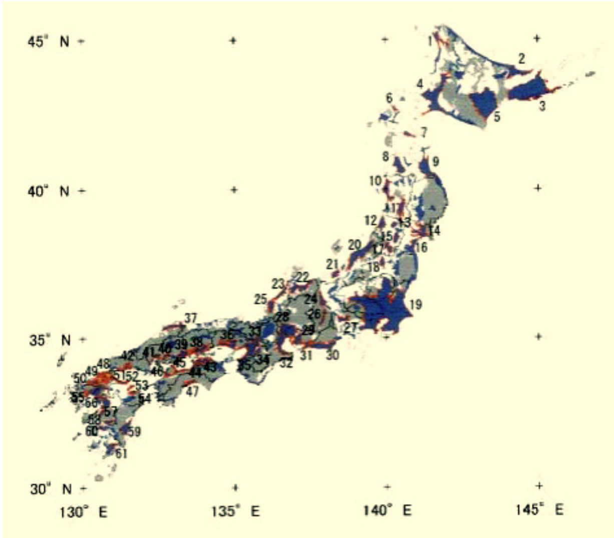

Fig. 1. Distribution of main transboundary aquifers crossing provinces/prefectures
in Japan (modified Marui *et al*., 2010).

system and using abandoned rice paddy fields is considered as an excellent example of the groundwater management system in Japan.

The purpose of the paper is to describe the outline of the system and the practical groundwater resources management under the concept of transboundary aquifers between provinces of Japan.

2. REGIONAL GROUNDWATER FLOW SYSTEM IN THE KUMAMOTO REGION

2.1 Transboundary aquifers in the Kumamoto region

There exists a vast groundwater reservoir and a regional groundwater flow system which cover 13 local governments including the Kumamoto City with the area of around 1,040 km^2 and 1 million residents for which city water is supplied in 100 % from their abundant groundwater resources. Most of the region is covered by pyroclastic deposits created with the four major eruptions of Mt. Aso occurred between 0.26 Ma and 0.09 Ma (Shimada, 2008). There are two main aquifer systems, namely the unconfined aquifer (No. 1 aquifer) and the confined aquifer (No. 2 aquifer). The No. 2 aquifer storages major groundwater resources in the Kumamoto region and is developed for water resources as a huge groundwater reservoir with relatively high local precipitation of around 2,200 mm/year and the high permeability of the pyroclastic deposits (Shimada, 2008).

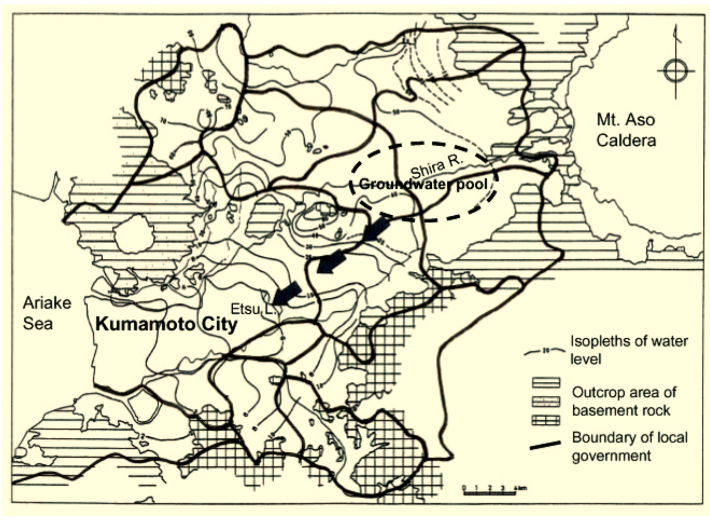

Fig. 2 Transboundary aquifer crossing 13 local governments in the Kumamoto region (modified Shimada, 2008).

Figure 2 shows the piezometric head distribution of the No. 2 aquifer in October, 1993 with the distribution of 13 local governments for which the groundwater reservoir covers the region. There exists geologically unique area called the "groundwater pool" as shown in fig. 2 at where a lacustrine deposit layer separating unconfined and confined aquifers is lacked and it allows that rainwater and irrigation water recharge directly into the No. 2 aquifer system (Shimada, 2008). The groundwater recharged in this area flows toward to the southwest along allows indicated in fig. 2 with flowing out in the lake of Etsu and many other locations in the Kumamoto City. The groundwater supplies city water in 100 % for the residents of 670,000 in the Kumamoto City, which is a prefectural government. In this regard, it is recognized that the No. 2 aquifer in the Kumamoto region is a transboundary aquifer crossing local governments/provinces. This is a typical feature in transboundary aquifer distribution observed in many other Japanese provinces as represented in fig. 1.

2.2 Groundwater resources condition in the Kumamoto region

The Kumamoto City has started to measure groundwater levels in the 1980s through observation well network. Figure 3 shows the annual change in groundwater level at Kikuyo around the groundwater pool area. The groundwater level has declined 4.4 m in recent 25 years from 1982 to 2006, meaning 0.18 m/year decline in average. This trend of groundwater level decline is also observed in other 12 observation wells located at the upland area in the region (Kumamoto Pref., 2009). The discharge of spring water in the representative spring lake of Etsu has also diminished by approximately 15 % during the last 15 years from 450,000 m^3/day to 380,000 m^3/day as shown in fig. 4. In the 1950s, it was approximately 1,000,000 m^3/day (Shimada, 2008). On the other hand, total withdrawals of groundwater in the region have been reducing mainly due to a considerable decrease in groundwater extraction for industrial and agricultural uses. The amount of city water supply is almost constant which now accounts for more than 60 % of total groundwater consumption (Kumamoto Pref., 2009). These facts indicate that the groundwater resources of the region are apparently decreased due to decreasing groundwater recharge rate in the Kumamoto region. The major reason for the decreasing groundwater recharge rate in the region is considered as the land use change in recent years due to the rapid urbanization.

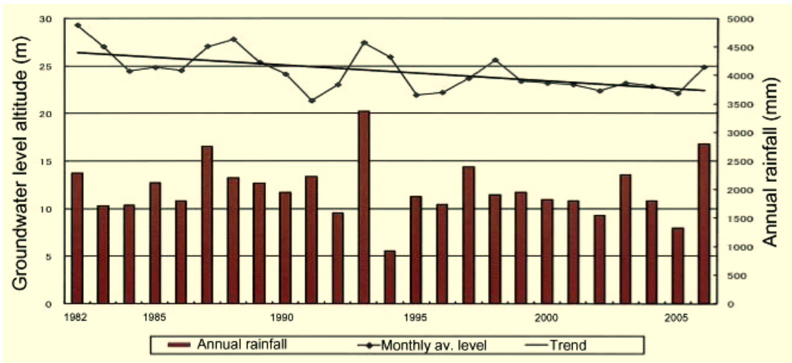

Fig. 3 Annual change of groundwater level in the observation well at Kikuyo (modified Kumamoto Pref., 2009).

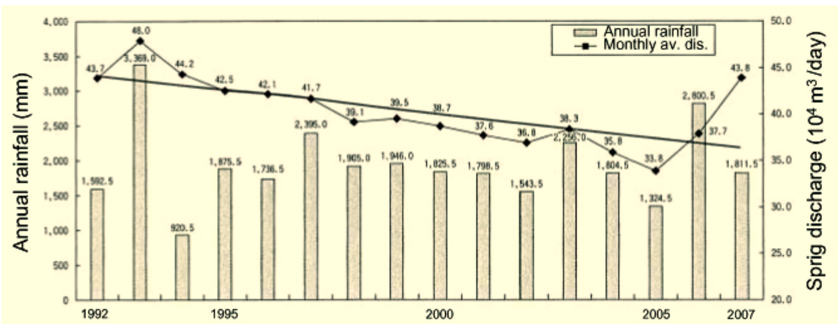

Fig. 4 Annual change of spring discharge in the lake of Etsu (modified Hoshiko, 2009).

3. COUNTERMEASURES FOR SUSTAINABLE USE OF REGIONAL GROUNDWATER RESOURCES

In the Kumamoto region, sources of groundwater recharge to the reservoir are mainly attributed to the surrounding mountain regions, forests, grasslands and paddy fields. Among them, groundwater recharge rate from the paddy fields is estimated about 46 % in annually (Kumamoto City, 2008). Therefore, the most effective measure to increase groundwater amount in the region is to use the paddy fields through the collaboration with local farmers. In this regards, Kumamoto Prefecture and Kumamoto City have created a unique funding system to encourage artificial groundwater recharge through abandoned paddy fields which exist in neighboring towns outside of the Kumamoto City for the sustainable use and management of the regional groundwater resources.

A "Conference on Utilizing Rice Paddies for Groundwater Recharge" consisting of Kumamoto Prefecture, Kumamoto City, relevant 2 local governments, 4 land improving districts and Japan Agricultural Cooperatives (JA) has been established in 2004 to promote the funding system for proceeding the artificial groundwater recharge through the abandoned rice paddy fields. Figure 5 shows the schematic diagram of this system. This groundwater management system is regulated by the Kumamoto City, 2 local governments and the large groundwater users in the city areas for supporting the funding system. Kumamoto Prefecture, Kumamoto City and 2 local governments together with JA organize each year to discuss development initiatives and the preservation of groundwater resources in the region (Shimada, 2008). The effects of the system during past four years, from 2004 to 2007, were as follows: involved farmer's number was from 298 to 410, recharged abandoned paddy fields was from 255 ha/month to 394 ha/month and estimated groundwater recharge volume was from 7,150,000 m^3/year to 11,820,000 m^3/year. Accepting those fruitful effects of the system for groundwater recharge, the Kumamoto Prefecture and 13 local governments in the region have made a "long term groundwater management plan" in 2008, for which the target year is 2024. In this plan, target groundwater recharge amount at the final year of 2024 shall be set as 73,000,000 m^3/year and the reduced groundwater withdrawals are set as 16,000,000 m^3/year in 2024 (Kumamoto City, 2008). This target groundwater recharge amount in the Kumamoto region corresponds to 6 times larger than that of the actual results during the past four years.

It is said that the transboundary groundwater management system established in the Kumamoto region may be a good example for assessing the impacts of human activities to groundwater resources and managing aquifer systems which cross boundaries between different provinces/prefectures like as transboundary aquifers.

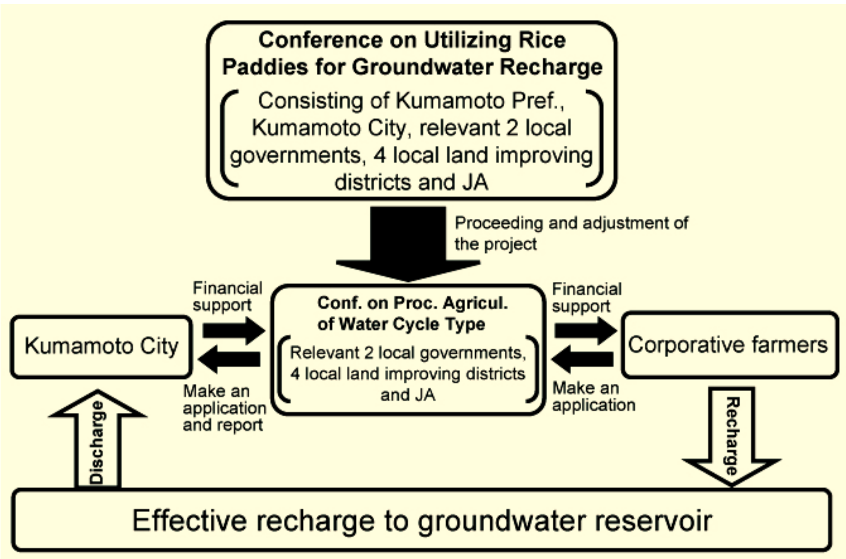

Fig. 5 Schematic diagram of the Conference on Utilizing Rice Paddies for Groundwater Recharge in the Kumamoto region (modified Kumamoto City, 2008).

4. CONCLUDING REMARKS

To start the "International Year of Planet Earth 2007-2009", IUGS and UNESCO (2007) have listed up 10 Scientific Programs as a science program, which is concentrating on globally important issues facing all Nations, named "Earth Sciences for Society". In those programs, "Groundwater - reservoir for thirsty planet" has been ranked up the top (first) program among other 9 scientific programs such as Hazards, Earth and Health, Climate, Resources Issues, Mega Cities, Deep Earth, Ocean, Soil and Life. This means that the groundwater is the most serious and resolved subjects necessarily at the present time in the world. On the other hand, the 63rd UN General Assembly has adopted the resolution of the draft articles on the "Law of Transboundary Aquifers" in December, 2008 (UNGA GA/10798, 2008). The draft articles of this resolution were prepared by the UN International Law Commission (ILC) cooperated with the UNESCO-IHP after 6 years works and discussions from 2003. The main concept of the law is depending on the fact that the groundwater is a shared natural resource as well as oil and natural gas. The American Society of International Law (ASIL) has evaluated the work by the ILC as constituting a "land mark event" for the protection and management of groundwater resources, which have been neglected as a subject of international law despite the social, economic, environmental and strategic importance of groundwater (Mechlem, 2008). The 36th IAH International Conference was held in Toyama, Japan in October, 2008 and the main theme of the conference was "Integrated Groundwater Science and Human Well-being". The UNESCO Chair Workshop on "International Strategy for Sustainable Groundwater Management: Transboundary Aquifers and Integrated Watershed Management" was held in October, 2009 at University of Tsukuba, Japan (Tanaka *et al*., 2009).

These recent new waves on groundwater occurred in the world indicate that the thought on groundwater is shifted from the development to the management and the management should be in mind that the groundwater is a shared natural resource. This concept is led and is based on the scientific knowledge that natural groundwater flow system depending on a aquifer system of which boundary does not coincide with the National State boundaries. The idea of this concept will apply not only for the National State but also for aquifers with crossing boundaries between different provinces in each country.

As mentioned before, under Japanese law condition, there is no unified national law to manage the groundwater resources as a whole. Groundwater resources in Japan, therefore, are mainly managed by the local government's ordinance which is limited to cover the area within the local government's boundary and is not coincide with the boundary of groundwater reservoirs, namely the transboundary aquifers. Recently, however, it became aware among Japanese local governments, communities and citizens that the groundwater resource is a shared natural resource and can find out some examples to define/include this concept in their groundwater reserve ordinances or practices as described in the paper.

The concept of "transboundary aquifers" provides us a very important stand point that the groundwater is a shared natural resource and we must be coexisting with those limited and important natural resources for getting a human well being as shown schematically in fig. 6. As world's water

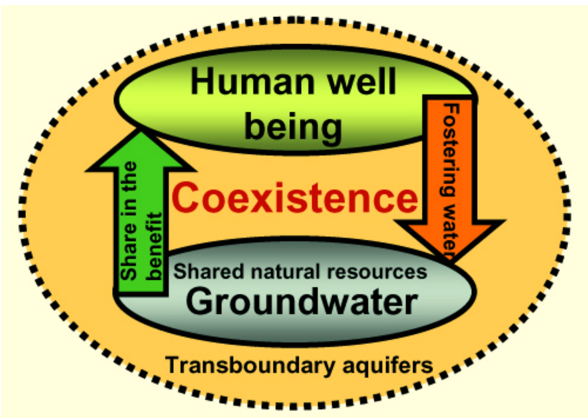

Fig. 6 Schematic diagram showing the concept of coexistence with groundwater as shared natural resources (modified Japan Geotechnical Consultants Association, 2008).

needs continue to grow, groundwater will become increasingly important, and the creation of the wisdom coexisting with groundwater will be the most urgent issue at the present time and effective planed activities will help ensure and adequate water supply for the future.

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Optimizing Groundwater Yield through Enhanced Stream-Aquifer Interaction: A Case Study of Lower Ghaggar Basin in India

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Key Words: Groundwater, Aquifer, Sustainable, Salinization, Productivity

Abstract:

A steady state hydraulic optimization model based on linear programming algorithm, with the objective of maximizing sustainable pumping yield in Lower Ghaggar Basin (LGB) extending over the three Indian states – Punjab, Haryana and Rajasthan, was set up. The model outputs included: optimum pumping rates (OPR), resulting potentiometric surfaces (PS) and the stream aquifer interaction (SAI) etc. The inter-cell variation in OPR was of the of 34 times, the values particularly in river cells being several times higher as compared to the existing pumping rates. OPR induced about 60 % additional flow from stream to the aquifer. The increased groundwater supply, if used in conjunction with canal water, will impact the agricultural productivity positively and interstate tensions arising due to water scarcity may be reduced

Introduction

The Lower Ghaggar Basin (part of Indus system) extends over three Indian states-Punjab, Haryana and Rajasthan, having predominantly an agrarian economy. The overall water supply being deficient, it often leads to interstate tensions. As the competition for limited water supply grows, the need to augment available water supply and use it more efficiently, is increasing. Amongst the various options to achieve the objectives of supply augmentation and improvement in water use productivity, enhanced groundwater recharge from monsoon flows in rivers, development of saline groundwater and its use in conjunction with canal water supplies and on-farm harvested rain-water appear to be quite promising (Tyagi et al,1995, Tyagi,1988). Mathematical models that help simulate the system response to the hydrologic stimuli and the management actions are often used for planning the development of groundwater. These models are essentially simulation models used for determining the feasibility of groundwater operations and aim at managing groundwater stresses such as pumping and recharge and treat the stress and hydraulic heads directly as decision variables (Peralta et al, 1985). This study explores the possibility of augmenting ground water supply by inducing recharge from the river along its length in LGB.

Description of Groundwater Basin

The LGB is a part of the large Indo-Gangetic quaternary basin in the northern part of India (Fig 1). The climate is semi-arid with rainfall varying from 150 to 600 millimeters (mm), but in the upper reaches of the river the rainfall exceeds 1000 mm. The basin has received the benefit of canal irrigation through the famous Bhakra system by way of inters- basin water transfer. Even though the water supplies are inadequate, the canal network is extensive and has caused water logging and salinity in some parts. The upper reaches being hilly, the river flows are quite high during monsoon months from July to September.

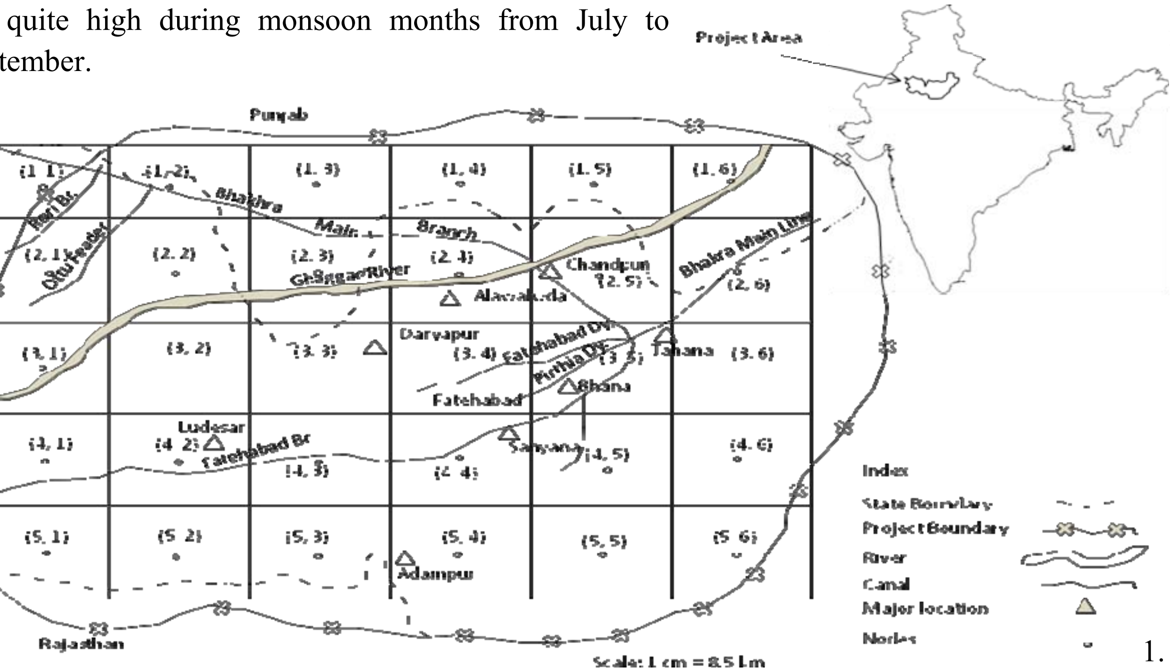

Fig. 1. Location map of the area discretized into finite difference cells

Detailed hydro- geological investigations of exploratory boreholes indicate that the basin has alluvial deposits of varying grades up to depths ranging from 200-300 meters (m) with basement rocks situated at a depth of 200-300 m on the western side and 270-330 m on northeast to southwest sides (HSMITC, 1983). Though there is only one aquifer complex in the area, but it is possible to differentiate locally shallow unconfined and deeper confined layers with thickness ranging from 20-50 m in a depth of 200 m. The hydraulic conductivity of river cells was in the range of 11.5 -19.4 m/day whereas aquifer specific yield varies from 12.5-15.5 %. The transmissibility showed vide variation, the range being 50-1200 m^2 per day. The groundwater quality along the river is fresh, but shallow aquifer layer away from the river have marginal quality waters.

Steady –State Flow Optimization Model

The steady state hydraulic optimization model with the objective of maximizing sustainable pumping yield under well identified constraints was set up (Table 1). The steady state excitation rates are values of pumping and recharge which, when applied to the system continuously, maintain constant potentiometric surface (PS) elevations. For a set of PS elevations, there exists a corresponding set of steady state pumping rates.

Table 1 Brief description of the model

Objective function: Set to maximize the groundwater pumping from variable head cells

Constraints: The following are the important constraints

1. Acceptable draw down- Limits imposed to prevent extreme rise or fall in groundwater table.
2. Hydraulic head- Upper and lower limits were placed to avoid water logging on one end and preventing the aquifer running dry on the other end.
3. Stream-aquifer flows- Limits the stream aquifer interaction and maintain certain base flow in the river.
4. Pumping rates- The minimum limit is current rate and maximum is a certain multiple of the current rate. The upper limit can be raised or decreased to suit lower and upper hydraulic head limits.

The whole area was divided into a nodal network (Fig 2). The size, number and distribution of nodal area and the location of the natural and arbitrary boundaries of the study area were decided on the basis transmissivity, specific yield and groundwater levels. Keeping in view the constraints of quality and availability of data, the area was discredited into 30 nodes, of which 15 were internal and the remaining 15 as external nodes. The internal nodes were variable head cells, used in the study to evaluate the pumping strategies. As the ideal boundary conditions seldom exist, the setting of boundaries was based on preliminary estimation of water table fluctuation arrived at in an earlier groundwater simulation study (HSMITC, 1983). The western boundary of the study area, where the condition of low recharge/low pumping existed with little variation in water table throughout the year, was considered as zero flow boundaries. On the three other sides the boundary behaved more or less as flow controlled. The reach conductance for river cells was estimated on the basis of hydraulic conductivity, the reach length, river width and thickness of river bed. The difference between river stage and river bottom elevations (water depth) was varying in the range of 1.5 3.0 m. Due to space limitations ,only range of values of different parameters has been mentioned as it would help in appreciating the type aquifers studied .

The hydraulic optimization model with linear programming algorithm was translated into GAMS and run with model inputs generated for the study area. The results obtained are presented in the next section.

Results and Discussions

The model outputs include: maximum pumping rates, resulting potentiometric surfaces and the stream aquifer interaction. The total sustainable pumping is the sum of the optimal pumping in different cells.

Pumping rates:

The pumping for different cells (Table 2) shows quite large variation in optimal rates with values ranging from 0.25 m^3s^{-1} to 8.48 m^3s^{-1}. The pumping values, particularly in river cells, are several times higher as compared to the existing pumping rates. The optimal pumping rates depend largely on the type of aquifer formation and the recharge opportunity, with cells along the river having higher opportunity for recharge as compared to cells located away from river/perennial canals. For example , the river cells 2,2; 2,3; 2,4; 2,5 and 3,1 have pumping rates 4 to 20 times of non –river cells 3,2; 3,3; 3,5; 4,1 and 4,2.

Table: 2. Values of model outputs

Internal nodes	Drawdown (m)	Saturated thickness (m)	Optimal head (m)	Optimal pumping (m^3s^{-1})
2,1	1.26	106.7	195.5	2.59
2,2	-8.00	108.5	200.6	7.93
2,3	1.33	102.3	202.6	8.48
2,4	0.67	93.6	210.6	8.10
2,5	1.00	118.8	214.0	2.39
3,1	8.00	112.2	176.6	2.42
3,2	-3.16	100.8	184.3	2.02
3,3	4.27	94.1	195.4	0.85
3,4	7.00	99.6	195.3	1.32
3,5	6.00	109.9	200.5	1.65
4,1	-2.80	135.2	185.8	1.90
4,2	-3.29	127.4	201.3	0.25
4,3	3.77	112.9	192.9	1.50
4,4	1.56	107.7	193.9	1.34
4,5	-0.35	118.2	197.8	1.39

Potentiometric surfaces (PS):

The optimal PSs obtained fall in the range of 184 to 214 m above mean sea level giving a depth to water table of 4 to 22 m from ground surface (Fig. 2). The maximum difference between the initial and steady state water table is 8 m in cell 3,1 whereas the minimum difference is of 1 m in cell 2,4.The cells 2,2;2,3;2,4 and 2,5 are river cells with continuous recharge. In few locations the difference between existing and desired pumping rates was responsible for rise in water table.

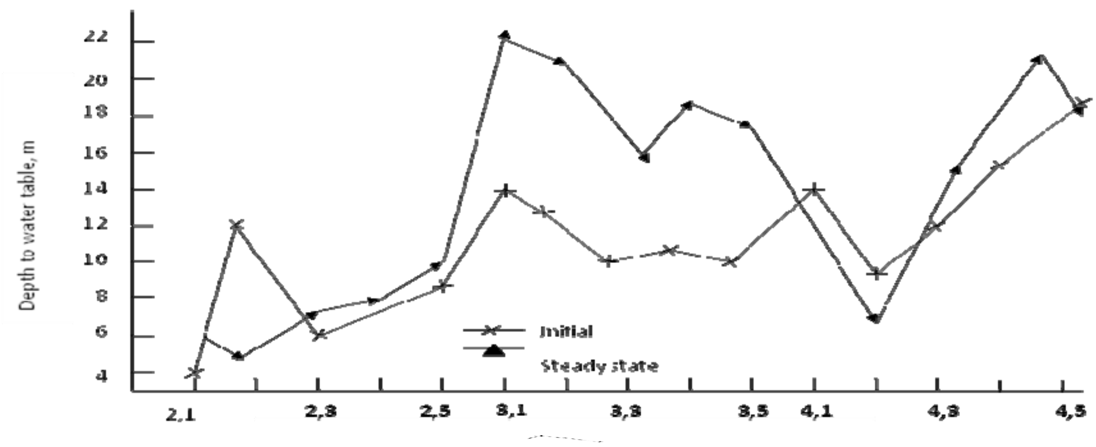

Fig. 2 Depth to water table under maximized pumping scheme

The maximum draw down did not exceed 50 % of the saturated thickness of the aquifer in all cases. The PSs elevations have several implications for groundwater management. Should the PS be high, it would lead to water logging resulting in direct evaporation from soil surface and would cause salinity. A very low PS elevation would increase the cost of pumping. As seen from fig. 2, in optimized pumping scheme, both these conditions have been avoided.

Stream –Aquifer Interaction (SAI)

The SAI may involve flow from aquifer to stream and vice-versa. The magnitude of SAI is determined by the hydraulic head differences between the water bodies and aquifer and the conductance of transmitting medium. The estimated SAI for different cells is shown in Table 2.

Table: 3. Stream –aquifer interaction, boundary flow and current interflow in each river cells and boundary cell under maximized steady–state scheme.

Nodes	SAI interflow (m^3s^{-1})	Boundary flow (m^3s^{-1})	Current interflow (m^3s^{-1})
2,1	1.73	0.095	1.73
2,2	6.97	0.095	4.77
2,3	6.97	0.095	4.75
2,4	7.08	0.095	5.26
2,5	1.38	0.015	1.38
3,1	0.45	-	0.40
3,2	-	0.070	-
3,3	-	0.080	-
3,4	-	0.090	-
3,5	0.11	0.090	0.12
4,1	0.45	0.140	0.45
4,2	0.30	0.090	0.31
4,3	0.34	0.090	0.34
4,4	0.15	0.090	0.15
4,5	0.17	-	0.17

It is seen that the total SAI is of the order of 26.10 m^3s^{-1} as compared to the existing SAI of 16.2 m^3s^{-1}. The model generated total maximized pumping is 44.1 $m^3s^{-1.}$ The optimized pumping induced about 60 % additional flow from stream to the aquifer. The increase in SAI with maximized pumping rates indicates the feasibility of generating more water resource from river flow which goes waste and creates water logging at the tail end of the river in Rajasthan. To achieve the goal of enhanced SAI, establishing optimized PSs is a pre-requisite which could be accomplished by increasing the number of tube well units. These additional tube wells would be needed in all the cells, but more of them in river cells. Based on the aquifer properties and the size of the strata, the number of tube well units can be estimated.

Conclusions

It is inferred from this study that there is need as well scope for augmenting the water supply through induced groundwater recharge from river flow, particularly during monsoon period when the river flows are high. In river cells the induced stream-aquifer interaction will substantially increase groundwater availability in the basin. To accomplish this objective, groundwater withdrawal in the area would have to be increased to establish desired hydraulic head differences between river flow stage and the groundwater table. It would be desirable to increase pumping in river as well as in non river cells by increasing the number of pumping units. In non river cells which have marginal quality groundwater in some areas, higher pumping will eliminate the possibility of water-logging and salinity by lowering groundwater table. The increased groundwater supply in the both situations (river as well as non river cells), when used in conjunction with canal water, will have a positive impact on agricultural productivity and will reduce interstate tensions arising due to water scarcity.

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Hydrological Investigation Challenges of Transboundary Watershed Aquifer in the Himalayan Region

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ABSTRACT

Trans-boundary may be defined by political, natural, geographical features or other anthropological activities or geo- referencing system. Further it may be defined by underneath geological strata and aquifers. A river has its own natural basin boundary consisting of multi sub-basins falling in or covering various local, regional, zonal, national or even international boundaries. Consequently, the river flows across all the concerned boundaries and the flow transportation can be realized as trans-boundary or inter sub-basin water transfer. The integrated study and investigation turn to be more challenging and complex. However, scientific and methodical planning makes this study of invisible processes more interesting, useful and applicable for sustainable and optimal development. Indian National Water Policy, 2002 has schedules for the planning and management of water resources and its optimal, economical and equitable use through hydrological unit planning such as drainage basin as a whole or for a sub-basin, which takes into account of surface and ground waters for sustainable use incorporating quantity and quality aspects as well as environmental considerations.

Snow and glaciers in the Himalayan regions took care of the flows in the river during the spring and summer by keeping it perennial. The lean flow of winter is necessarily from confined and unconfined aquifer. It may be possible that the ground flow of a watershed may appear in the stream of adjacent mountainous watershed and vice-versa. Few major Himalayan river basins of India have their upper catchment in the territory of other nations, having no snow and meteorological stations or data sharing platforms leading to problems of hydrological analysis. The paper discusses the trans-boundary nature and problems with prospects of hydrological analysis in typical Himalayan streams as well as the invisible aquifer contribution essential for flow in the stream at the time when each and every drop of water become precious due to climate change scenario. This flow is life sustaining flow as pious. There is a need of mutual cooperation and resolution of issues legally related to share and management of watershed, water resources and observations for the analysis and equitable developmental utilization.

Key words: Snow & Glacier, Lean flow, Groundwater, Inter basin aquifer, Base flow

1. INTRODUCTION

Effective utilization and efficient management of water resources are essential for the socio-economic development. Water resources management is neither complex nor simple due to its, generalized, diverse and stochastic hydro-geopolitical nature. The National water policy has provided sufficient guidelines to develop the resources. Several plan proposals and detailed project reports are still at the level of evaluation in paucity of fund, regional issues and environmental clearance. Direction of the court upon public litigation appeal is expected even to maintain the roadside drainage. Further, administrative trans-boundary development involves treaties and non-technical part. Whereas, inter or trans-boundary watershed/aquifer water transfer/flow is technical-cum-political to legal. Intra basin/aquifer water utilization and management deal with in-depth science, society, technology, initiative and equity issues. Privatization of natural resources may weaken the federal structure and demoralize the voluntary workers by keeping the stakeholders and poor population away. An individual dweller/user or agency has to know their watershed and aquifer basins potential and status to have fare share and participation. Non-commercial water right subsists with individual locals and the state. Only surplus surface or ground water or in conjunction temporally or spatially can be allocated or considered as commercial commodity. To develop the management practice of transboundary aquifer since 2000, the International Association of Hydrologist (IAH) and UNESCO's International Hydrological Programme (IHP) have established Internationally Shared (transboundary) Aquifer Resource Management (ISARM) and it is clear that case studies under different conditions will be needed (Puri, 2003; Puri & Aureli, 2005) as transboundary ground water overexploited by one state may be detrimental to another (Jarvis *et al.*, 2005) and pollutants might also migrate to contaminate a neighbour aquifer.

1.1. Transboundary basin a hydrological and national challenge

There is a need to define the boundary. The surface boundary may be defined by geo-referencing system based upon political, natural basin and geographical setup or any other anthropological activities. Further, it may be defined by underneath geological strata and synchronized with physical and political boundaries. A river has its own natural basin boundary consisting of multi sub-basins containing local, district, regional, state, zonal, national and international boundaries. Consequently, the river crosses all the concerned boundaries and the water transportation can be realized as trans-boundary if it crosses more states/nations; as inter basin if it crosses adjacent basins or as intra basin if it passes through sub-basins within a basin area. It is difficult to define or design the water availability for practical purposes on annual average basis or to designate an area of scarcity, if the availability of water is less than 1000 cum per capita per year. Himalayan rivers valley in India gets 80 to 90% precipitation in four monsoon months (June to September) only. The ground water recharge and aquifer potential developed during monsoon and latter through seepage of tank, reservoir and perennial streams augmented through snow and glacier melts help in meeting the demand from ground water resources. Ground water flowing downward through confined or unconfined aquifer or trapped in perched aquifer may not necessarily follow the basin or district boundary. It has its own geological strata and boundary to be relieved under pressure or to get released under gravity, if not trapped in between. Under world-wide hydrological mapping and assessment programme and hydrological map information system (WHY MAP/MIS), international hydrological map of Europe (IHME) having 90 transboundary aquifers were fitted (Struckmeier, 2007) with geo-referenced UN ECE data for conceptualizing hydrological model. Indeed, to assign the statistics for designating an area of scarcity a detailed and sound technical criteria are desired with reference to availability and risk involved with space and time. As an example, north-eastern states including Bengal, Bihar, UP and the state of Assam are not only prone to receive water logging and frequent floods but are also prone to recurrent drought and famine. To have non-monsoon period water supply and all weather fresh water, created surface storage or aquifer (unconfined and confined) waters are the last option.

Kathpalia & Kapoor (2006) discussed with an objective to transfer quality water for the people below poverty line. In order to keep the cost minimum, ground reserves are needed to be maintained. The springs and glaciers of the Himalaya keep the flow perennial in the rivers during the spring and summer are now drying up and receding due to climate change scenario. Thus, new storage scheme would have to take care of the flow deficiency. Analysis is difficult due to lack of observational network, especially in transboundary catchments. Having upper catchment of the river Sutlej in Tibet, remotely sensed imagery/data is the only source of any information at present. National Water Policy (MoWR, 2002) laid down specific policy prescription for an optimal development of the country water resources. Studies and investigations are supposed to be under taken through integrated basin-wise (Intra & Inter Sub-basin) development at war footing. The extracts of the water policy relevant to the topic are given below:

- <u>PS3.3.</u> Water resources development and management will have to be planned for a hydrological unit such as basin as a whole or a sub-basin, taking into account of surface and ground waters for sustainable use incorporating quantity and quality aspects as well as environmental considerations.
- <u>PS3.5</u>. Water should be made available to water short areas by transfer from other areas including transfers from one river basin to another adjacent basin.
- <u>PS19.1</u> Priority should be given to reduce the vulnerability of drought prone areas through water conservation, water harvesting, water recharge, evaporation loss prevention and transfer of surface water required from surplus areas, wherever it is feasible and appropriate.
- <u>PS27.</u> Planning and management of water and its optimal, economical and equitable use are a matter of the outmost urgency. Success of the water policy will depend entirely on amicable national consensus and commitment to its underlying principles and objectives.

1.2. Transboundary and multilayer aquifers assessment

The runoff generated from hilly region is not always Hortonian (Beven & Kirkby, 1979). Proper infiltration factors on slopes (steep/gentle/flat) and depressions are needed to be assessed. The main limitation is the estimation of water holding capacity of aquifer and also estimation of withdrawal of ground water (GW) from different abstraction structures. Hilly areas may contain isolated pockets of storage. Sedimentary areas may have single aquifer or multi layered multi-quality aquifer systems. Hard rock watershed may have single water table aquifer. The inter-aquifer flow can be defined either by the subsurface vertical flow between two aquifers in a multi-aquifer system or by horizontal flow across the boundary between adjoining aquifers or in combination of both (Keshari, 2010). In most cases boundary of the study area does not coincide with the natural boundary. It may also be possible that assessment unit would have hydraulic connectivity with the surrounding aquifer systems. In these cases the horizontal subsurface flow moving out of the aquifer under assessment unit can not be neglected. Similarly in a multi-aquifer system there may be percolation or leakage to the confined or deeper aquifer from the unconfined aquifer. In general the inter-aquifer flow may not exist on a watershed scale unless there is some influence of geological features or hydro-fracturing. Delineation of vertical and lateral boundary of aquifer with type determination of recharge area and estimation or assessment of ground water is important.

Current national water policy recommends safe yield policy supported by GW recharge using water budget, soil moisture balance and mathematical model techniques. Planned depletion policy become important in declining conditions of GW reserve year after year due to over exploitation or less recharge and overall lowered water table. A case study of the Kosi project held at Patna in 1979 recommended that utilisation of GW in conjunction with surface water must be promoted to improve the irrigation performance of the project. In fact, it is the adhoc emergence of extensive GW use through cheap, improved bamboo tube wells in the Kosi command over the years that has covered up irrigated agriculture and saved the project from what would have been a catastrophic failure on the irrigation front (Prasad *et al.*, 1994). Models employed for estimation are sophisticated to simple depending upon the nature of data required. Methods generally used in India for the groundwater recharge estimation are Empirical methods (relate area specific GW recharge to Rainfall based on Chaturvedi, Amritsar and CGWB formula), Groundwater level fluctuations, Temperature based model (which utilizes sub-surface temperature profile), Hydrologic budgeting approach and Numerical method. Type of analysis includes pre and post monsoon water table or saturated thickness of the aquifer and water table fluctuation. Through repeated radiocarbon measurements, it is possible to understand the aquifer conditions by observing the changes in the radiocarbon ages. It provides valuable information in determining the recharge area, groundwater flow direction and ground water flow rates. When different aquifers exist in one area it is essential to determine aquifer to aquifer interaction in term of recharge and exploitation. In an unconfined aquifer, river and aquifer interaction are sensitive and need to be handled with care. The altitude of water table in the vicinity of stream should be lower than the altitude of stream water surface. Transboundary basins (watershed/aquifer) need to be managed and designed conjunctively as both ground and surface waters are complementary and supplementary to each other (Verdhen *et al.*, 1996). References on conjunctive management are indeed incomplete (Wilson *et al.*, 2006), as work under IDRC, USAID, IMMI/IWMI and Government of India conducted in early 1990's is commendable bench mark. MODFLOW is considered good but data requirement is massive.

1.3. Transboundary aquifer co-operation

To have sustainable and productive co-operation among co-basin states and countries for development of water resources a dynamic co-ordination, transparency and sound understanding are the pre requisite criteria. The natural and cultural bonding in terms of geographical affinity and historical events have positive role to strengthen the process of co-operation. Evolution and implementation of international law on scientific basis includes the principle of riparian rights, theories of prior appropriation, ideas of equitable distribution and issues of climate and environmental.

Typology conceptualisation (Eckstein and Eckstein, 2005) reflects the geo-political and hydro-geological features of transbounary aquifers. Transboundary relation of Nepal and India on north Bihar river basins is like model C, model D or E. Over the year Nepal feels deprived from its fair and rightful benefits while India considers the claim as unreasonable demands, intransigent attitude and deliberate stalling. Both are suffering under the syndrome of danger from big and benefit of small storage dams.

Presentation (Yamada, 2009) on international law of transboundary aquifers revolves around the preamble and general obligatory directions necessary and sufficient through Article 7: Aquifer states shall co-operate on the basis of sovereign equity, territorial integrity, sustainable development, mutual benefit and good faith in order to attain equitable and reasonable utilization and appropriate protection of their transboundary aquifers or aquifer systems. Consequently, aquifer states shall observe, analyze, monitor, manage, share, safeguard, operate and co-operate establishing independent and joint mechanism of cooperation.

2. RESULTS AND DISCUSSIONS

Transboundary watersheds and aquifers are needed to be monitored and managed simultaneously. However, likewise National Highways and Power Grid connectivity, inter basin water transfer grid or river interlinking is not a valid proposition as water does not flow against gravity at its own. Conflict-ridden project consists of 14 links (namely 1.Manas-Sankosh-Tista-Ganga, 2.Kosi-Ghagra, 3.Gandak-Ganga, 4.Ghagra-Yamuna, 5.Sarda-Yamuna, 6.Yamuna-Rajasthan, 7.Rajasthan-Sabarmati, 8.Chunar-Sone, 9.Sone dam-Southern tributaries of the Ganga, 10.Ganga-Damodar-Subaranarekha, 11.Subaranarekha-Mahanadi, 12.Kosi-Mechi, 13.Farkkha-Sunderbanas, and 14th an alternate to 1.) as Himalayan rivers component (Fig. 1) and 16 links as peninsular rivers component (Gopalakrishnan, 2009). Most of the concerned states are not convinced with the linking project.

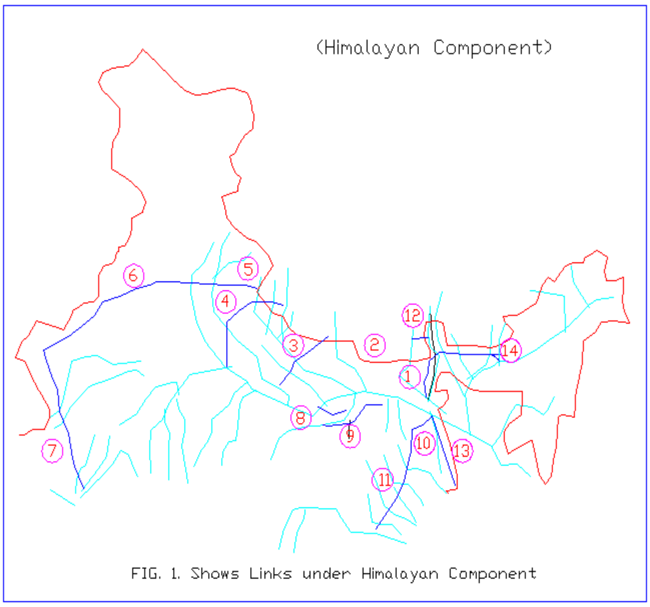

Fig. 1 The Himalayan Rivers link components.

Central government constituted a parliamentary standing committee understanding the deficiency in the approach, planning and design of the project and invited consent, comment and suggestion from all the concerned states, experts and stake holders in order to achieve socio-economic-effective and feasible solution. Inter-basin transfer entirely depends on the consensus amongst all the co-basin states and nations of the donor basin, in-route basin and recipient basin (Iyer, 2009). Hydrologic unit based intra-basin integrated water planning and management are the backbone of sustainable development.

Out of 12 identified transboundary aquifers in Asia (Ramasamy *et al.*, 2009), 7 to 9/10 are originating from the Himalaya, i.e. the Indus, the Ganga and the Brahamputra basins of India are transboundary in nature with Afghanistan, Pakistan, Nepal, Bhutan, Tibet (China), Bangladesh and Myanmar. Percentage of basin area and non-monsoon eight month's annual flow (Table 1) can be considered as a combined component of rain, drain, ground and glacier spawn flow, envisaged as 'Base Verdhen Flow (BVF)', which is 14 to 17%, distributed over non-monsoon period under the constraints of storage, recession and depletion. During monsoon it may increase twice to thrice, i.e. 30 to 40%. Summing up annually, it goes up to 55%. The Kamala and the Bagmati, being snow and glacier free basins, show only 7 to 8%. Above and all the fissure flow, Darcy's sub-surface flow and GW extraction have an influence on post to pre-monsoon ground water fluctuation. During subzero winter temperatures, the stream gets only ground and spring flow. A typical peak winter (Jan-Feb) weekly average discharge and monthly flow (Fig. 2) in Kothi/Solang nala of the Beas sub-basin with catchments area of 70/130 sq km are 1.3/3.5 cumecs and 0.06 mcm per sq km. Further, unit area monthly snow and ice melt flow with rise in temperature increases six times by the month of May. However, climate change impact shows rise in temperature and reduction in snowfall.

Table 1 Himalayan transboundary basins in India having internationally shared watershed and aquifer.

Name of the river basin/Sub-basin	Basin area (Sq. km)	%age area in India	Co-basin countries	Total length (km)	%age length in India	Annual flow (mcm)	%age monsoon flow	%age Non-monsoon flow
Indus	1165000	28	Afghanistan, Tibet and Pakistan	2880	37	209700		
Sutlei	75369	70	Tibet, Pakistan	1536				
Ghaghra	140606	50	Nepal and Tibet	1080	55	98438	84	16
Gandak	45942	24	-do-	630.4	40	53201	75	17
Burhi Gandak	12500	81	Nepal	550	99	7059	85	15
Bagmati	13690	44	-do-	593	67	5671	92	8
Kamla	5563	65	-do-	328	78	2156	93	7
Kosi	74500	15	Nepal and Tibet	468	53	78282	86	14
Mahananda	25043	70	-do-	376	85	13566	85.5	14.5
Ganga	1860000	46.3	Nepal and B. Desh	2525		525020	90	10
Brahmputra	580000	34	China, Bhutan, B. Desh	2900	32	607087	83	17

Indian Water Resources Society (Rangachari, 2005)) reviewed and presented critique on the effectiveness of Bhakhra dam and agreement to utilize it fully. The Indus Waters Treaty (1960) signed by India and Pakistan enabled the full development of the Sutlej waters by India. Article II says that all the waters of the eastern rivers (defined as the rivers Sutlej, Beas and Ravi) shall be available for the unrestricted use by India, except as otherwise expressly provided. Hence, India was not obliged to share any water of the Sutlej beyond the border, which facilitated Beas-Sutlej link effectiveness. Whatever needs are at lower are to be taken care of by themselves. Water surplus states at present are not irrigated significantly and almost all cities and towns in these states are having their own plan to develop hydrology and water resources. Also, the riparian states through which these rivers pass have their own plans to use the surplus water to develop their backward regions. Present performance of existing irrigation projects are not good enough due to various technical and non-technical reasons.

Generally, minor canals and water courses are incomplete resulting in ground water dependency for protective irrigation.

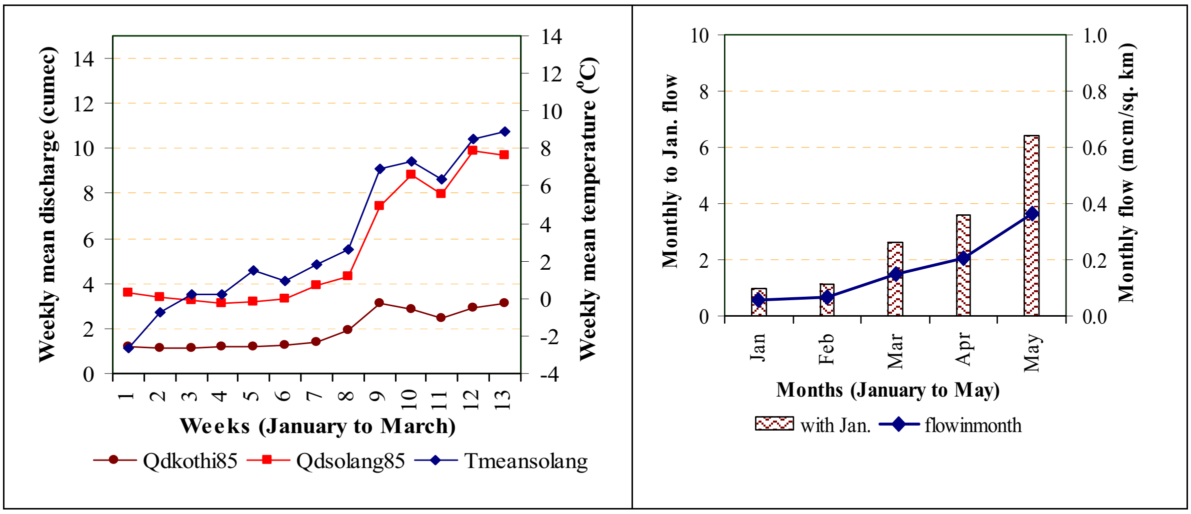

Fig. 2 at left shows weekly winter discharge(m^3s^{-1}) of kothi and Solang nalas of the Beas sub-basin with mean temperature at Solang, whereas at right it shows monthly flow (mcm km^{-2}) and relative to Jan.

Damaging or worst situation to an aquifer may arise by handing over the drinking ground water supply and irrigation operation under the hand of commercial group as concessionaire. To meet the cost, farmers are bound to be in debt and the government has to promise subsidiary or concession. We may need to pay the high economic and environmental costs of river inter-linking, as incomplete or inoperative (due to lack of water) Sutlej-Yamuna link canal was a cause of flood a. The international dimensions of sharing are equally critical. The holiest national river Ganga is at the centre of trans-boundary water management involving Nepal and Bangladesh. Legal issues may arise, as it pertains to local and natural issues. Recently, the country is witnessing differences among the states of Karnataka and Tamil Nadu over the sharing of water from rivers Kaveri and Krishna, even though both the states are riparian.

3. CONCLUSIONS

Certainly, scientific study, investigation and engineering design cum execution are required based upon technically sound and socially effective criteria keeping all the options open. The immediate need is to examine the basin watershed and water aquifer properties and interaction in conjunction with other adjacent basin and administrative boundaries. Studies on natural pattern and behaviour of surface and ground waters by having process based water balance within simulated boundary conditions are required. Assessment, utilization and management of surface water comparatively to ground water are apparent. However, mapping the aquifers boundary layers below surface and administrative boundary layers along with source of recharge, flow direction and discharge laterally as well as vertically are of prime importance. The aquifer planning and management strategies resolving the transboudary issues pertains to observation, analysis and utilization responsibility, share and legal agreement. Physically distributed model like SHE and MODFLOW are technically sound to have online decision under GIS environment provided process input variables and parameters are available. First step towards that is to have a complete framework for surface water optimal utilization resolving equity, sustainability and transboundary water share issues. The intra basin development of water resources is much more scientific and technical which should be taken up first (Verdhen, 2009) before the water utilization and distribution through links as a complex inter-basin transfer of unmanageable flood or scarce precious lean flow (base Verdhen flow) or ground water. Intra and inter aquifers basins together with transboundary aquifer management will backup as secondary but essential source to resolve the issues and to achieve a happy, healthy and amicable solution, minimizing legal conflicts.

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Simply-structured groundwater model analysis for informing management of transboundary aquifers:
Examples from Bengal Aquifer System (Bangladesh, India) and Nubian Sandstone Aquifer System (Chad, Egypt, Libya, Sudan)

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ABSTRACT

Important information for management of transboundary aquifers can be obtained via a parsimonious approach to groundwater modeling. This approach requires (1) development of groundwater models with very simple hydrogeologic structures, and, (2) basic application of these models to answer fundamental questions about the natural functioning of the aquifer system and its responses to human and other external forces. A 'parsimonious' approach implies active avoidance of overly-complex features when constructing models and model-based analyses. 'How simple' and 'how complex' should a particular model analysis be? The answer must rely on hydrologic expertise and experience, and on open scientific discussion.

The need for effective simple modeling is pertinent to large transboundary aquifer systems that do not have informative and extensive hydrogeologic databases. Effective simple models and insightful approaches to analysis account for the limitations of both the modeling approaches and knowledge of aquifer system structure. Simple models can provide clear and robust answers to pertinent questions about transboundary aquifers. This approach was applied for study of two very large transboundary aquifer systems, the Bengal Aquifer System (BAS) of Bangladesh and India, and, the Nubian Sandstone Aquifer System (NSAS) of Chad, Egypt, Libya and Sudan. For BAS, where dissolved arsenic is the noxious substance of the world's largest contamination problem, parsimonious modeling allowed identification of a management approach that could supply a sustainable arsenic-free groundwater supply. For NSAS, development of a parsimonious model is a key step in providing a technical basis for international discussion concerning management. Initial application of the model shows that development of this non-renewable water resource will require effective management of primarily local impacts, as transboundary impacts are of lesser magnitude.

Keywords: Groundwater modeling, Management, Transboundary Impacts, Bengal Aquifer System, Nubian Sandstone Aquifer System.

1. PARSIMONIOUS GROUNDWATER MODELING

Effective simple models include only salient features of the aquifer system that control primary aquifer behaviors of interest regarding understanding and management. A 'parsimonious' model has only enough features to represent key data and processes needed to answer questions at hand. Effective analyses evaluate impact of alternative model structures and features on questions being answered. Complex models often include all available data just because some data details are available, but the practical value of adding model complexities that do not impact results of interest is questionable. Moreover, the processes of developing complex models and using them for analyses are more difficult and time-consuming than for simple models. Potential advantages of complex models are ultimately limited because of inherent uncertainty in knowledge of aquifers. Aquifers can rarely be measured and characterized at spatial-temporal scales required for complete characterization and effective complex modeling, but sparse characterization and parsimonious modeling often allow well-posed questions to be answered. Mere addition of all available hydrogeologic details should thus not be the model-development objective; rather, the central model-development objective is identification of hydrogeologic and other factors that allow questions at hand to be answered.

2. BENGAL AQUIFER SYSTEM

In the Bengal Aquifer System (BAS) of Bangladesh and India, access to groundwater is generally not a problem. Indeed, groundwater is the primary domestic water source for tens of millions of inhabitants. However, shallow groundwater being used has very high levels of dissolved arsenic. This is adversely impacting public health. Deeper groundwater in BAS is currently arsenic-free (meaning: As < 10 µg/L), but any wide-scale program to deepen wells to tap this As-free resource may cause shallow arsenic to migrate downwards, permanently spoiling this sole-source transboundary aquifer. Alternatives are being sought that will provide a sustainable arsenic-free water supply. Parsimonious model-based analysis of the entire BAS (Michael and Voss, 2008, 2009a, 2009b; Burgess *et al*., 2010) has allowed evaluation of key controls on regional groundwater flow. The robust result of this analysis is that, by deepening only domestic wells in the impacted areas while keeping irrigation wells pumping from the shallow part of the aquifer, a sustainable arsenic-free groundwater supply is provided for most of the impacted region. Regarding implementation, it is important to note that this is a low-tech solution that employs socially-functional and passive technology, deepening the common tube wells already preferred by the population. However, it is important that deepening of shallow domestic wells is accompanied by close monitoring and is undertaken with great care and precautions to prevent creation of preferential and rapid pathways for As-laden water to reach the deeper aquifer.

3. NUBIAN SANDSTONE AQUIFER SYSTEM

In the Nubian Sandstone Aquifer System (NSAS) of Chad, Egypt, Libya and Sudan (*http://water.cedare.int/cedare.int/files15%5CFile2813.pdf*), water availability is a key problem and there are concerns about transboundary impacts of water use. Reserves are extensive, particularly in areas where NSAS is thick (Libya and northern Egypt), but there is no modern recharge in most areas. Thus, this resource has limited volume, particularly in areas where NSAS is thin (southern Egypt and Sudan). Transboundary concerns include excessive depletion of groundwater reserves by individual countries and the spread of water-table drawdown across borders, causing shallow wells to dry and oases to disappear. There are also local concerns, including excessive local drawdown within pumping centers, local contamination by untreated waste recharge, and disappearance of oases where most pumping centers are co-located. Simply-structured model analyses, undertaken as part of an IAEA/UNDP/GEF project (*http://www-naweb.iaea.org/napc/ih/IHS_projects_nubian.html*), have shown that transboundary issues should not be an obstacle to practical management of NSAS water resources. Although the foremost transboundary impact of development was indeed found to be drawdown crossing national boundaries, the large scale of the NSAS and its plausible ranges of aquifer parameter values make the magnitude and extent of such transboundary drawdown small and likely not an issue of practical significance in the next century. On the contrary, parsimonious modeling forecasts large local drawdown, potentially impacting the existence of oases in pumping centers. Thus, primary NSAS management concerns should be focused at the local scale. Indeed, new management and engineering approaches may be required to maintain both economical production of groundwater in the face of drawdown and environmental stability in the face of spring flow reduction.

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Managing Transboundary Aquifers:
Lessons from the Field

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ABSTRACT

What are the factors that foster or impede the creation and implementation of international agreements for the management of transboundary groundwater? While legal scholars and management experts tend to highlight the importance of scientific knowledge and institutional frameworks in the norm-making process, others connect the development of institutions for international waters to the existence of threats to States' security, to sovereignty, and to the existence of stakes in the resource's management. This study focuses on three markedly different experiences of transboundary groundwater management, drawing on the analysis of historical documents and more than 40 semi-structured interviews from the field. While the management of the French-Swiss Génévois Aquifer is the subject of a formal international agreement, the authorities dealing with the Guaraní Aquifer System have preferred the implementation of coordinated policies to an overarching international agreement. Conversely, in the case of the U.S.-Mexican Hueco-Bolsón Aquifer, the transboundary aquifer is competitively exploited, without any joint-management policies or agreements, and official cooperation is limited to local-level dialogues about the shared resource. In line with the literature, this study suggests that hydrogeological conditions, the compatibility of institutional frameworks, and geopolitics are key factors behind alternative approaches to groundwater governance. This research, however, emphasizes the substantive role of mutually-recognized local-level assessments of transboundary resources—knowledge about the aquifers—in the configuration of the usual explanatory variables. In fact, the governance of transboundary aquifers depends ultimately on calculations and decisions at the local level. Actors at the local level with an interest in the resolution of transboundary groundwater problems may bypass formal institutional restrictions to implement less formal, if nonetheless functional, governance solutions. They can also shield themselves with geopolitical differences, or the incompatibility of institutional settings, in order to block the development and effective implementation of governance initiatives that threaten their interests. These findings contribute to the study of international norm-making processes by shedding light primarily on the dynamics of international environmental governance, and secondarily on issues of local-level policy-making in border settings.

Key words: Transboundary Groundwater Governance, Knowledge, Hueco-Bolsón Aquifer, Génévois Aquifer, Guaraní Aquifer system

1. INTRODUCTION

Groundwater is a critical component of the global supply of freshwater. Its increased exploitation has resulted in significant economic and welfare gains, as well as declines in the quantity and quality of the resource that seriously threaten the sustainability of ongoing practices (Llamas and Custodio 2003). Despite the vital role played by these resources, international agreements dedicated to the protection and governance of groundwaters that span across boundaries are rare (Burchi and Mechlem 2005, Delli Priscoli and Wolf 2009). In fact, most of the international agreements currently dealing with international waters either incorrectly define or do not properly include transboundary groundwaters, and the few working governance schemes addressing these waters are marked by their uneven geographic distribution, reach, and political contentiousness (Jarvis, et al. 2005, Matsumoto 2002). What are the factors that foster or impede the creation and implementation of international agreements for the management of these waters?

2. THEORETICAL EXPLANATIONS FOR TRANSBOUNDARY WATER REGIMES

International Relations theories suggest that the creation of environmental regimes[1] is exclusively a matter of State power (Ruggie 1998, Young 1989). In other words, the creation of water management agreements is a tool for rational territorially-based sovereign States. In depth studies of water regimes, particularly those of the "water wars" literature, use hydropolitical analyses to argue that water management institutions are responses to geopolitical tensions created by threats of water scarcity (Dinar 2000, Elhance 1999). Water regimes are presented as rational instruments for the prevention of conflicts fostered by specific environmental conditions (Gleick 1993, Homer-Dixon 1999). The explicit assumptions of these studies are that states require minimum quantities of water, or at least stability in the access to the water resources, and that threats of scarcity are resolved either through violence or institutions. According to this approach, international agreements over the management of transboundary groundwater develop from threats posed by scarcity to state security. The resulting agreements are conditioned by the relative power of each party to push for the establishment of regimes serving its interests.

Socio-legal and political science studies focus on issues of knowledge and institutions to explain agreements over shared waters. Framing groundwater as common pool resources, some point to the functional-rational nature of institutional arrangements (Gardner, et al. 1997). Rules permit more effective access to resources, as well as their protection and sustainable exploitation, and can prevent competitive use of groundwater. Agreements are hence connected to rational calculations by users, which in turn depend on the specific properties of the shared resources (Chermak and Brookshire 2005). More specifically, it is the interpretation of knowledge of hydrogeologic conditions that determines the urgency of agreements, and the goals of the management arrangements (Blatter and Ingram 2001). The creation of new rules occurs within the boundaries set by culture, politics and institutional frameworks, which may, however, not always be compatible with new regulatory initiatives for transboundary groundwater.

This paper aims to challenge two aspects of existing theoretical approximations: the macro-scale of analysis proposed by International Relations theory and the relevance of structural restrictions in the making of rules in institutionalist perspectives. Drawing from more than 40 semi-structured interviews and original documents gathered in the field, this study presents three alternative cases of transboundary groundwater governance: the Franco-Swiss Génévois Aquifer, the Argentinean, Brazilian, Paraguayan and Uruguayan Guaraní Aquifer System, and the U.S.-Mexican Hueco-Bolsón Aquifer. These case-studies highlight three different approaches to managing these resources, and suggest that the development of governance mechanisms always depends on the availability of mutually-recognized assessments of transboundary resources. Indeed, this sort of knowledge is necessary for the common framing of groundwater management problems and can foster the creation of cooperative solutions. More generally, the selected cases expose that different hydrogeologic conditions, institutional frameworks and geopolitics dictate distinct logics in the development of groundwater agreements. However, the cases also show that the implementation of joint, or coordinated, governance mechanisms is effectively determined by local-level users and decision-makers. Actors at the local level with an interest in the resolution of transboundary groundwater problems can sometimes bypass formal institutional restrictions and implement less formal, albeit functional, governance solutions. They can also shield themselves in geopolitical differences or the incompatibility of institutional settings to prevent the development and effective implementation of transboundary groundwater governance initiatives that threaten their interests.

[1] Regimes are defined by Young as "social institutions that consist of agreed upon principles, norms, rules, decision-making procedures, and programs that govern the interactions of actors in specific issue-areas" (1989: 5-6).

3. THREE APPROACHES TO TRANSBOUNDARY GROUNDWATER MANAGEMENT

3.1. The Génévois Aquifer: Governance through a Formal Groundwater Management Agreement

The Génévois aquifer is located at the border of the canton of Geneva, Switzerland, and several French collectivities in the Haute-Savoie region. Relatively small in size, it spans across about 19 kilometers and is used to complement the freshwater supply of the city of Geneva and a few French towns along the border. The aquifer's waters are relatively close to the surface, at depths that range from 15 to 80 meters, and are recharged naturally principally from infiltrations of the Arve River, a torrential river fed by the Alps' glaciers (Amberger, et al. 1981, De Los Cobos 2002). The main management problem of the Génévois aquifer is the over-pumping of its waters. During the sixties and seventies, the water levels in the aquifer began to decrease significantly as a consequence of higher demand from the growing regional urban centers. The lowering water table jeopardized infrastructure investments, namely wells and water supply infrastructure (De Los Cobos 2002) and exposed the need to find solutions to guarantee regional urban freshwater supply.

The deteriorating conditions of the aquifer and its acknowledged bi-national nature pushed regional stakeholders and policy-makers to consider alternative strategies for its protection and sustained exploitation. In 1978, the region of Haute-Savoie and the Geneva Canton signed a thirty-year renewable agreement, the first of its kind for a transboundary aquifer, which mandated the construction of an artificial recharge facility (managed and constructed by the Swiss) and established a water pricing scheme to charge the French for groundwater exploitations beyond a specific quota (Wohlwend 2002). The artificial recharge plant compensated over-pumping of the aquifer with the injection of waters from the Arve River into the aquifer. The agreement regulated groundwater exploitation, the protection of the resource, and engaged the Canton of Geneva and neighbouring French collectivities in the systematic exchange of information about the use of the aquifer[2].

Multiple factors contributed to the formulation of the agreement. The artificial recharge of aquifers had been successfully implemented in other Swiss aquifers, and tests showed that the aquifer would respond appropriately to injection. In addition, in 1975, the construction of the artificial recharge facility cost about 20 million Swiss francs, while a treatment plant to exploit waters from the Léman Lake was estimated at 150 million Swiss francs (De Los Cobos 2002). The chosen approach also permitted the city of Geneva to maintain a diversified water supply that insured it against unexpected contamination of the surface water sources. Furthermore, the agreement guaranteed the continued exploitation of wells, which depends on the maintenance of certain water levels in the aquifer. Knowledge about the aquifer's properties and the economic and strategic viability of the recharge solution supported decision-making. The agreement permitted the parties to focus on the resolution of the concrete technical issues of groundwater management at the local level. However, although the legality of the agreement was never effectively questioned, its actual legal validity remained dubious until the agreement's renewal in 2008. This is because while the canton of Geneva had the legal authority to engage in international negotiations, the French local-level counterparts lacked, nominally, the autonomy to sign international agreements. The agreement was signed by the Prefect of Haute-Savoie. To summarize, in this case the development and implementation of the agreement was possible because of the national-level indifference about the issues of transboundary groundwater management on the French-Swiss border, good knowledge of hydrogeologic conditions, and local interest in effective management of the transboundary aquifer.

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[2] In 2008, after 30 years, the agreement was renewed with minor adjustments. The content of the agreement was mostly preserved. The addendums specified the legal precedents that legitimize the agreement.

3.2. The Guaraní Aquifer System: Local-Level Coordination of Groundwater Governance

The Guaraní Aquifer System spans over one million square kilometers underneath Argentina, Brazil, Paraguay and Uruguay, and has an estimated total reserve of more than 30 trillion cubic meters of water, 90 percent of which is potable (Cox, et al. 2009). As a consequence of its size and complex geologic composition, the aquifer's groundwater can be found at different depths and with different and diverse chemical compositions, depending on the location. For example, at the Brazilian city of Riberão Preto, the Guaraní aquifer is relatively shallow and is used for urban water supply. It is threatened by potential pollution, contamination and over-drafting. In contrast, at the border of Uruguay and Argentina, the sister cities of Salto and Concordia exploit the aquifer for geothermal tourism. There, the Guaraní's water-bearing formations are at depths of more than 200 meters and are confined by a thick layer of basalt. The management problems include the competitive use of the aquifer and the lack of both standardized well perforation techniques and control of discharges.

The increasing acknowledgement of the transboundary nature of the aquifer and the diversity of issues posed by groundwater management triggered proposals for the creation of a joint management framework for the aquifer. Talks about the aquifer were initially fuelled during the nineties by regional hydrogeologists. They led, in 2001, to a project supported by the four countries and financed by the Global Environmental Fund to study the Guaraní Aquifer System. The "Environmental Protection and Sustainable Management of the Guaraní Aquifer System Project" was preventive in nature: it would create a knowledge base to support protection of the aquifer and to prevent potential conflicts that could arise between the countries. The project successfully concluded in 2009 and permitted the characterization of the aquifer and the development of management solutions. It also created awareness of groundwater issues at both the local and national levels.

Initial treatment of the Guaraní aquifer in political debates framed the challenges of its management in terms of upstream-downstream dynamics (as if they were surface waters); the countries voiced fears that competitive exploitation of the shared resource could hinder them. Research derived from the joint project showed, however, that the aquifer's general lateral flow of water is naturally slow, as dictated by the hydraulic gradient, and significantly accelerates only with human intervention at the local level (Cox, et al. 2009, Tujchneider, et al. 2007). As a result, for local transboundary areas with potential risk of conflict, the countries developed specific coordinated policies. For example, the cities of Concordia and Salta agreed upon common regulation of drilling practices, waste disposal and the establishment of minimum distances between wells. The city of Riberão Preto began regulating groundwater abstraction and the protection of the aquifer's local recharge zones. In lieu of a formal agreement for the joint management of the aquifer, the countries opted for specific local-level operational arrangements. The official joint assessment simplified the common framing of groundwater problems and simplified policy-making at the local level. It also helped dispel ill-informed assumptions about the aquifer's features that, paradoxically, had initially mobilized the countries to undertake further research about the transboundary aquifer. In this case, although the formalization of an agreement did not occur, countries introduced groundwater into their agendas and coordinated policies for its management. The compatibility of institutional frameworks was not an issue because transboundary impacts were restricted to border cities with the autonomy and will to enact coordinated policies. In this case, hydrogeologic information helped reframe geopolitical concerns and supported the creation and implementation of local-level solutions for the management of the transboundary aquifer.

3.3. Hueco-Bolsón: Informal Cooperation for Groundwater Governance

The Hueco-Bolsón Aquifer is located underneath the sister cities of El Paso, Texas, and Ciudad Juárez, Chihuahua, in a region known as the "Paso del Norte" at the center of the U.S.-Mexico border and the northern section of the Chihuahua Desert biome. The aquifer spans between two U.S. states, New Mexico and Texas, and the Mexican state of Chihuahua. Aquifer recharge is limited and its reserves consist mostly of "fossil" waters that accumulated during the more humid conditions of the Pleistocene (Cliett 1969). In fact, the aquifer freshwaters constitute only a fraction of the total groundwater reserve, and they are being progressively mined. Measurements show the aquifer's water level has been reduced by as much as 45 meters since the nineteen forties, and water quality continues to deteriorate (Chavez 2000). Consequently, for the main users of the aquifer, the cities of El Paso and Ciudad Juárez, management challenges include the establishment of limits to groundwater pumping, the definition of allocation principles among different users (irrigators, cities, industry), and the minimization of groundwater treatment costs.

Regional water regulation is a sensitive and highly contentious political issue. In fact, the region's water availability is restricted not only due to the region's arid conditions, but also by existing surface water allocation agreements. Agreements signed in 1906 and 1944, which regulate the use and allocation of surface waters between the U.S. and Mexico, have asymmetrically allocated the shared surface waters between the two countries, and local-level stakeholders fear that groundwater regulation will impose new limits and inequalities in access to transboundary groundwater resources. In addition, new overarching agreements for groundwater would defy established ownership rules and historical power allocations (Mumme 2003). Indeed, the rules governing groundwater on both sides of the border and among different U.S. states are incompatible (Milman and Scott 2010, Schlager 2005). While groundwaters are controlled by the federal government in Mexico, the American federal government has limited jurisdiction over them. In the U.S., authority over groundwater depends on individual state legislation. In Texas, groundwater property rights are akin to those of mineral resources and provide property owners with unfettered rights to pumping, while in New Mexico, groundwater is subject to adjudication by the State Engineer's office.

The geopolitical tensions and institutional incompatibilities have not, however, stopped local-level actors from acknowledging the problems of the Hueco-Bolsón Aquifer. Indeed, understanding the complexity of the institutional situation and pressing environmental conditions, local water planners have managed to develop informal information-sharing mechanisms about hydrogeologic conditions, as well as about their long-term water supply planning strategies. In 1997 and 1998, the water utilities of Ciudad Juárez and El Paso signed agreements, under the auspices of the International Boundary and Water Commission, for the exchange of data to update and refine the hydrogeologic characterization of the aquifer[3]**.** These arrangements did not seek to regulate groundwater exploitation. The local water utilities have independently pursued strategies to deal with the increasing costs of the exploitation of the shared aquifer. Although the transboundary governance concerns are similar, the parties have failed to cooperate in the creation of joint solutions to resolve groundwater problems. In this case, large-scale geopolitical tensions and institutional incompatibilities, as well as local-level concerns about the potential threats posed by groundwater regulation to current exploitation schemes have prevented the development of cooperative solutions.

4. KNOWLEDGE AND THE LOCAL IN TRANSBOUNDARY GROUNDWATER GOVERNANCE

[3] Respectively, the "*Joint Report Of The Principal Engineers Regarding Information Exchange And Mathematical Modeling In The El Paso, Texas And Ciudad Juarez, Chihuahua Area Aquifer*" from 1997, and the "*Transboundary Aquifers and Binational Ground Water Database For the City of El Paso / Ciudad Juarez Area Report*" of 1998. More recently, the U.S. Congress passed a "*Transboundary Aquifer Assessment Act*" aimed at encouraging and funding research of the transboundary groundwater resources along the US-Mexico border. The 2008 Act provides financial support for the regional universities to develop joint-research projects about transboundary groundwaters.

Dealing with groundwater presents challenges different than those posed by surface watersheds. Indeed, transboundary groundwater problems depend on complex geographically-specific factors (Llamas and Custodio 2003). Although the lack of knowledge about these elements makes governance agreements either vacuous or impossible, controversies over what constitutes politically legitimate knowledge and how to translate it into formal international arrangements are recurring issues of environmental governance. The understanding of the hydrogeologic features of the Guaraní Aquifer System, the Hueco-Bolsón and the Génévois Aquifer does not necessarily lead to joint management solutions. In all cases, however, because groundwater problems are always geographically specific, the local level is the scale on which governance effectively operates. Scientific knowledge is necessary for the specification of the problems and reaching consensuses, but its translation into policy is conditioned by institutions and politics.

Politics and institutions condition local-level action. Nonetheless, actors at the local level are ultimately those that make or break transboundary groundwater regimes. The first and one of the few formal agreements exclusively dedicated to transboundary groundwaters, the agreement for the Génévois aquifer, was signed by parties whose legal authority was questionable. Regardless, the 1978 agreement was implemented because the substantive content of the agreement could be enforced without the intervention of third parties. The canton of Geneva had the resources to build and manage the artificial recharge facility, while the French collectivities had the ability to pay for groundwater abstractions beyond the pre-specified quota. The extant institutional framework was not a barrier to the implementation of the agreement. In the case of the Guaraní Aquifer, once the countries understood that transboundary impacts (geopolitical concerns) were limited, national-level authorities eschewed the need to formalize a large-scale agreement. Local authorities ultimately coordinated rule-making. In the case of the Hueco-Bolsón Aquifer, notwithstanding geopolitical tensions and institutional incompatibilities, joint-solutions have lacked because local stakeholders actively refuse to regulations that may affect local interests of autonomy and the maintenance of current exploitation patterns.

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TOPIC 3
Building capacities and strengthening institutions

A Critical Analysis of the 2008 Draft Articles on the Law of Transboundary Aquifers in the European Context

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ABSTRACT

In 2008, the *International Law Commission* adopted a set of 19 articles that aim to contribute to the codification and development of the law governing transboundary aquifers. In 2009, the UN General Assembly a) took note of the draft articles; b) commended them to the attention of governments without prejudice to the question of their future adoption or other appropriate action; c) encouraged the states concerned to make appropriate bilateral or regional management arrangements, taking into account the draft articles; and d) decided provisionally to examine the question of the form that might be given to those articles at its 66th Session. The ILC Draft Articles offer an important and valuable basis for the progressive development of international groundwater law, including through the negotiation of future agreements applying and adjusting draft articles' provisions to specific regions or transboundary aquifers. In this sense, both the ILC Draft Articles and the above UNGA resolution address the complementary relationship between universal and regional (or aquifer-specific) legal instruments. In this context, the paper will conduct a comparative analysis and evaluate the relationship between the ILC Draft Articles and relevant laws applicable to the UNECE region, with special focus on EU legal instruments. The analysis will show that these global and regional developments are mutually supportive, but some important differences exist in the extent and content of the obligations under each of them. The paper will consider such differences, in particular, in the context of requirements pertaining to the monitoring and sustainable use of recharging aquifers.

Key words: Groundwater; Draft articles; WFD; sustainable use; monitoring

1. INTRODUCTION

In the past ten years or so, there have been significant developments with respect to improving the legal framework for managing international groundwaters. Most notable among these is the work of the International Law Commission's (ILC) Draft articles on the Law of Transboundary Aquifers ("Draft articles"), set forth in 2008. In some ways, the draft articles attempt to fill a gap left by the 1997 Convention on the Law of the Non-Navigational Uses of International Watercourses ("1997 Convention") as the latter deals only with groundwater insofar as it is connected to shared surface waters. At the regional level, improvements in the water management in the European Union have been driven by the 2000 Water Framework Directive ("WFD") and, to a lesser extent, more recently, by the associated Groundwater Directive ("GWD"). The WFD and the GWD represent specific cases of supra-national law compared to the UNECE international legal framework on water.

2. OBJECTIVES

The aim of this paper is to examine the ILC Draft Articles and the WFD to elucidate two contrasting aspects of groundwater management, in particular: the extent to which each promotes and facilitates sustainable development, and the respective robustness of the monitoring frameworks established for the appropriate management of shared aquifers and for ensuring compliance.

The ILC Draft Articles offer a potentially critical approach to allow States to better manage the transboundary aquifers underlying their respective territories. States are obliged to use shared aquifers in accordance with the principle of equitable and reasonable utilization, the objective being to maximize "the long-term benefits from the use of the water contained therein" (art.4) as part of the broader global push for optimal and sustainable development of water resources (preamble). The WFD, on the other hand, is focused principally on the question of the quality of both surface and groundwaters, managed in an integrated way through river basin districts. Achievement of the directive's environmental objectives drives the programmes of measures to be prepared by Member States, in contrast to the draft articles' focus on the undefined "effective functioning" of recharging aquifers or maximization of the benefits to be derived from aquifers more broadly. While the WFD's basin districts may be intra-national, the reality in continental Europe is that the vast majority of the region is covered by international basin districts, either between Member States or between them and non-members. It is important, therefore, to compare the approaches advocated by the draft articles with those under the WFD system. The following analysis will examine the degree to which sustainable resource use is facilitated by the ILC Draft Articles and European statutes, especially in relation to recharging aquifers, before going on to assess the respective frameworks for monitoring and data exchange. Uncertainty over the extent of aquifers and the effect of use means that effective monitoring is crucial, particularly in transboundary contexts.

3. SUSTAINABILITY OF RECHARGING AQUIFERS

Art. 4 of the ILC Draft Articles incorporates the principle of reasonable and equitable utilization, stating as follows:

> Aquifer States shall utilize transboundary aquifers or aquifer systems according to the principle of equitable and reasonable utilization, as follows:
> (*a*) They shall utilize transboundary aquifers or aquifer systems in a manner that is consistent with the equitable and reasonable accrual of benefits therefrom to the aquifer States concerned;
> (*b*) *They shall aim at maximizing the long-term benefits derived from the use of water contained therein*;
> (*c*) They shall establish individually or jointly a comprehensive utilization plan, taking into account present and future needs of, and alternative water sources for, the aquifer States; and
> (*d*) *They shall not utilize a recharging transboundary aquifer or aquifer system at a level that would prevent continuance of its effective functioning*. (emphasis added)

While this makes no direct reference to the idea of sustainability in the use of recharging aquifers, two further provisions in the instrument make explicit mention of the principle: the Preamble and draft Article 7(1), which establishes a general obligation to cooperate.

Notwithstanding the latter two provisions, from the commentaries that accompany the Draft articles, it is clear that the concept of yield maximization, rather than a strict rule of sustainable use, would govern the utilization of both recharging and non-recharging aquifers: "*it is not necessary to limit the level of utilization to the level of recharge"* (ILC, 2008). In this sense, Art. 4 does not include a limitation on extractions to either respect the level of recharge, "*even as an average over a period of years*" (ILC, 2008) or to consider the rates of the aquifer's discharge into connected bodies of water. The illuminating commentaries take this to the logical extreme by leaving aquifer states to determine the nature of the benefits to be protected, enjoyed and over what period (ILC, 2008). This approach leaves too much room for discretion and potential abuse by governments that, in making such decisions, might overlook the needs of vulnerable communities and fragile ecosystems dependent on the aquifer in question.

This decision to favor the approach of maximization of long-term benefits to the detriment of sustainable use was explained by Special Rapporteur Yamada. In his Third Report, he opined that States should not be limited by a strict rule of sustainable use, as this would "*in reality deny aquifer states the right to utilize the valuable water resource, accumulated over the years*" (Yamada, 2005, para.22). In language that is reflected in the final Art.4(d), he instead stated that aquifers "*should be kept in a condition to maintain*" their function. This complicates matters, instead of imposing a solid environmental standard, when requiring states not to utilize a recharging transboundary aquifer at a level that would prevent continuance of its effective functioning: "*rapidly falling water tables might not appear until some years after a serious overdraft begins, by which time it might be too late to do much about it*". (ILA, 2008).

In contrast, Art. 4(ii) of the WFD requires Member States to balance abstraction and recharge rates "*with the aim of achieving good groundwater status".* In addition, Member States have to take into account the amount of water that the aquifer discharges into connected surface waters. Annex V, Para.2.1.2. defines *good quantitative status* for groundwater as "*the level of groundwater in the groundwater body [being] such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction*." The definition of "available groundwater resource" in Art. 2, however, also introduces ecological requirements: "*the long-term annual average rate of overall recharge of the body of groundwater less the long-term annual rate of flow required to achieve the ecological quality objectives for associated surface waters specified under Article 4*". The WFD thus goes further than simply balancing recharge and abstraction, but reduces the potential abstraction rate still further to accommodate ecological requirements in relation to linked surface waters. The WFD approach seems more sensible. Under the draft articles, aquifer states would be in a position to decide among themselves that a certain aquifer could be mined for irrigation purposes for a certain period, leading up to its exhaustion beyond that time. This could have serious impacts on dependent ecosystems, however. This is especially true since, while draft Art. 10 requires States to "*take all appropriate measures ... to ensure that the quality and quantity of water retained in an aquifer…, as well as that released through its discharge zones, are sufficient to protect and preserve*" the ecosystems contained in or dependent upon that aquifer, the accompanying commentaries point out that this obligation extends only to "relevant" ecosystems, allowing States flexibility for other justifiable uses (ILC, 2008).

During negotiations on the draft articles, numerous delegations, including from European nations, voiced their support for the principle of sustainable use to be a fundamental cornerstone of the draft articles. The ambiguity of the term "effective functioning" was also recognized (ILC, 2008, A/CN.4/595, p.11, 13, 25). The Netherlands pointed to a potential conflict between the draft articles and the 1997 Convention. As the draft articles stand and if they were to prevail over the convention, aquifers that are transboundary *per se* would be subject to a less strict standard – that of maximization of long-term benefits – than those domestic aquifers connected to international watercourses. The latter type of aquifer does not fall under the scope of the draft articles. Therefore, the principle of sustainable use, as codified in Art. 5 of the 1997 Convention, would apply in such cases. This state of affairs would go against the very motivations for initiating the development of the draft articles – a process intended to apply and adjust the convention to the special characteristics of groundwater systems, which are far more vulnerable to irreversible harm than surface waters.

The idea of maximizing the yield in the long-term is appropriate in the case of non-renewable resources, such as fossil aquifers. Transboundary recharging aquifers, however, should be subject to the principle of sustainable use. As the Preamble of the WFD highlights, "*surface waters and groundwaters are in principle renewable natural resources*". For recharging aquifers, abstractions that consider only the formation's storage capacity over the years, i.e., which do not reflect *current* recharge and discharge rates, disregard the aquifer's capacity for natural renewal, leading to its gradual exhaustion. Therefore, maintaining, to the extent possible, an overall balance between rates of extraction and discharge, and actual rates of natural or artificial recharge is vital for ensuring the *conservation* of renewable groundwater resources. Hence, the authors favor the WFD's approach of applying the concept of sustainability, rather than that of mere maximization of long-term benefits, to *recharging* aquifers.

Yet, the question remains as to how international groundwater law will evolve. In the interest of the sustainability of recharging aquifers, allowing for abstractions (and discharges) to exceed the rate of recharge should not develop into a rule of customary law, but rather be seen as an exception. Such an exception would apply, e.g., to cases of prolonged drought and when sustainable and feasible alternatives for meeting vital human needs are absent. Moving beyond recharging aquifers, "*customary international law actually imposes a clear and rather strong duty to exploit all resources, including aquifers, sustainably*" (ILC, 2008, p.8). For example, Art. 5(1) of the 1997 Convention refers to "*optimum* and *sustainable* utilization" as the fundamental goal to be attained through the equitable and reasonable use and development of international watercourses and any related water bodies, including aquifers. In its turn, Art.40(1) of the Berlin Rules calls on states to "give effect to the principle of sustainability in managing aquifers, taking into account natural and artificial recharge." (ILA, 2004)

Existing international agreements, including among those governing specific European river basins, follow the same approach, including, e.g., the *Danube River Protection Convention* and the *Convention for the Cooperation for the Protection and Sustainable Use of the Waters of Portuguese-Spanish Hydrological Basins*. At the regional level, the UNECE Water Convention incorporates the principle of sustainable water management in Art.3(1)(i). Therefore, countries should only exceed actual recharge rates under exceptional circumstances, such as emergency situations. In such a case, there should be a requirement, once the crisis had passed, for the relevant users to compensate for periods of overexploitation by limiting their extractions. For instance, recharge during wet seasons or wet years, when groundwater requirements are commonly less significant, could make up for excessive extractions during a dry season or dry years, when recharge is at its lowest and water needs tend to be higher. (ILA, 2008) Under the WFD, for example, Art.4(7) creates an exception to the rule of sustainability, carefully establishing the conditions under which countries would be exempt from complying with that rule.

4. MONITORING AND ASSESSMENT

In contrast to the 1997 Convention, which only provides for the regular exchange of information and data among riparian States (Art.9), the ILC Draft Articles require aquifer States to establish monitoring activities on transboundary aquifers or aquifer systems (Art.13). Monitoring is, in fact, an essential requirement for the proper management and protection of water resources, especially groundwater. Monitoring may be carried out jointly or individually (Art.13(1)). When a joint mechanism does not exist, States are obligated to share certain information on the characteristics (Art.8(1)) and uses of the aquifer with the other aquifer States concerned (Art.13). Harmonized standards and methodology as well as an agreed conceptual model among aquifer States (Art.13(2)) help to assess the results of the monitoring.

Several instruments applicable to the European region highlight the importance of water resources monitoring. For example, Art.11 of the 1992 Water Convention requires parties to "*establish and implement joint programmes for monitoring the conditions of transboundary waters*." In order to facilitate the implementation and the design of monitoring programmes by UNECE members, the *2000 Guidelines on Monitoring and Assessment of Transboundary Groundwaters* and the *2006 Strategies for Monitoring and Assessment of Transboundary Rivers, Lakes and Groundwaters* have been developed. In the EU context, monitoring is essential in order to meet the objective of the "good groundwater status" by 2015 (Art.4(1)(b)(ii)). Member States must ensure the establishment of monitoring programmes covering both the quantity and chemical status of groundwater bodies within each river basin district (Art.8(1)). In this context, States are required to set up the groundwater level monitoring network, assessing the quantitative status; and the surveillance and operational monitoring systems, the aim of which is to provide a "coherent and comprehensive overview" of the chemical status of groundwaters (Sections 2.2 and 2.4, Annex V, WFD).

The WFD contains general provisions on the pollution of groundwaters, providing for the adoption of specific measures to prevent and control groundwater contamination (Art.17(1)), as further refined in the new Groundwater Directive (GWD). According to this directive, the monitoring programmes should be designed to identify "*significant and sustained upward trends in concentrations of the pollutants*" (Art.1, Annex IV, part A). Other than with respect to nitrates and pesticides, the directive does not impose uniform standards on the limitations of pollutants, leaving member States to establish threshold values for the particular polluting substances that are most locally problematic for them, in the context of particular rivers if necessary. If groundwater quality standards relating to pesticides and nitrates are not adequate for achieving the environmental objectives set out in WFD, Member States must establish more stringent values (Art.3, Annex I, GWD).

Although the WFD and the GWD establish a common approach on monitoring, they do not mandate joint monitoring activities on transboundary groundwater. Nevertheless, the GWD points out that in the case of groundwater bodies "*shared by two or more member States and for bodies of groundwater within which groundwater flows across a member State's boundary*", threshold values on pollutants must be developed "in coordination" between member States (Art.3(3)). Member States "*may, for this purpose, use existing structures stemming from international agreements*" (Art.3(4)), WFD). When a groundwater body extends beyond the boundaries of the Community, threshold values have to be decided "*in coordination with the non-member State(s) concerned*" (Art.3(4)), GWD). In order to facilitate the obligations on monitoring, a guidance document under the umbrella of the Common Implementation Strategy regroups the Member States of the EU, Norway, Switzerland and the countries applying for accession (Guidance Document n°15 on Groundwater Monitoring, 2007).

Member States should coordinate their monitoring programmes for international river basin districts including when they cover the territory of non-Member States. In this sense, the Danube basin monitoring programme under the 1994 Danube River Protection Convention (Accompanying document, Commission Report, 2009, p. 52) – the Transnational Monitoring Network, established in 1995, constitutes a joint monitoring programme for 14 basin countries. In 2004, the Network has been upgraded in order to meet the requirements of the WFD. In 2006, an international monitoring programme was established under the 1999 International Convention for the Protection of the Rhine. In addition, under the 2008 Arrangement on the protection, utilisation, recharge and monitoring of the Franco-Swiss genevois aquifer, between the Canton of Geneva and the French Department of Haute Savoie, Swiss and French authorities perform a joint monitoring programme within their respective territories (Art.10).

Monitoring therefore plays a critical role for the sustainable management of groundwater resources (McCaffrey, 2009, p. 279). Although joint monitoring provides the ideal situation to gain knowledge regarding the conditions of transboundary groundwaters, it still represents an exception in Europe. The ILC Draft Articles and the UNECE instruments, emphasizing the importance of having joint monitoring and harmonized standards to assess data and information resulting from monitoring, may be useful when developing mechanisms on transboundary groundwaters shared among EU member States and non-member States as well as beyond the European Union.

5. CONCLUSIONS

Sustainable use of transboundary groundwater is clearly dependent on the quality of the monitoring infrastructure and capacity in place. The ILC Draft articles recognize the value of having joint monitoring programmes in place, and this may be useful in the EU context, where such joint programmes may be unusual. However, the capacity of the draft articles to deliver sustainable groundwater use irrespective of the monitoring network may be much more limited because of flaws in the standards that it demands. The ecology-driven approach of the WFD is of greater utility here as it takes fully into account the potential vulnerability of transboundary aquifers to political myopia at the expense of sustainability.On the other hand, EU Law provides a framework to achieve comprehensive protection of groundwater resources. However, EU member States are only required "to coordinate" their actions in dealing with transboundary groundwaters shared between EU Member States or with non-members. Although the ILC Draft Articles could not be quite as comprehensive as the WFD system, it provides a model for the adoption of treaties on transboundary aquifers, which are almost inexistent in the European region. At the same time, both universal and regional developments on ground waters may be of utility to fill the gaps in existing water agreements covering surface and groundwaters in the European region. In such cases, it is of crucial importance to adopt measures taking into account the specific characteristics of groundwaters, which are more vulnerable to risks of contamination and overexploitation than surface waters.

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Transbsoundary Guarani Aquifer System and Groundwater Management Mechanisms

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ABSTRACT

The Guarani Aquifer resources are public in all four involved countries: Argentina, Brazil, Paraguay and Uruguay. In general legal differences are applicable to mineral and water resources in those countries, and in both cases management is under national or state or local specific law and institutions. In absence of groundwater management schemes, national and state legislations tried to adapt for groundwater the same approaches valid for surface water. Aspects related to time and space scale are the main problems which occur and must be considered on the definition of adequate laws and management structures. For this reason hydrogeologists did not want to adopt surface water resources management structures and regulation. Using the umbrella of watershed committees or involving communities from both sides of national boundaries some groundwater local committees have been implemented and succeed. In fact those small structures are much more applicable to the scale of conflicts related to well field interference between some specific users. Groundwater use conflicts and environmental protection actions can be efficiently locally addressed with the support of national and subnational governments. Regional aspects of groundwater management and land use development strategies have also to be considered on cooperation strategies. According to the results of Environmental Protection and Sustainable Development of the Guarani Aquifer System Project (2003-2009) main aspects of the aquifer characteristics and functioning can be evaluated and related to current water management schemes. Consequently some guidelines and orientations can be proposed to enable new advances on groundwater management in the region. Those suggestions just confirm how suitable is the maxim "think global, act local" on groundwater protection and management.
Key words: Guarani Aquifer, Groundwater management, management local committees

1. INTRODUCTION

Argentina, Brazil, Paraguay and Uruguay agreed to execute the Environmental Protection and Sustainable Development of the trans-boundary Guarani Aquifer System (GAS) Project (Fig. 1: GAS localization). Significant part of the resource (US$13M) was provided by the Global Environment Facility (GEF), with the support of the World Bank, as implementation agency, and the Organization of the American States, as regional execution agency. The four beneficiary countries provided an active institutional participation as counterparts that reached more than donated amount (US$15M). The German Geological Survey and the International Atomic Energy Agency supported some specific studies. Based on a participatory process and knowledge development, the project allowed the countries to elaborate a Strategic Action Program (SAP), which was approved by the Project Steering Committee.

The project was executed in the period from March 2003 to January 2009 and all objectives were reached. A Quality Control Process was implemented by institutions of the four countries. All technical basic information was published in 26 volumes available in some bibliotheca in the region.

The Strategic Action Program (SAP) is the main project document that summarizes relevant management developments and priorities based on different knowledge advances. Its elaboration process involved directly more than 300 institutional representatives and experts from different areas. National representatives (water resources and environmental institutions, universities, civil society and NGOs) participated in the execution process through Project National Execution Units (including sub-national levels), that were established in each country to support execution process and promote integration of dispersed information from different institutions dealing with groundwater.

Into the SAP process Argentina, Brazil, Paraguay and Uruguay defined a list of national priorities to improve groundwater management; developed Guarani aquifer tailored made management instruments and finally agreed a cooperation structure to integrate all necessary efforts and to support technical instruments functioning and maintenance. The main treats of national and sub-national institutions now are the implementation of all Guarani management instruments, the priorities in national and sub-national level to strength groundwater and water resources management and cooperation framework proposed. The cooperation framework will support local, national, sub-national and regional priorities implementation and to develop an effective integration between different technical institutions responsible to groundwater management. August 2010, Argentina, Brazil, Paraguay and Uruguay signed the Guarani Aquifer Agreement and parliamentary approval is required in all countries. The agreement shows the way to strength Guarani Aquifer management and setup countries to proceed to the SAP implementation process.

Figure 1: GAS localization

2. BASIC KNOWLEDGE FOR MANAGEMENT

Main knowledge advances are related to a more precise definition of the limits and characteristics of the aquifer system; groundwater flow regimes; recharge and discharge areas; and changes in the use of water and soil in the region, extensively changed in recent decades. Knowledge internalization was promoted since project beginning through a comprehensive training and support program participation of institutions for water management in the countries and states. A quality control program included also representatives of technical scientific community in countries.

For the first time in the region, an integrated basic map was prepared with 191 topographic maps of the SAG in the countries, using a common projection and coordination system. The Guarani Aquifer System - SAG was defined jointly by stratigraphy specialists of the four countries as underground sandstone layers of the sedimentary basin of Parana-Chaco deposited. The development of the hydrogeological map of the Guarani Aquifer System resulted in the reduction of its total area to 1,087,879 km^2, of which approximately 21% in Argentina, 68% in Brazil, 8% and 3% in Paraguay in Uruguay. In outcrops of sandstones located at the edges of the SAG region with an area of 124,650 km^2, there are both recharge (83,500 km^2 or 67%) and groundwater discharge areas (33%), significant difference with respect to prior knowledge.

The static water reserves were calculated as higher than 29,551 km^3 (4,000 km^3 ±), but the deep recharge in 1.4 km^3/ano, indicating the occurrence of mining water in confined areas. The exploitable volumes were calculated in 2,014 km^3 (± 270 km^3), or 6% of SAG reserves, considering the maximum drawdown of water levels by pumping as 400 m. If current exploitation was maintained at 1.04 km^3/ano, through the 1,800 wells that reach the SAG (a total of 8,000 known wells in the region), available reserves could be exploited by more than 2,000 years at current patterns of consumption.

Mathematical models were developed to predict the behaviour of the aquifer in pilot areas considered as critical. In the thermal area of Concordia-Salto, municipalities border Argentina and Uruguay, the model simulates the construction of seven new wells will lead to a strong interference between the flows and water temperatures in local thermal wells over a period of 40 years. The model in Rivera-Santana do Livramento (border of Uruguay and Rio Grande do Sul) oriented the migration from wells toward an area protected in the western portion of municipal areas.

Based on regional studies carried out were established in seven major GAS areas that should guide the use and management of groundwater. Internally, each area presents special characteristics of flows, naturally slow through the rock pores and fissures. In the transition between the northern and southern areas, the groundwater flow is limited by the occurrence of deep tectonic movement (Arc de Rio Grande-Assumption) and were estimated between 45,000 and 405,000 m^3/day, less than 1% of the average flow of Parana River (173 million m^3/day). Other barriers smaller like lava dykes make wells on one side and other shows natural different features, as in Parana State. In confined areas, water is extracted from wells more than a thousand m deep and temperatures that can reach 50°C.

Regional studies were also supported on environmental isotopes behaviour and dating of water in the aquifer. The range of the water age is from recent in the outcrop area to max 38,000 years in Santa Catarina. In Mato Grosso do Sul as well as in Paraguay waters range is 4,000-28,000 years, where basalts windows allow direct recharge to the aquifer that feeds some springs flowing into Pantanal wetland.

Currently, 87% of water use from GAS occurs in Brazilian territory. In general, the main use of the waters of GAS is for public supply (66%). The industrial use (refrigerators, sugar/alcohol plants, etc.) reaches 16%, while in the countryside it is only 5%. Recreational uses in thermal areas have reached 13%, and 100% of the water in Argentina are intended for tourist use. In Paraguay and Uruguay more than 90% of GAS water is used to supply urban areas. In general, main concentrated threats on water quality of the SAG are related to the risk of manmade contamination in the outcrop zones. Regarding water availability greater risks are interference between wells and mining waters from areas under intensive use.

The assessment of changes in land use occurred between the years 1973 and 2007 and shows a continuous replacement of areas of dense forest and degraded (initially 42%) to agriculture (which now affects 47% of total area). The areas without cultivation remained virtually stable (reducing from 23 to 19%) and are concentrated in areas of Argentina, Uruguay and Rio Grande do Sul State.

The SAG is not a feature at risk of imminent exhaustion or contamination, despite being localized conflicts and problems that need support to be properly managed. However, the combination of increased water use, lack of adequate sanitation and amendment of land use can lead to a rapid modification of the current situation and the emergence of new critical areas.

3. MANAGEMENT INSTRUMENTS DEVELOPED

Developed management mechanisms need to be implemented and security measures enhanced to prevent the inappropriate use and harm same portions of the aquifer in a not too distant future. The resources of the SAG ensure superb opportunities to countries where it occurs. However, users and local communities must be engaged on rational use, as well as national governments, state and local authorities should strengthen the management and protection measures of groundwater in order to prevent emerging conflicts.

From a set of results and products developed and made available to countries, four specific tools have been selected and prioritized by countries, two technical, one to support local management and other to promote knowledge dissemination and capacity building on groundwater management. Each instrument should have the guidance of an Advisory Committee of Experts, established by countries. According to the Strategic Program of Action approved, each country will be responsible for providing the support needed to operate a management tool.

<u>Geographic Information System of the Guarani Aquifer System (SISAG)</u>: The objective of SISAG is to make information available of more than 8,000 wells to all different users in the region of the

SAG. The System is comprised of 32 workstations that were delivered to the government responsible institutions for water resources management in countries, states and provinces and local authorities as well as water supply companies). The information provided by the responsible country is automatically shared with other countries and shall be accessed by stakeholders through web (i.e. www.ana.gov.br). A Technical Advisory Committee was integrated by the institutions responsible for water information and support to the operation of SISAG will be provided by Argentina, which placed a support structure in the National Board of Yaciretá dam. In Brazil SISAG is integrated with Groundwater Information System (SIAGAS) developed by CPRM (Federal Geological Survey) and adopted by States for inclusion of data.

Network Monitoring and Mathematical Modelling (M & M): were initially selected and sampled 180 wells with static levels of data, exploitation and water quality in order to support the management of the Guarani aquifer by national institutions and responsible sub-national states. Additionally, mathematical models for simulation and prediction of changes in use of groundwater have been developed in regional and local levels in selected pilot areas. The national monitoring network under implementation by the Brazilian government, including State of Sao Paulo network will be completely integrated to the regional network. Brazil will be responsible for providing all required support to operate the instrument and to support the Network Technical Advisory Committee of Experts created by the countries.

Local Management Support Committees: In order to support the development of appropriate mechanisms for the protection of SAG in areas where significant impacts occur, the creation of Local Management Support Committees should be encouraged. The experience of the creation of local committees has been very positive in the pilot areas, as in Ribeirao Preto where the community has proposed and the State Water Resources Council approved zoning measures like protection areas and controlled use zones of groundwater in the county, to deal with water lowering in the aquifer (60 m occurred in the last 30 years in the downtown area). In Concordia (Argentina) - Salto (Uruguay) countries anticipated the definition of minimum distance between wells to avoid water level and temperature interference. Local committees in Ribeirao Preto and Itapúa shall be supported by Brazil and Paraguay respectively. The transboudary committees of Concordia (Argentina) - Salto (Uruguay) and Rivera (Uruguay) - Santana do Livramento (RS) shall be supported by Argentina and Uruguay respectively.

Capacity Building for Groundwater Management and Knowledge Dissemination: The importance of knowledge dissemination and empowerment of involved institutions have often been aspects highlighted by all country representatives to develop a better management of groundwater and Guarani aquifer resources. The Project provided a fruitful process of involving national responsible institution press officers, environmental journalists from general media, NGOs and academic sectors that formed a base for communicational necessary actions implementation. In the first phase the commission involved only the press officers of the national responsible institutions and need to be strengthened for a more comprehensive and decisive action. Paraguay will support the implementation of planned procedures, which can count on with the support and expertise of agencies and national institutions.

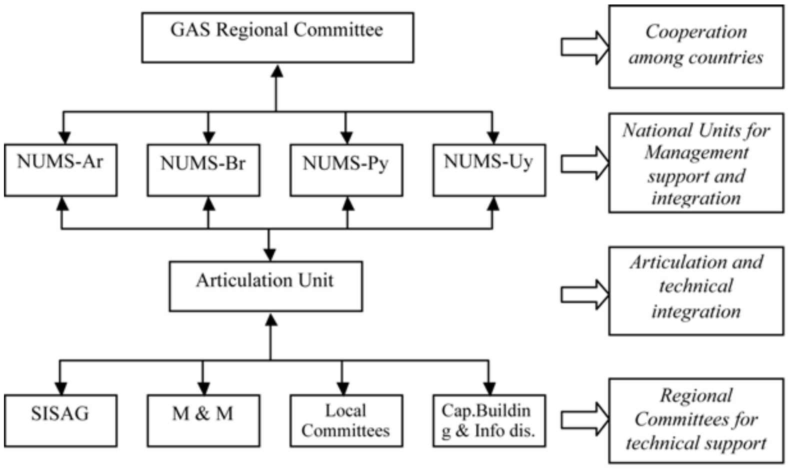
4. REGIONAL COOPERATION AND LOCAL MANAGEMENT CHALLENGES

The development of the Guarani aquifer management tolls depends on responsible countries integration efforts. The Strategic Action Program of the Guarani Aquifer established different priorities for national, state and local management development in the country and improved mechanisms for regional cooperation and adequate functioning of management tools developed.

All established priorities shall be incorporated into the actions of water resources management institutions in the various fields of public administration. Actions at country level must be integrated by a National Unity for Management Support to gate and integrate the efforts of all institutions, till now acting in a dispersed and fragmented manner in the use, management and protection of SAG. In the case of federal countries such as Argentina and Brazil, should be created Units of State management support, considering groundwater domain and necessities. At local level, institutional articulation shall be promoted by the Local Management Support Committees established in the pilot areas and those places where a real problem in groundwater use occurs.

As the National Units Management Assistance are installed by country and the Technical Advisory Committees by thematic managerial instruments, with experts from all countries, an Articulation Unit of technical nature was proposed to integrate actions, facilitate communication and support decision making process (Figure 2: Regional Cooperation Framework). According to the Guarani Aquifer Agreement signed in 2010 a Commission comprised by the four countries, shall coordinate the cooperation efforts. The commission will be established into the River Plate Intergovernmental Coordination Committee (CIC) level under the umbrella of the Treaty of the River Plate Basin (1969).

Figure 2: Regional cooperation framework



The Office of the Articulation Unit was installed in Montevideo with the support of Uruguay. After Guarani Aquifer Agreement countries are able to put office and integration efforts forward to support groundwater and Guarani Aquifer management at regional level.

5. CONCLUSIONS AND RECOMMENDATIONS

With the objective to support the decision making process for sustainable use and protection of the Guarani Aquifer national institutions have been installed groundwater management instruments in the countries. Correct functioning and up date process of those regional instruments necessarily depends on the cooperation and support institutional framework to be implemented in the next cooperation phase. The cooperation phase was recently launched by countries with the Guarani Aquifer Agreement signed on August, 2010. Set up all necessary coordination process to support the Strategic Action Program implementation in the countries is next main challenge.

The implementation of the four management instruments and SAP main actions will need to reach the lowest governmental level to be effective. The next implementation phase necessarily depends on well data collection, validation, analysis and dissemination of the information. Community in pilot and critical areas has to participate to make all information useful for users and all society. Considering all national available legislation different countries could consider to develop or detail some technical norms to support managerial process.

As compared to water resources in general, groundwater movement is very slow and interference scales are space and time limited. Despite of main instruments are the same, sustainable use and protection strategies of the Guarani Aquifer have to be adapted to be implemented at local scale. Very successful measures were implemented in the local project pilots (i.e. Ribeirao Preto, Concordia-Salto). Capacity building to social empowerment and local institution strengthening will be a key element to prepare the implementation of effective actions to the management and protection process of the Guarani Aquifer.

The Project serves as an excellent example for other trans-boundary aquifers. The basis of those aquifer developments must be technical to have an understanding of the resource. The management instruments: Geographic Information System of the Guarani Aquifer System, Monitoring Network and Mathematical Modelling, Local Management Support Committees and Capacity Building for Groundwater Management and Knowledge Dissemination are necessary for any decision making process and further developments. A peaceful integrated political decision can only be reached on such management base.

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The UN Watercourse Convention and the Draft Articles on Transboundary Aquifers: the way ahead
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ABSTRACT

In December 2008, the UN General Assembly adopted a Resolution on the law of transboundary aquifers including in its annex the 19 draft articles that had been prepared by the International Law Commission (ILC). In this Resolution, the UN GA "*encourages* the States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers, taking into account the provisions of these draft articles".

This happens at a time, when the existing UN Convention on the Law of the Non-Navigational Uses of International Watercourses (1997) has still not been ratified by enough countries to bring it into force. Specifically codifying and developing international water law, the UN Watercourse Convention is the key global legal instrument on transboundary water use, protection, preservation and management. Being the first and only comprehensive international agreement covering the regulation of the use of international watercourses with a global claim, the UN Watercourse Convention indeed constitutes a quantum leap in international water law.

For now, the ILC refrained from formulating provisions on the relationship between the Draft Articles and other international agreements. Yet, the ILC is conscious of the fact that by proposing the Draft Articles to govern all transboundary aquifers and aquifer systems regardless of whether they are hydraulically connected to international watercourses, the relationship between the Draft Articles and the UN Watercourse Convention will need to be determined at some point.

This article's objective is to look in the future and analyse what the relationship between the two sets of rules could be like. To this purpose, the presentation will discuss the scopes of application of both the Draft articles and the UN Watercourse Convention. It will then examine the material rules of both instruments and will come out with a conclusion on their complementary or contradictions, and will draw the consequences with possible solutions.
Key words: transboundary aquifers, Draft articles, UN Watercourse Convention, scope, rules.

1. INTRODUCTION

On 11 December 2008, the UN General Assembly ("UNGA") Resolution A/RES/63/124 on the Law of Transboundary Aquifers and included in its annex the Draft Articles ("Draft Articles"), which had been prepared by the International Law Commission ("ILC") as a set of international rules governing the utilization, management and protection of transboundary aquifers and aquifer systems. The Resolution "*encourages the States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers, taking into account the provisions of these articles*". The Resolutions equally decided "*to include in the provisional agenda of its sixty-sixth session* [i.e. 2011] *an item entitled "The law of transboundary aquifers" with a view to examining, inter alia, the question of the form that might be given to the draft articles*".

This happens at a time, when the already existing UN Convention on the Law of the Non-Navigational Uses of International Watercourses ("UN Watercourse Convention") of 1997 has still not been ratified by enough countries to bring it into force (19 States have ratified this Convention (out 35 required), the last one being Guinea Bissau on 19 May 2010)). Specifically codifying and developing international water law, the UN Watercourse Convention is the key global legal instrument on transboundary water use, protection, preservation and management. When adopting the Draft Drticles, the ILC refrained from formulating provisions on the relationship between the Draft Articles and other international agreements; yet, the ILC was conscious of the fact that by proposing the Draft Articles to govern all transboundary aquifers and aquifer systems regardless of whether they are hydraulically connected to international watercourses, the relationship between the Draft Articles and the UN Watercourse Convention will need to be determined at some point: "*when the present draft articles were to become a legally binding instrument, the need would arise to determine the relationship between the present draft articles and the 1997 Convention.*"

This paper's objective is to look in the future and analyse what this relationship between the two sets of rules could look like. To this purpose, the paper firstly discusses the scopes of application of both the Draft Articles and the UN Watercourse Convention, secondly examines the compatibility, complementarities and contradictions of the material provisions of both instruments, and thirdly presents some options for possible solutions.

2. SCOPES OF APPLICATION OF THE DRAFT ARTICLES AND THE UN WATERCOURSE CONVENTION WITH REGARD TO GROUNDWATERS

As per article 1, the Draft articles formulated by the ILC apply to transboundary aquifers and transboundary aquifer systems, whereas the UN Watercourse Convention covers international watercourses and their waters (article 1). While the respective scopes of both instruments seem to be clear and distinct, some uncertainties and possible overlaps remain.

2.1. The scope of the Draft Articles

When they finally adopted the definition of a watercourse during the preparation of the articles of UN Watercourse Convention, the members of the ILC recognized the importance of groundwater on earth and agreed on the necessity of regulating "unrelated groundwaters" (ILC 1993). In 1998, the Planning Group of the ILC identified shared natural resources as one of the topics for inclusion in the ILC's long-term program of work, (confined groundwater and single geological structures of oil and gas), recommending the preparation of a syllabus on the topic. The syllabus was prepared by Robert Rosenstock (ILC 2000) and submitted to the ILC in 2000. Based on this document, the Commission agreed to include the topic of "Shared Natural Resources" focusing on "confined" transboundary groundwater, oil and natural gas, to its program of work, and the topic was finally added to the agenda of the ILC in 2002.

"Confined" transboundary groundwaters

In his first report "*On outlines*", the Special Rapporteur drew the background of the topic of "shared natural resources" at the ILC focusing on transboundary groundwaters., Regarding groundwater, the Special Rapporteur indicated that he will cover water bodies that are shared by two States or more "but are not covered by article 2 (a) of the Convention on the Law of the Non-navigational Uses of International Watercourses" (Yamada 2003). In clear, the Special Rapporteur expressed here his intention to cover those groundwaters which are not included in the scope of the Watercourse Convention, with the idea of avoiding any overlap between the two instruments.

Transboundary aquifers

Based on the scientific information gathered from groundwater experts, the second report (2004) of the Special Rapporteur marks an evolution in his thinking, and his consideration of the topic. To start with, the Special Rapporteur droped the word "confined". He recognized the difference of meaning of the word as adopted by the Commission from its meaning for hydrogeologists. Moreover, "after consultation with hydrogeologists" (Yamada 2004) the Special Rapporteur introduced the concept of "aquifer" which is a «scientific and more precise term" as he mentioned in his oral introduction at the ILC (Stephan 2008). By choosing to deal with "transboundary aquifers" rather than "transboundary groundwaters", the Special Rapporteur widened in some way the scope of the topic as the term "aquifer" covers both the rock formation which stores waters and the waters in these formations; it is the container and its content. Furthermore, reverting to his first assumption (Yamada 2003) to cover those groundwaters which are not included in the scope of the Watercourse Convention; the Special Rapporteur acknowledged that it might need reconsideration in view of the hydrogeological scientific realities that were not considered during the preparation of the Watercourse Convention. He therefore expressed his intention to extend the study to all aquifers (Yamada 2004, ILC 2004). Finally, as per article 1 on scope, the Draft Articles apply to the use, protection and management of transboundary aquifers and aquifer systems, as well to other activities that may have an impact upon such aquifers or aquifer systems. This addition, which does not have its equivalence in the UN Watercourse Convention seemed necessary in order to properly manage and protect an aquifer or aquifer system (ILC 2008).

The Special Rapporteur engages in a way corresponding to the scientific reality, as for groundwater it is also necessary to consider the geological formation and not only the water itself.

2.2. The scope of the UN Watercourse Convention

The UN Watercourse Convention applies to international watercourses (Article 1 UN Watercourse Convention). A watercourse is defined as "*a system of surface waters and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus*" (Article 2(a) UN Watercourse Convention). It is international if parts of the watercourses are situated in different States (Article 2(b) UN Watercourse Convention).

It is clear from these definitions that certain, but not all groundwaters fall within the scope of the UN Watercourse Convention: the rules codified in the Convention do only apply to those groundwater resources that a part of a "*system*" with surface waters "*constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus*". On the one hand, for instance, so called "international aquifers" (i.e. aquifers which are part of a system where groundwater interacts with surface water that is at some point intersected by a boundary) fall under the scope of the UN Watercourse Convention (McCaffrey, 2007). On the other hand, aquifers which are not related to an international watercourse and intersected by an international boundary (sometimes wrongly referred to as "confined groundwater") are clearly not covered by the UN Watercourse Convention, as there is not link to surface water and they were intentionally omitted by the ILC (Mechlem, 2004). The same applies for non-recharging groundwaters, which are never related to a surface water body (Eckstein, 2005). Finally aquifers related to a surface water body and not flowing to a common terminus are also excluded from the scope of the Convention.

In many cases, however, it is unfortunately not clear from these definitions where exactly to draw the line between those groundwaters within the scope of the UN Watercourse Convention and those without its applicability (Behrmann, 2008). The ILC's commentary to the draft articles of the UN Watercourse Convention as well as its Resolution on transboundary confined groundwater (1994) give some guidance in this matter, but legal scholars have been able to demonstrate that there is still a substantial lack of clarity. The approach taken by the ILC to make the decision of whether to include or exclude groundwater from the scope of the UN Watercourse Convention on the basis of whether the groundwater is "*confined [...], meaning that which is unrelated to any surface water*", has met wide criticism (Eckstein, 2005). As a matter of fact, the terminology used by the ILC in this context is technically incorrect and confuses "confined" with "non-related aquifers": in hydrological terms, a confined aquifer is an aquifer overlain and underlain by an impervious or almost impervious formation, in which water is stored under pressure. Confinement is thus a matter of hydraulic state and not a question of being connected or related to bodies of surface water.

As a consequence of this lack of clarity, it is, for instance, unclear whether those aquifers which are intersected by international boundary and fed by water percolating from insignificant streams such as seasonal wadis are covered by the UN Watercourse Convention. The lack of a more comprehensive and hydrologically sound formulation suggests that the UN Watercourse Convention was formulated without a firm understanding of hydrologic reality.

3. COMPATIBILITY OF MATERIAL RULES

The UN Watercourse Convention has served as the basis for negotiations on the Draft Articles, which represents the continuation of the ILC's work on the law of the non-navigational uses of international watercourses (ILC, 2008). However, the dual applicability of independent and separately evolving international sets of rules bears obvious risks: in the best case, both instruments are complementary, in the worst case they are contradictory. This is why the ILC saw the need to determine the relationship between the present draft articles and the 1997 Convention, if the Draft Articles were to become a legally binding instrument (ILC 2008).

The language used in both instruments is not identical. This includes key provisions, such as the principle of equitable and reasonable utilization (codified in Articles 5 and 6 of the UN Watercourse Convention and Article 4 and 5 of the Draft Articles respectively) and the obligation not to cause significant harm (Article 7 of the UN Watercourse Convention and Article 6 of the Draft Articles) as well as the relationship between these two rules. Contrary to the UN Watercourse Convention, the Draft Articles include an article on "Sovereignty" (Article 3). Also, the provisions on planned measures (Articles 11 et seq. of the UN Watercourse Convention and Article 15 of the Draft Articles) and protection, preservation and management (Articles 20 et seq. of the UN Watercourse Convention and Article10 et seq. of the Draft Articles) differ considerably in their language.

These differences in the wording are not insignificant, as can be illustrated - by way of example – with regard to the aim of the balancing process of all important aspects defining the equitable and reasonable utilization. On the one hand, pursuant to the UN

Convention, the balancing process is aimed at the "*optimal and sustainable utilization*" of the waters "*and benefits therefrom*", both objectives having in common that they integrate economic and ecological interests. On the other hand, the Draft Articles postulate that aquifer States should "*aim at maximising the long-term benefits derived from the use of the water contained therein*" and should "*not utilize a recharging transboundary aquifer or aquifer system at a level that would prevent continuance of its effective functioning*".

4. OPTIONS

4.1. Amendment of the UN Watercourse Convention

While the optimal solution, namely one instrument that covers comprehensively surface and groundwater and their hydraulic linkages, is hardly feasible as the UN Watercourse Convention already exists, it has been suggested that the final status of the Draft Articles could be that of a protocol to UN Watercourse Convention (Dellapenna and Loures, 2007). A unified treatment of surface and underground waters would consider the interconnection and distinctive features and govern them under a coherent and integrated international legal system. Freshwater systems as hydrological units require integrated river basin management, i.e., conjunctive use and management of water systems as a integrated whole. This is true even for non-renewable aquifers, since comprehensive planning must consider all available water sources within a border region, so as to manage them all in an integrated fashion. As the UN Watercourse Convention has served as a primary basis of the elaboration of the transboundary aquifers articles and thus to the development of international groundwater law, adopting them as a protocol could be seen as a logical outcome of this process. However, the fact that the UN Watercourse Convention has not yet entered into force raises the question of whether its provisions truly represent international law applicable to any ground waters at all.

4.2. Broadly interpreted "watercourse"

A further option would be to interpret "*watercourse*" in the UN Watercourse Convention broadly, including (i) either all groundwater or at least (ii) all surface water - "related" groundwater.

The first option had been proposed by Rapporteur Rosenstock ("*Inclusion of 'unrelated' confined groundwaters is the bare minimum in the overall scheme of the management of all water resources in an integrated manner*", ILC - Rosenstock, 1994), but the ILC did not accept this proposal. The UN Watercourse Convention is heavily focused on surface water. Considering the very different characteristics of surface and ground water, a replication of the principles contained in the UN Watercourse Convention alone would probably not meet the specific requirements of groundwater management (Mechlem, 2004). What would be at least needed would by a greater stringency in the application of the UN Watercourse Convention rules in the case of groundwater, including a heightened standard of diligence (Articles 7, 20 et seq.), reversal of burden of proof for harm, more careful with planned measures, possibly even an exception to general priority of equitable utilisation rule over no harm-rule or et least a flexible application of the equitable utilisation principle to accommodate the special requirements of ground water, etc. (McCaffrey, 2007).

The second option would only exclude non-recharging aquifers from the scope of the UN Watercourse Convention. In this case, one would avoid that "watercourse" equals "drainage basin". Yet, one could argue that if – in order to avoid overlap – the scope of the Draft articles on Transboundary Aquifers is limited to those cases that are not covered by the UN Watercourse Convention, there will be one legal regime for groundwater not related to surface water (the new instrument) and another one for groundwater related to surface water (the UN Watercourse Convention). This situation would be problematic as the challenges faced in the management of the both types of groundwater are essentially the same. Also, an analysis of state practice shows that identical rules have been devised for all types of groundwater. After all, regulating essentially the same subject matter in two different ways should be avoided.

4.3. Broad scope of application of Draft Articles on Transboundary Aquifers

Some authors (Dellapenna and Loures 2007) suggested to expand the scope of the Draft Articles to include domestic aquifers linked to international watercourses. Such aquifers fall already under the scope of the UN Watercourse Convention. However under the provisions of this Convention, they do not receive the same level of protection that would apply under the Draft Articles. Such an extension of the scope of the draft articles to domestic aquifers seems unlikely in the current status of international law.

4.4. Overlapping scopes

It has been argued that the dual applicability of independent and separate evolving international instruments would create confusion, increasing the potential for interstate conflict, as well as fail in supporting and guiding states in applying integrated river basin management (Dellapenna and Loures, 2007). Also, one single regime would represent an economy in costs related to conferences of the parties and executive bodies and conformed to a recognized need to limit the proliferation of global environmental agreements.

Yet, one option would be to have the Draft Articles deal with all transboundary aquifers and to accept that there will be overlap with the UN Watercourse Convention (Eckstein, 2005). In the absence of a provision that indicates which regime takes precedence, contradictions between the two instruments could only be excluded and their complementarity ensured by consequently interpreting the Draft Articles in conformity with the UN Watercourse Convention.

This does not seem impossible. By way of example, the fact that contrary to the UN Watercourse Convention, the Draft Articles include an article on "Sovereignty" is less dramatic as it looks at first sight, as also the UN Watercourse Convention explicitly foresees the right of riparians to utilize the watercourse (Article 5 (2)). As the ILC puts it: "*the rule* [expresses an] *entitlement, namely that a watercourse State has the right, within its territory, to a reasonable and equitable share, or portion, of the uses and benefits of an international watercourse.*" (ILC – Draft Articles, 1994)

5. CONCLUSION

By way of conclusion, it can be shown that there is an overlap of the scopes of the Draft Articles and the UN Watercourse Convention when is comes to aquifers. To make matters worse, at least as far as the UN Watercourse Convention is concerned, it is not entirely clear where exactly to draw the line between those groundwaters within the scope of the UN Watercourse Convention and those without its applicability. The language used in both instruments is not identical and these differences in the wording are not insignificant. In order to avoid non-compatible, maybe even contradicting rules for the same object, possible solutions include (i) an amendment of the UN Watercourse Convention, (ii) a broad interpretation of the term "watercourse" in the UN Watercourse Convention, (iii) a wide scope of application of the Draft Articles, or (iv) a consequent interpretation of the Draft Articles in conformity with the UN Watercourse Convention. Option (iv) appeals through its pragmatism.

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North American Transnational Groundwater Issues: Cooperation and Conflict

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ABSTRACT

Transnational groundwater issues among Canada, the USA, and Mexico are being addressed using existing institutions and *ad hoc* approaches. The International Boundary and Water Commission (IBWC; USA-Mexico) and the International Joint Commission (IJC; USA-Canada) were originally established to consider surface water but have been adapted to consider groundwater. The North American Free Trade Agreement (NAFTA), implemented in 1994, may prove to be applicable to groundwater. Case studies illustrate specific examples and the issue of groundwater in the Great Lakes basin illustrates a more general situation. Examples of cooperation include the Abbotsford-Sumas aquifer (USA-Canada) and the Santa Cruz basin (Mexico-USA). A task force was created for the Abbotsford-Sumas aquifer to address water quality issues impacting both Canada and the USA. Mexico and the USA funded a study to address water quality problems in the Santa Cruz basin on the USA-Mexico border. NAFTA creates some interesting predicaments; the Hermosillo aquifer in the Mexican state of Sonora is a prime example. Although it is not a transnational aquifer, it supplies water for agricultural products that are in high demand in the USA due to the easing of trade restrictions. This increased demand has created internal conflict over the rights to and use of the water in the aquifer. An exception to bilateral transnational cooperation is the case of the Sierra Blanca nuclear waste facility in Texas. The USA's desire to site this facility relatively close to the border strained relations between Mexico and the USA. The IBWC, IJC, and individual stakeholder groups illustrate that transnational groundwater management is generally functioning well in North America. Although disagreements do exist, cooperation among countries is the general rule. The unknown is NAFTA's approach to groundwater as an economic good, which interjects yet another consideration into transnational groundwater management in North America.

Key words: transnational, North America, groundwater, management, cooperation

1. INTRODUCTION: INTERNATIONAL LAWS AND INSTITUTIONS

1.1 USA-Canada: The Boundary Waters Treaty of 1909 and the International Joint Commission

Transboundary water conflicts between the USA and Canada can occur all along the 8,000-kilometer border (Carroll, 1986). Rules concerning transboundary waters were created almost one hundred years ago with the signing of the Boundary Waters Treaty (BWT) of 1909. This treaty created the International Joint Commission (IJC) in Article IV, which is involved in administrative, quasi-judicial, arbitral, and investigative aspects of conflicts (Carroll, 1983). This mature governmental process includes scientific investigations into one country's impact on the water in another country and illustrates the results of an effective interface between government and science. However, this government-science interface is not always appropriately balanced; the IJC's power is limited to the role the governments want it to play—both governments must agree to request the IJC's intervention (Carroll, 1983). This can lead to an unbalanced interface when one country's stakeholders fail to persuade its government to bring the issue to the IJC for resolution; the government processes are more powerful than the societal processes.

The absence of groundwater from the treaty and the IJC's jurisdiction is a real issue. However, as Everts (1991) explains, both countries can agree to address groundwater issues. This has been done on a smaller scale, province to state, for the Abbotsford-Sumas aquifer underlying Washington, USA, and British Columbia, Canada (Campana *et al.,* 2007).

1.2 Mexico-USA: International Boundary and Water Commission

The USA and Mexico share an international border of 3,110 kilometers with river boundaries comprising around 66% of the border. The Rio Grande/Rio Bravo borders the USA state of Texas and the Mexican states of Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas for 2,020 kilometers. The Colorado River separates Arizona, USA, and Sonora, Mexico, for 27 kilometers. The international border between both countries was first established by the Treaty of Guadalupe Hidalgo in 1848, just prior to the end of the Mexican War.

The first border water issues dealt with the location of the international boundary. The Convention of November 12, 1884 was adopted to help deal with the ever-changing international boundary as a result of meandering by the Rio Grande and Colorado River (IBWC, 1884). Five years later, the International Boundary Commission was created in 1889 (changed to the International Boundary and Water Commission (IBWC) in 1944) to specifically deal with boundary and water issues (IBWC, 2005). The IBWC is also a mature governmental process that incorporates both scientific and societal processes into its decisions and actions.

Water use for irrigation was important to both countries and controversies surfaced in the late 1800s and early 1900s about the equitable distribution of water. The Convention of May 21, 1906 was the first treaty regarding water quantity and stated that the U.S. must deliver 74 million cubic meters (MCM) per year to Mexico via the Rio Grande (IBWC, 1906). The 1944 Treaty was more comprehensive and described specific actions that each country must take to reduce water sharing conflicts (IBWC, 1944). Water quality issues were addressed through the passage of "Minutes" or legally binding agreements between both countries. Specifically, water quality minutes addressed salinity from irrigation return flows and wastewater treatment plants on both sides of the border (IBWC 2005a; IBWC, 2005b).

1.3 North American Free Trade Agreement (NAFTA)

In 1994, the North American Free Trade Agreement (NAFTA) was adopted by Canada, Mexico, and the USA as a way of cooperating on trade issues. This agreement essentially removed tariffs to facilitate increased trading which would lead to greater economic opportunities for all three countries.

The parts of Mexico that stood to benefit the most from NAFTA are the states that border the USA Any USA or Canadian corporation could open a factory on the Mexican side and benefit financially from cheaper labor costs. 'Maquiladoras' (foreign-owned manufacturing facilities) had already been operating in Mexico since the 1960s, but they were required to take manufacturing wastes back into the country of origin. After the passage of NAFTA, the wastes could remain in Mexico. Given the differing environmental standards, many believed that the border area would become a dumping ground for USA companies who wanted a cheaper way to dispose of manufacturing wastes. However, the adoption of treaties and subsequent 'Minutes' have attempted to regulate these practices. This is an example using the government-science interface to restrain the economic emphasis of NAFTA.

2, NORTH AMERICAN TRANSNATIONAL GROUNDWATER: CASE STUDIES

2.1 Abbotsford-Sumas Aquifer

The Abbotsford-Sumas aquifer, in the Fraser River Basin, underlies British Columbia (Canada) and Washington State (USA); its water flows southward from Canada to the USA (fig. 1). The aquifer is unconfined and provides water for over 115,000 people (Mitchell *et al.,* 2003; Cox and Liebscher, 1999). The current concern is the high concentration of nitrate in the aquifer from agricultural practices in both British Columbia and Washington (Washington State Dept. of Ecology, 2003; Mitchell *et al.,* 2003). The presence of the Abbotsford-Sumas Aquifer International Task Force demonstrates the presence of cooperation (A-S Task Force, n.d.). This task force is the product of the 1992 Environmental Cooperation Agreement between the province and state and was created specifically to address aquifer transboundary problems (A-S Task Force, n.d.). The agreement covers the broad area of "groundwater protection" which can be expanded to include future issues.

An example of small-scale cooperation surrounding the protection of the aquifer is British Columbia's proposal to reclaim a gravel pit and transform it into Aldergrove Lake Regional Park, which would use biosolids and biosolids compost to re-vegetate the area (Van Ham *et al.,* 2000). The public on both sides of the border was concerned about the effects that biosolids would have on the aquifer's water quality in general and specifically for regions of the aquifer that people rely on for their drinking water (Van Ham *et al.,* 2000). In order to allay people's fears, open meetings were held and stakeholders (elected officials, Abbotsford-Sumas Aquifer International Task Force, residents within a one-kilometer radius of the park, and local and U.S. interest groups) were informed about the

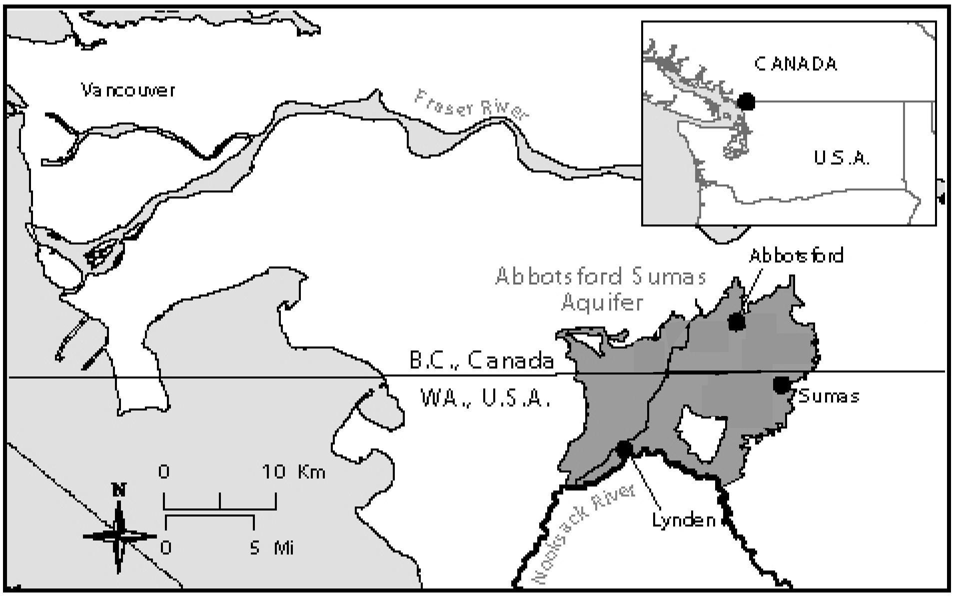

Figure 1. Abbotsford-Sumas aquifer, USA-Canada border.

project (Van Ham *et al.,* 2000). The project, which was shown to potentially improve the aquifer's water quality, was approved and demonstrates how open cooperation from the beginning of a project led to success. This open cooperation included governmental (the task force), societal (the initial concern and subsequent meetings), and scientific (the study on the impact of biosolids on the aquifer's water quality) elements. In this case, the elements were balanced—everyone was satisfied with the outcome and no element was used in isolation or at the expense of another element.

2.2 Santa Cruz River Basin

The border cities of Nogales, Arizona (USA) and Nogales, Sonora (Mexico) were the subject of a study completed by the Binational Technical Committee, headed by the Border Environment Cooperation Commission (BECC). This group, comprised of local, state and federal water agencies, developed a plan to mitigate wastewater runoff originating in Mexico and flowing into the U.S. (BECC, 2004). The purpose of this project is to fix existing leaky wastewater pipes on the Mexican side, which will in turn improve water quality in the Nogales Wash that flows into the USA. These actions used both government and scientific processes.

The project was jointly funded by the U.S. Environmental Protection Agency (EPA) and the Mexican government, and is an example of cooperation between both countries in response to deteriorating water quality on both sides of the border, and public health issues that arose due to the presence of untreated wastewater. This area was also the subject of the first binational groundwater quality monitoring project between the two countries and set the stage fixing the wastewater leaks in Nogales, Sonora (Castaneda, 1998).

Other aspects of this project will eventually bring more water to those on the Sonoran side by increasing groundwater pumping (Walker and Pavlakovich-Kochi, 2003). However, some in Arizona are worried that growing water use on the Sonoran side will lower water tables on the Arizona side, increasing pumping costs (Walker and Pavlakovich-Kochi, 2003). The direction of water flow in the transboundary aquifer is from south to north, with those in Sonora having the ability to use water first before it flows across the international border. This places those in Nogales, Arizona, vulnerable to the increasing population in Nogales, Sonora, especially since there is no agreement on the apportionment of groundwater. While governmental processes exist, an agreement would create more specific governmental processes in managing the transboundary groundwater in the Santa Cruz River basin. In addition, concerns by citizens on groundwater use may result in future societal processes playing a role in the management and instigating scientific studies on the impact of groundwater use by each country on the water table levels. This basin has all the factors required to create a trialogue (government, science, and society), but only two are currently in use.

2.3 Hermosillo Aquifer

The Hermosillo aquifer is located in the state of Sonora, Mexico (fig. 2) and does not straddle the USA-Mexico border. However, its use for agricultural production as a result of NAFTA has caused local conflict due to competing demands. This region typically grew crops for local consumption;

however, after the removal of trade barriers, many higher-valued fruits and vegetables replaced traditional crops and are primarily shipped to the USA for consumption. The change in what was produced led to the consolidation of many farms in the region with larger farms controlling most of the acreage. The resulting shift in agricultural production has placed a strain on the coastal aquifer with sea-water intrusion threatening many wellfields (Rodriguez, 2002; Steinich *et. al.,* 1998). At the same time, the municipal government has decided to expand its industrial sector and needs water to do so. The government proposed pumping salt-water from coastal wells and desalting the water; however, this has created tension with the growers who hold the current monopoly over the coastal aquifer.

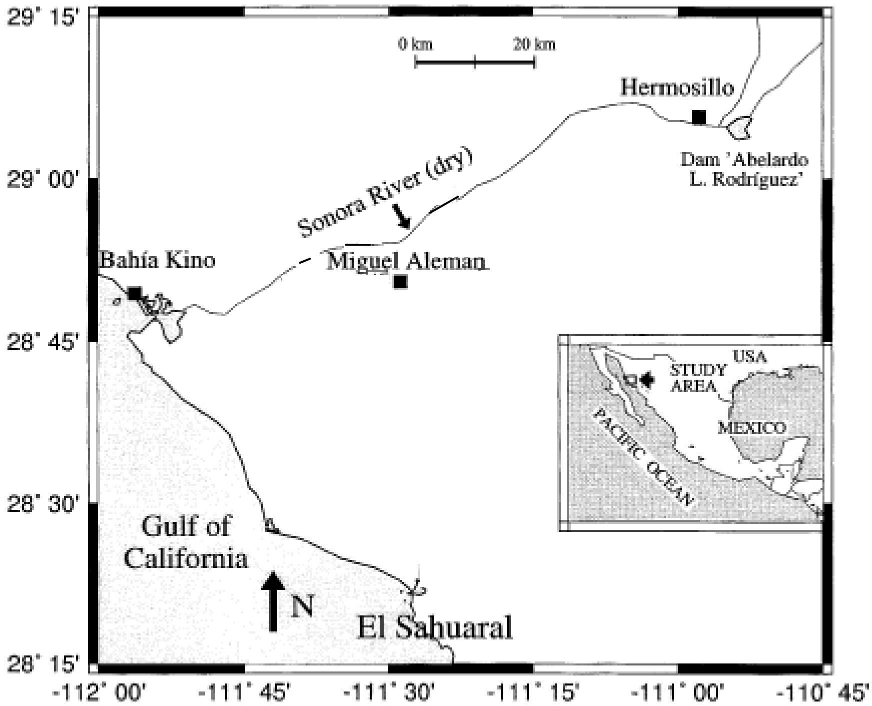

Fig. 2. Map of the Hermosillo basin (Steinich *et al.,*1998). Reprinted with permission.

This example shows the relationship among government, science, and society and how the decision will affect the different areas. This tension, as a partial result of trade between the USA and Mexico, leaves the aquifer vulnerable to over-exploitation and is a direct result of economic growth in the Hermosillo Valley. Any expansion can further reduce groundwater quality by drawing in more sea water. The government will have to decide if the value of new industry outweighs existing agricultural exports, and it may be that a switch to a different industry has a positive effect on the aquifer but might bring in less money to the region. The government knows the scientific and potential societal impacts of its decisions and must determine how to manage the aquifer in a "sustainable" manner so that the entire region does not suffer.

2.4 Sierra Blanca Low-Level Nuclear Waste Site

The issue of nuclear waste storage facility siting in the USA has created a great deal of tension between the USA and Mexico. In 1991, the state of Texas determined that a low-level nuclear waste repository would be built near the town of Sierra Blanca, approximately 25 kilometers north of the USA-Mexico border. Both USA and Mexican citizens heavily opposed this repository because it was to be located close to the international border in one of the most seismically active areas in Texas, right above an aquifer that discharges to the Rio Grande/Rio Bravo (Boren, 1997).

Those within Mexico who opposed the repository used the 1983 La Paz agreement as an argument against it. They interpret the treaty as banning the siting of new pollution-generating facilities. The U.S. Environmental Protection Agency (EPA) interpreted the agreement as requiring 'consultation and notification' (Boren, 1997). In the end, the facility was not built in Sierra Blanca due to a lack of research into the geologic hazards and a lack of planning to understand the socioeconomic impacts to the surrounding community.

2.5 Great Lakes Basin

No treatment of transboundary groundwater in North America is complete without at least some mention of the Great Lakes, which straddle the USA - Canada border. Although the Great Lakes represent the largest reservoir of liquid fresh surface water in the Western Hemisphere – almost 23,000 km^3 (Galloway and Pentland, 2005) – little attention is paid to the groundwater resources of the region, whose volume is approximately equal to that of Lake Michigan, 4168 km^3 (Grannemann *et al.,* 2000). Despite the large amount of groundwater in storage, groundwater provides only about 5% of the total water use in the basin and relatively little is known of the quality and quantity of groundwater in the Great Lakes region. However, evidence indicates that groundwater is an important component of the water balance of the Great Lakes, either directly as seepage into the lakes or indirectly as baseflow of streams which discharge into the lakes (Holtschlag and Nicholas, 1998; Grannemann *et al.,* 2000). Baseflow contributions to streams entering the lakes range from a low of under 20% on the Canadian side to about 42% to both Lakes Ontario and Huron. Low contributions in Canada are the result of less permeable groundwater reservoirs (Holtschlag and Nicholas, 1998). Lake level changes can effect changes in the groundwater flow into/out of the lakes.

As discussed in Section 1.1, the Boundary Waters Treaty is silent on the issue of groundwater, although there is a way the IJC can consider groundwater (Everts, 1991). Certainly, the groundwater resources of the Great Lakes basin will come under increasing scrutiny as the competition for water becomes more intense among the basin riparians – two Canadian provinces and eight USA states. Climate change may also affect water availability. In the case of water transfers outside the basin, all the aforementioned provinces and states must concur. Not only will there be quantity issues, but also water quality and ecosystem health issues. Galloway and Pentland (2005) suggested that, by 2050, a variety of issues – climate change, unfettered diversions, overuse, pollution - could mount to the point that the social and economic fabric of the region would be adversely affected. The problems may be daunting, but the potential for solving them exists.

3. CONCLUSIONS

The adaptability of institutions such as the IBWC and the IJC and their ability to resolve bilateral disputes and promote cooperation between the countries is demonstrated in the examples of cooperation and conflict. Cooperation is demonstrated by the voluntary use of the institutional entities available to each country such that effective management of transnational groundwater resources is accomplished. Institutions like the IJC and IBWC, while not specifically established to consider groundwater, have managed to function properly whenever groundwater is an issue, thus effecting transnational groundwater management, if on an *ad hoc* basis (see also Neir and Campana, 2007; Campana *et al.*, 2007) There is no predetermined process that clearly defines the role of government, science, and society in transnational groundwater management; however, at least two of these three elements are usually used in making decisions and agreements. NAFTA has also shown that it, too, can affect groundwater, although in the USA NAFTA's approach to groundwater as an economic good may jeopardize the use of scientific processes. Groundwater needs more attention, and attempts to "fit" groundwater into existing surface water compacts and agreements should be eschewed.

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Juggling Water: Transboundary Issues Facing the Guarani Aquifer: UNESCO-IAH-UNEP Conference, Paris, 6-8 December

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Abstract

This paper begins with an overview of the ecology of the Guarani Aquifer region before turning to the legal and ecological problems it faces. Because the majority of the Guarani Aquifer underlies Brazil (with the rest residing below Argentina, Paraguay & Uruguay), the laws and policies of Brazil have a significant managerial impact. Consequently. the Brazilian legal regime forms the focus of the first section of the paper. The paper then analyzes the international transboundary framework before turning to the recently enacted Agreement on the Guarani Aquifer. This Agreement, signed but not yet ratified by four countries, represents a major step forward in transnational cooperation. However, its language is so broad that it elides some of the principal management challenges facing this and all transboundary aquifers. The paper then looks at the legal and policy issues that climate change presents for the management of the aquifer.

The complexity and environmental importance of the region, as well as the looming threats presented by climate change, make the need for accurate and detailed scientific and technical information urgent and crucial. Yet, relying on such information to manage such a complex natural resource also presents risks. Too often, the role of uncertainty in risk assessment and in legal and managerial decisions gets reduced or ignored.

Lessening uncertainty requires reducing asymmetric information. The recent international agreement regarding the Guarani represents a significant (albeit preliminary) step forward in this regard. Increasing knowledge over the regulated resource demands categorizing "hard" and "soft" uncertainties. In addition, the regulatory framework must acknowledge the unitary nature of the aquifer while yet remaining sensitive to differing national and local priorities.

Keywords: Guarani, climate change, hard/soft uncertainty

1. OVERVIEW OF REGIONAL ECOLOGY

The Guarani Aquifer – the world´s largest – underlies Brazil, Paraguay, Uruguay, and Argentina. It contains 30 trillion m^3 of water, 1.2 million km^2 of surface area and comprises one of the most important eco-regions in the world (Almanaque Brasil Socioambiental, 2008). It is integrally connected through overland rivers (the Parana and the Paraguay) with the Pantanal, the largest wetland in the world, which oversits Bolivia, Paraguay and Brazil (Almanaque Brasil Socioambiental, 2008). The health of the Pantanal and that of the Guarani, both of which reside in the La Plata River Basin, are inexorably intertwined and the issues created by that transboundary overlap presents a complex management dilemma. Furthermore, the region's delicate ecology faces a present and growing threat from climate change, extractive industry, and the expansion of the agricultural frontier.

2. BRAZILIAN LAWS AND POLICIES REGARDING THE GUARANI AQUIFER

We focus here on Brazilian laws and policies regarding the Guarani Aquifer for several reasons. First, the largest portion of the aquifer underlies Brazilian territory, thus making any Brazilian management practices potentially more influential. This influence is underscored by the recently signed (but not yet ratified) agreement (Acordo 2010) amongst the four overlying nations regarding the Guarani's management. The agreement cedes exclusive authority for managing each portion of the aquifer to the nation overlying it. This means that Brazil will have an outsized influence over the Aquifer's management.

Second, Brazil's agribusiness activities rely heavily on its water resources – a reality that renders the Guarani vulnerable to policies that do not necessarily address the aquifer directly (Almanaque Brasil Socioambiental, 2008). Third, from a practical perspective, the background and expertise of the authors permits us far more insight into the Brazilian (as well as the international) legal framework for transboundary and groundwater management. Nonetheless, we acknowledge that a truly comprehensive analysis of the Guarani must include a similar treatment of Paraguay, Uruguay and Argentina. The longer version of this paper will do just that.

2.1 *The Legal & Regulatory Framework*

Historically, Brazilian legislators have paid very little attention to groundwater (Benjamin *et al.*, 2005). Growing pressure over this scarce resource is forcing policymakers to address the regulatory gap between surface water and groundwater. Consequently, the legal regime dealing with groundwater issues in Brazil is of comparatively recent vintage. The challenge has been to integrate surface and groundwater management (Benjamin *et al.*, 2005).

A new paradigm in water law was established in Brazil by the 1988 Federal Constitution and the 1997 National Water Policy Act. Prior to 1988, private ownership over water resources was permissible (Pompeu, 2006). The 1988 Constitution introduced the notion that the environment is an asset of common use and essential to a healthy quality of life. This principle covers water as well (Freitas, 2002). Codifying statutes soon followed. For example, article 99 of the 2002 Brazilian Civil Code states that rivers and oceans are public assets of common use and article 1, I of the National Water Policy Act declare that water lies within the public domain.

However, the above-described shift focused primarily on surface water. The issue of groundwater in the 1988 Constitution was limited to jurisdictional issues regarding the managerial powers of the federal and state governments. Article 20, section III, of the 1988 Constitution entrusts the federal government with managing lakes, rivers, and watercourses on lands within its domain, that wash more than one state, that serve as boundaries with other countries. It also extended jurisdiction over beaches and the territorial sea. By contrast, Article 26 entrusts States with managing groundwater. This created a serious management problem for aquifers such as the Guarani that underlies multiple states and extends beyond national jurisdiction. .

The main problem with this provision is that it did not account for interstate and/or international transboundary aquifers. Entrusting individual states with differing priorities and management strategies to manage a resource of multilateral and international significance creates federalist tension and jeopardizes international bilateral agreements. To solve this problem, judicial opinions and legal scholars maintain that the concept of watercourses in article 20 should be broadly construed to include groundwater that serves as boundaries with other countries and/or that wash more than one state. However, this interpretation is not yet settled and seems to flout the plain language of the Constitution. A constitutional amendment has been proposed to address this issue, but has not yet been ratified by the Congress.

Meanwhile, a set of different regulations have been enacted to close the gap between the groundwater and surface water management regimes. The need for integration has become particularly urgent as a result of ballooning demand for water by agribusiness. In 2001 the National Water Resources Council ("CNRH") enacted a series of resolutions aimed at integrating ground and surface water management. In addition, the National Environmental Council ("CONAMA") also promulgated groundwater quality standards in 2008.

Those states overlying the Guarani have also taken steps to control access and promote conservation. For instance, the state of São Paulo, the main consumer of the Guarani Aquifer, has created the State Water Resources Council ("CERH-SP") to regulate to protect the state's water resources. It has established restricted zones for the perforation of tubular wells in the city of Ribeirão Preto (one of the major consumers within São Paulo) in order to protect the Guarani from contamination. This regulation was approved based on the conclusions of al report produced by the Companhia Ambiental do Estado de São Paulo CETESB. Another example of a brewing conflict lies in the state of Mato Grosso do Sul, where the passage of Resolution 8 in July, 2009 empowers the state Environmental Authority to require permits for property owners seeking to operate wells on their land. However, as the agency begins rationing permits to prevent groundwater overdraft, property owners whose title predates the 1988 Constitution could potentially file takings claims.

3. INTERNATIONAL LEGAL FRAMEWORK

The international legal framework on groundwater is constantly evolving. In general, international laws regarding groundwater build on rules already in place for surface water. Of particular relevance to the Guarani is the 1966 Helsinki Rules on the Uses of the Waters of International Rivers, which was adopted by the International Law Association (ILA) and laid out foundational principles for transboundary water issues (Benjamin, 2005). This agreement was followed by the 1997 UN Convention on Nonnavigational Uses of Watercourses which, in turn, was superseded by the 2004 Berlin Rules on Water Resources.

With respect to groundwater, the international legal framework encompasses the 1986 Seoul Rules on International Groundwaters, the 1994 UN International Law Commission Resolution on Confined Transboundary Groundwater. International agreements specifically dealing with the Guarani Aquifer include the 1969 Treaty on the Prata Basin (Benjamin, 2005). This Treaty provides the foundation upon which the Guarani Aquifer Environmental Protection and Sustainable Development Project was construed.

3.1 *Agreement on the Guarani Aquifer*

Arguably the most important development on the international legal front regarding the Guarani was also the most recent. We refer to the signing on August 2, 2010 of the Agreement on the Guarani Aquifer by Argentina, Brazil, Paraguay and Uruguay – the four nations whose territory overlies the watercourse. The agreement, outlining basic principles adopted by all the signatory countries, will (if ratified by the 4 nations) represent a major step forward for the aquifer's management. It will also represent a significant achievement in the field of international water law. To date, only a handful of international groundwater management agreements exist (Benjamin, 2006) despite the existence of at least 270 transboundary aquifers, which provide water to millions of people.

The agreement adopts a number of important management principles. For example, the four nations agreed to share information as well as to inform fellow signatories of any domestic initiatives that may cause transboundary impact. Furthermore, Article 4 of the agreement acknowledges the multilateral importance of protecting and conserving the resource and the need to identify areas requiring special attention, especially those near borders (Acordo 2010). However, as is often the case in multi-party agreements, the language is broad and may simply be papering over disputed issues that remain in dispute (Benjamin, 2005). Similarly, Article 15, which creates a multilateral commission to oversee and manage cooperation between the parties, does not set out any specific duties or authority of the Commission. Instead, it simply states that the Commission will propound its operating regulations at a later date.

Another area of concern in the agreement is the amount of power ceded to the individual nations. Article 2 states that each party will have exclusive dominion over the groundwater that lies within their respective boundaries. The fact that such language could find itself into a transboundary water agreement in 2010 reflects the enormous difficulty that continues to bedevil international ground (and surface) water management (Eckstein 2010).

There is no hydrological logic to apportioning groundwater management by overland national boundaries. Because groundwater migrates and because the policies of the respective nations toward overdraft, pollution, etc. will inevitably impact the rest of the aquifer and the countries claiming sovereignty over the water, the management strategies of the four countries must be either interlinked or fundamentally incoherent. The Agreement implicitly recognizes this even while ceding management authority over the groundwater underlying each country to those individual countries alone. That recognition appears in the form of the adoption (in Articles 3&4) of the principles of reasonable and equitable use as well as (in Articles 3, 6 & 7) of that of no significant harm (Acordo 2010). However, even as it recognizes these precepts, the Agreement offers no means of enforcing their adoption and instead gives signatory nations the means through which to ignore them. This approach is understandable in light of the different national interests involved. However, it offers little hope for future efforts to manage the resource multilaterally. Given the looming challenges of climate change, that reality becomes especially sobering (Hall, 2008).

4. HYDROLOGICAL CHALLENGES PRESENTED BY CLIMATE CHANGE

4.1 *The Brazilian Legal Approach*

Climate change presents significant challenges relating to water availability. The situation in Brazil is serious and rapidly worsening. Long periods of drought are becoming more frequent, even in wet states in the south, like Paraná and Rio Grande do Sul. A major diversion project aimed at diverting water from the San Francisco River for the arid northeast region of Brazil offers another example of how water management policies in a country known for its water abundance must now focus on avoiding water shortages.

According to the IPCC, `There is `*high confidence´* that northeastern Brazil `will suffer a decrease in water resources due to climate change.´ The report projects significant adverse impacts on agriculture, water supply, energy production and health. While dry regions will become drier, there will also be changes in rainfall patterns and runoff in traditionally humid zones. This will impact water availability and quality and present challenges to infrastructure. (Hall, 2008).

Brazil has implemented a national climate change policy at the end of 2009 that highlights the need to manage natural resources in light of the risks posed by climate change. However, the policy provisions offer guidelines rather than any specific plan of action. Specific regulatory measures were left to the executive branch to enact and also delegated to states and municipalities.

Incorporating the guidelines of the new climate change policy act into existing water law will present significant new challenges. The principles embedded in the 1997 National Water Policy Act demonstrate an emerging awareness that water management must adapt to modern environmental realities, including climate change (Hall, 2008). Together with the 2009 National Climate Change Policy Act, principles such as the precautionary approach, intergenerational equity, multiple use, and risk assessment now infuse the Brazilian water regime. Enforcement, however, remains a significant issue for Brazil (as well as the other three countries) (McAllister, 2008).

The task now facing the nation involves fashioning an independent regulatory apparatus that can withstand campaigns to manipulate public opinion and undermine sound policymaking. Sound water policymaking in the post-climate change world requires acknowledging the principles and guidelines already in place despite the pressures and allures created by large-scale development projects that fail to account for the new water-scarce reality.

4.2 *Transboundary Challenges*

The recent evolution of international laws and agreements regarding the Guarani Aquifer offers a first step toward a successful management regime (Benjamin, 2005). International cooperation enabled the involved countries to assess the challenges imposed by the many ecosystemic and political variables. Those variables range from the threat of climate change to significant and potentially irreversible impacts on different ecosystems including the Pantanal (Hall, 2008). Inventorying uncertainties is also a crucial component of providing for the needs of the overlying countries (Sunstein, 2004).

Development pressures and conservation goals offer fertile ground for conflicting interests within and among the overlying countries. These conflicts can lead to a Tragedy of the Commons if not properly managed. On the other hand, overregulation can cause suboptimal use, thereby impairing development. Optimizing regulation presents an ongoing challenge but the obstacles grow larger when the commons is as complex as the Guarani Aquifer. The complexity and environmental importance of the region, as well as the looming threats presented by climate change (Hall, 2008), make the need for accurate and detailed scientific and technical information urgent and crucial. Yet, relying on such information to manage such a complex natural resource also presents risks (Beck, 1986).

Environmental uncertainty can never be eliminated; at best it can be quantified and certain aspects of it reduced (Schroeder, 1986). Too often, however, the role of uncertainty in risk assessment and in legal and managerial decisions gets reduced or ignored (Wildavsky, 1966). Understanding the role of uncertainty is a necessary part of achieving a stable regulatory framework – not just for the Guarani region, but for all transboundary water regimes .

Decreasing uncertainty requires reducing asymmetric information. In other words, policymakers must bridge the gaps among scientists coming from different areas of knowledge as a first attempt to mitigate the impacts of the socio-economic burdens (Krier, 1990) born by the regulated sectors. The less asymmetric information, the lower the degree of uncertainty and, consequently, the more likely the regulating decision will be a better one (Rowe *et al.*, 2004). In this context, better, means both more legitimate and more procedurally efficient (Laffont, 2000).

4.3 *Challenges for the Guarani Aquifer*

With regard to the Guarani, recent developments reveal a laudable (if still nascent) collaboration aimed at reducing asymmetric information at all levels: international, regional and local. However, public participation must also play a key role. Vital pieces of the puzzle sometimes are only provided by traditional and local knowledge (Benjamin, 2005). Another crucial component of a successful multilateral management strategy (and here we refer both to multi-state as well as multinational resource management) lies with coordinating actions and plans. Shared information is often a crucial and overlooked management tool.

Underlying the need for comprehensive information sharing on the Guarani involves determining whether management strategies face challenges predicated on hard or soft uncertainty. Soft uncertainty arises "where [a] precise outcome cannot be predicted but a probability distribution can be specified…"(Wildavsky, 1966). Hard uncertainty occurs "where one does not even know the parameters of the outcomes." (Wildavsky, 1966). Identifying which policies fall under which category is crucial.

For example, development issues present a soft uncertainty challenge. Potential threats are, for the most part, knowable and their potential impact calculable. Climate change impacts, by contrast, present a problem of hard uncertainty (Posner, 2008). The dimensions of the threat are not yet measurable and the impacts remain mostly unknown. Expressed thus, the threats posed by development present a known unknown while climate change presents multiple challenges predicated on unknown unknowns.

For the former, local policies organized and coordinated by a common of principles that acknowledge the transboundary nature of the resource might be most efficient. As mentioned, the recent multilateral agreement exemplifies both the advantages and the drawbacks to this approach. For the threats posed by climate change, strategies and policies built at the local level must take into account the hard uncertainty underlying the global problem. No local strategy can possibly address the complexity of the dilemma, nor should it. However, local strategies that do not account for global challenges and strategies are doomed to fail.

The policy challenge at both the local and international levels will require close attention to the precautionary approach, which includes understanding and managing for the catastrophic potential of low probability events. This involves constructing mitigation policies that navigate dangers presented by unknown and unpredictable events while remaining non-exclusionary and not unnecessarily burdening regulated sectors (Schelling, 1992). Expressed thus, the task seems impossible. Yet it must be done. The Guarani – and much more – hang in the balance.

5. CONCLUSION

In sum, the legal framework for the Guarani represents progress but also highlights the challenges and risks ahead. Increasing knowledge over the regulated resource demands categorizing management challenges into hard and soft uncertainty problems. Once categorized, policymakers must allow for public participation through the promotion of awareness, capacity building, community involvement and traditional knowledge. In addition, the regulatory framework must acknowledge the unitary nature of the aquifer while remaining sensitive to differing national and local priorities. This challenge – faced by every transnational water negotiation – looms particularly large with the Guarani because of the size and importance of the resource and because of its impact on other sensitive and protected regions.

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Towards Transboundary Aquifer Management in Southern Africa

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Abstract

The sustainable and efficient management of water resources became one of the priorities of the SADC to ensure water supply security for the future. River basin organizations (RBO) have been established for all major river basins in the region to ensure the joint transboundary management of surface and groundwater resources and avoid future conflicts. Especially in the more arid part of the SADC region namely Namibia, Botswana and the north-western part of South Africa groundwater is the main source of domestic water supply. Nevertheless sustainable groundwater management, especially on a transboundary level is missing or inadequate. Critical shortcomings in transboundary groundwater management (TBA) appear to be in the organizational framework, and the institutional as well as individual capacity. The project "Integrating Management of Transboundary Groundwater Resources into the River Basin Organisations" (with a focus on ORASECOM) has been developed and proposed to GEF for funding. The project aims at improving the development and management of transboundary aquifers in two pilot areas within the framework of the Revised SADC Protocol on Shared Watercourses and the UNILC Draft Articles on the Law of Transboundary Aquifers. Two rather different transboundary aquifers, the Stampriet Kalahari-Karoo Aquifer and the Ramotswa Dolomite Aquifer were chosen to ensure that a full range of different management needs and challenges are addressed in the project. Increased water supply security for local, regional and transboundary development within a context of growing climatic unpredictability and change is expected to be the direct benefit/impact of the project. The interventions of the project will address the existing knowledge gaps and common understanding of the pilot TBA and the capacity development needs on the relevant intervention levels. Furthermore it will contribute to enhance coordination among countries, donors, projects and agencies and establish cooperative processes for the integration of groundwater resources management into a river basin organizational framework such as ORASECOM. It is envisaged that the project will serve as a demonstration of replicable approaches and that its results will be recognized and used as "best practices" for the joint management of other TBAs within the SADC region.

1 INTRODUCTION

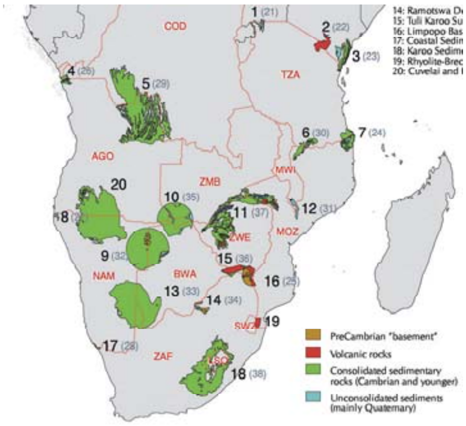
Although groundwater resources are critically important for poverty alleviation and socio-economic development throughout Africa, the sustainable utilization and management of the resource has remained inadequate relative to its importance. The internationally preferred approach is to manage groundwater resources in the context of (transboundary) basin management and within the IWRM process. Major policy, legal, and institutional reforms regarding the joint utilization and management of both transboundary surface water and groundwater resources have been adopted by the Southern African Development Community (SADC). Nevertheless the unique role and advantages of groundwater as a significant source for sustainable water supply has not been sufficiently addressed in the portfolio of the transboundary RBO and the local basin management committees (BMCs).

This paper provides the background to the occurrence and use of groundwater resources in Southern Africa, with special reference to transboundary aquifers, as well as the water institutional development within the region. The first steps towards integrated management of groundwater resources across international boundaries within the region are discussed, and to show the methodology of the process and the way forward, is illustrated by means of a major transboundary aquifer management project that is planned by three of the countries in cooperation with a major river basin organisation.

2 GROUNDWATER IN SOUTHERN AFRICA

Hydrogeology

Approximately 60 to 65% of the SADC region is covered by crystalline rocks with aquifer systems developed in the weathered regolith and within the fractured bedrock. The aquifers developed in these areas are generally unconfined, locally developed and relatively small in aerial extent. A further 10% of the region is covered by areas designated as "complex hydrogeological structures", such as folded and faulted meta-sedimentary sequences as well as lavas. Approximately 25 to 30% of the region is covered by major groundwater basins that are aerially extensive and exhibit primary porosity and permeability. These basins include the Permian-Triassic Karoo sedimentary basins that cover large areas in South Africa, Botswana, Zimbabwe, Zambia, Namibia and Angola. The large Tertiary sedimentary basin in the Democratic Republic of Congo (DRC) and western Angola has hardly been exploited as it lies in a humid zone. Along the coastal areas, especially in Mozambique and Tanzania, extensive Cenozoic coastal plain deposits constitute an exploitable aquifer resource. Similar deposits occur to a lesser extent along the west coast of the region. The Kalahari basin is a vast area of unconsolidated aeolian sand, tertiary to recent in age, which potentially forms a huge primary aquifer resource. However, areas with saline groundwater occur in the Kalahari within the three countries, where this unit is extensive. The transboundary nature of several of these groundwater systems has been recognized for a long time, but a more systematic mapping of transboundary aquifers only commenced recently through the launching of UNESCO IHPs International Shared Aquifer Resources Management (ISARM) project in SADC. The transboundary aquifers within Southern Africa, based on a first inventory, are shown in Figure 1.



No	Aquifer name	Countries
1	Kagera Aquifer	Tanzania, Uganda
2	Kilimanjaro Aquifer	Tanzania, Kenya
3	Coastal Sedimentary Basin I	Tanzania, Kenya
4	Coastal Sedimentary Basin II	DR of Congo, Angola
5	Congo Intra-cratonic Basin	DR of Congo, Angola
6	Karoo Sandstone Aquifer	Mozambique, Tanzania
7	Coastal Sedimentary Basin III	Mozambique, Tanzania
8	Coastal Sedimentary Basin IV	Angola, Namibia
9	Northern Kalahari/Karoo Basin	Namibia, Botswana
10	Nata Karoo Sub-basin	Angola, Namibia, Zambia, Botswana
11	Medium Zambezi Aquifer	Zambia, Zimbabwe, Mozambique
1	Shire Valley Alluvial Aquifer	Malawi, Mozambique
1	Stampriet Kalahari/Karoo Basi	Namibia, Botswana, South Africa
14	Ramotswa Dolomite Basin	Botswana, South Africa
15	Tuli Karoo Sub-basin	Botswana, South Africa, Zimbabwe
16	Limpopo Basin	Zimbabwe, South Africa, Mozambique
17	Coastal Sedimentary Basin V	Namibia, South Africa
18	Karoo Sedimentary Aquifer	Lesotho, South Africa
1	Rhyolite-Breccia Aquifer	Mozambique, Swaziland
20	Cuvelai and Etosha Basin	Angola, Namibia

Figure 1: Transboundary aquifer systems in Southern Africa (Vasak, 2008)

Availability and use of groundwater

The climate of the eastern and northern part of the SADC region is characterized by humid tropical and equatorial conditions. Perennial surface water is mostly utilised in these areas and groundwater resources receive less attention and is generally not as carefully monitored and managed when utilised. In the more arid parts of the SADC region, especially in Namibia, Botswana and north-western South Africa, surface water is predominantly only available for short periods during the rainy season. Groundwater therefore assumed great importance because it is perennially available and in most cases is the only principal source of fresh water. Groundwater is the largest water source for domestic water supply in the region, while it also plays a significant role in stock watering, irrigation and mining. It is estimated that 36% of the urban population in the SADC Region relies on groundwater (Molapo et. al., 2000), compared to 23% that is supplied with surface water. The remaining 40% of the population, mainly in rural areas remains unserved with formal water supply schemes, and largely depend on informal and traditionally developed groundwater sources (*i.e.* hand dug wells, springs, etc). The importance of using groundwater for bigger settlements and larger scale water supply is often underplayed. Drought events are endemic in large parts of the SADC region and their frequency and intensity are expected to increase in the future due to global climate change. Groundwater supplies already play a critical role during both short-term and extended droughts. Its availability where it is needed reduces the need for large-scale investments in long distance water supply infrastructure.

Groundwater Use and Management in the SADC Region

There is still a general prejudice among the public and political authorities against the use of groundwater as a reliable, cost-saving and clean source of water supply and its importance for socio-economic development in the SADC region is still poorly understood. Groundwater resources are often under-utilized, unsustainably exploited, and not adequately managed. In a recent assessment (Braune *et al*, 2008) found that despite some progress has been made, the performance in IWRM is still poor compared to relevant international best practice in particular regarding institutional capacity and the establishment of an enabling environment. There appears to be awareness at the decision-making level about the importance of groundwater management, but this is not yet adequately reflected in policies, legislation and their implementation. Some of the broad conclusions from this assessment were:

- Despite the inability of bulk water supply to satisfy remote demand at reasonable costs there is still a general bias towards surface water resource development and long distance piped water supply systems within the region;
- Critical shortcomings in groundwater management appear to be the lack of an organizational framework, institutional and technical capacity and of information and awareness at all levels;
- A lack of macro-planning for groundwater prevails, as most of the activities are undertaken on an ad-hoc or crisis response basis. This is one of the most neglected areas in relation to groundwater development and management.

The SADC Groundwater Management Programme (SADC, 2005) is trying to address these shortcomings and is making progress at a regional level, e.g. the development of a Code of Good Practice for Groundwater Development, a regional Hydrogeological Map and, recently, the establishment of a Groundwater Management Institute.

3 ADDRESSING TRANSBOUNDARY AQUIFER MANAGEMENT

General Context

It must be recognized, that equitable multilateral management of a transboundary aquifer is in itself not an easy accomplishment. International law has thus far only rarely taken account of groundwater. While surface water treaties abound, groundwater is either nominally included in the scope of these instruments, mainly if it is “related” to surface waters, or it is not mentioned at all. Spatial variation, the groundwater rights of stakeholders within each Basin State, water quality degradation, water conservation, and the potential of conflict, in particular because of the unseen and little understood nature of groundwater, are issues that need to be resolved. Ultimately a cooperative management model needs to be jointly developed, which yields the highest level of net social welfare (Peck, 2010). The Law of Transboundary Aquifers, adopted by the General Assembly of the United Nations on 15 January 2009, explains in detail the issues to be covered while introducing TBA management.

Regional Context

The SADC region appears to be well placed to pilot transboundary aquifer management. Formal regional cooperation in the water sector was established in 2000 through a Revised Protocol on Shared Watercourses in the SADC. This formal regional roll-out of the international water law, initiated by the Helsinki Rules, is unique in Africa. The overall objective of the Protocol is to foster closer cooperation for judicious, sustainable and co-ordinated management, protection and utilisation of shared watercourses and advance the SADC agenda of regional integration and poverty alleviation. The main measure in terms of the Protocol is ‘to promote and facilitate the establishment of shared watercourse agreements and shared watercourse institutions for the management of shared watercourses’ (SADC, 2000). Of the 15 major river basins which are shared by two or more nations, 11 already formed an institutional framework for shared management. An important groundwater milestone has been the resolution in 2007 by the African Ministers Council on Water (AMCOW), as part of a major Africa Groundwater Initiative, to '*promote the institutionalisation of groundwater management by river basin organisations to ensure regional ownership of the initiative'.* SADC endorsed the AMCOW policy in 2008.

4 PROGRESS TOWARDS TRANSBOUNDARY AQUIFER MANAGEMENT IN SOUTHERN AFRICA

General Project Outline

In 2007, the International Hydrological Programme of UNESCO launched the International Shared Aquifer Resources Management (ISARM) project in SADC, starting with an inventory of major transboundary aquifers in the region. As one of the main outputs the ISARM Steering Committee recognized the need to develop and apply transboundary aquifer management principles on a pilot basis. The Stampriet Kalahari-Karoo aquifer system (Basin No. 13 in Figure 1) and the Ramotswa Dolomite Aquifer (Basin No. 14 in Figure 1), involving Namibia, Botswana and South Africa were identified and included in the final project proposal. These rather different transboundary aquifers have been chosen to ensure that different management needs and challenges are addressed in the project. The Stampriet Kalahari-Karoo aquifer has been already investigated while developing a management plan for the Namibian part of the Stampriet Kalahari-Karoo aquifer system, the so-called Stampriet Artesian Basin (JICA, 2002). As part of the study, a conceptual model as well as an exploratory numerical model, was developed for the larger part of the transboundary aquifer system (Peck, 2010). While commercial irrigation accounts for approximately 46% of total abstraction on the Namibian side, Botswana mainly uses its abstraction for pastoral farming and domestic use, whereas in South Africa the use is mainly in a very large game reserve and for stock watering on commercial farms. A key finding was that, given the episodic recharge events and the flow patterns postulated under those conditions, over-abstraction in Namibia would have regional impacts on the system. Therefore the concluding recommendation of this study was that joint transboundary management of this aquifer system is needed to ensure long term water supply security.

The transboundary Ramotswa Dolomite Aquifer represents a completely different aquifer type and different management requirements. The aquifer is of critical importance for bulk water supply in both Botswana and South Africa, but is highly vulnerable and currently in a state of deterioration caused by multi-source pollution and inadequate cross border management and collaboration. Water from the aquifer is used for domestic water supply by the Ramotswa community in Botswana and is listed as one of the resources which need protection to secure sustainable future use. Botswana plans to rehabilitate the Ramotswa well field in order to augment the supply of water to the capital, Gaborone. The aquifer was investigated in 2002 by the Water Research Commission in South Africa to develop an institutional framework for groundwater management. The implementation of this exercise is still not fully functional, especially where transboundary conditions prevail, and the proposed TBA project is expected to address these shortcomings in a transboundary approach.

The SADC endorsed the proposed project from the beginning and at its 3rd SADC Multi-stakeholder Water Dialogue in 2009, recommended that the recently published UN International Law Commission Draft Articles on The Law of Transboundary Aquifers should be fleshed out within the framework of the SADC Protocol on Shared Watercourses as part of the project.

The three Basin States agreed to approach the Global Environmental Facility (GEF) for a funding contribution. A Project Information Form (PIF) was prepared and will be sent for approval in the early part of 2011. The project title is “Integrating Management of Transboundary Groundwater Resources into the River Basin Organisations with a focus on ORASECOM”. The expected GEF Focal Area outcome is to catalyze multi-state cooperation to balance conflicting water uses in transboundary surface and groundwater basins while considering climatic variability and change.

Project Objective, Approach and Expected Impacts

The overall project objective is "to improve development and management of transboundary aquifers" in two pilot areas within the framework of the Revised SADC Protocol on Shared Watercourses and the UNILC Draft Articles on the Law of Transboundary Aquifers.

The chosen approach foresees to concentrate on two major project components, firstly filling existing knowledge gaps and reaching satisfactory common understanding of the TBA (resulting in decision support tools and a common database), and secondly developing the necessary capacity on the relevant intervention levels. The capacity development interventions will target primarily the ORASECOM basin and the national (partner countries') institutions such as basin management committees, and it will address institutional, organizational and individual capacity development needs. The project intends to bridge a major gap between regional policy expression and the reality on the ground by shared learning of the functioning of the local TBA systems and its joint management requirements. The experience gained will be built into IWRM processes and structures at national, river basin and regional management levels in a harmonized and sustainable way (PIF, 2010). The main direct benefit/impact is increased water supply security for local, regional and transboundary development within a context of growing climatic unpredictability and change.

The different interventions of the project will address:

(a) Improvement in scientific understanding of the TBA systems through the development of a Transboundary Diagnostic Analysis, in order to reach an informed consensus on the factors affecting its integrity at the national and at the transboundary level,

(b) Capacity development on all intervention levels within the relevant structures of the partner countries and the RBO to enable joint TBA management,

(c) Enhanced coordination among countries, donors, agencies and projects,

(d) An established, cooperative process for the integration of groundwater resources management into a river basin organizational framework.

It is envisaged that the results of this project will be recognized and used as “best practices” for the joint management of other TBAs within the SADC region and globally.

5 CONCLUSIONS

Groundwater is of strategic importance in the Southern African region, particularly for the up-liftment and prosperity of thousands of communities living in poverty. It also serves as a critical buffer during droughts, which are endemic within the region, and will play a crucial role in adaptation to climate change. Despite this importance, there is still a wide-spread bias towards the utilization and management of surface water resources in the region.

The SADC has made significant progress in water institutional development, including the establishment of river basin organisations, all functioning within the framework provided by the Revised SADC Protocol on Shared Watercourses. Good regional assessments of groundwater resources have been made and guidelines for their utilization and management have been developed. However, harmonized implementation of the management guidelines by the Member States is still lacking. Groundwater management performance must therefore still be rated as “below expectation” when compared to relevant international best practice.

Encouraged by recent high level continental and regional policy direction regarding the institutionalization of groundwater resources management in basin organisations, there is now a significant thrust towards transboundary aquifer management within the region. At the heart of this development is a pilot project in which Botswana, Namibia and South Africa have joined forces under the umbrella of the Orange-Senqu River Commission, to transfer their pilot aquifer management experience into IWRM processes and structures at national, river basin and regional management levels in a harmonized and sustainable way.

This exciting initiative is seen to have continent-wide significance, because of the general struggle of African countries to meet the challenge to achieve socio-economic development without compromising the sustainable utilization of their vital groundwater resources in meeting the Millennium Development Goals and combating the adverse effects of climate change.

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The transboundary aquifer of the Geneva region (Switzerland and France):
successfully managed for 30 years by the State of Geneva and French border communities.

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ABSTRACT

The Genevese aquifer is used for the supply of drinking water harnessed from ten wells on the Swiss side and five on the French side. During the 1960's and 1970's, over pumping lowered the groundwater level by more than 7m, thereby depleting about one third of total groundwater storage over a period of 20 years. While technical and scientific studies were being undertaken to resolve the problem of over exploitation, including possible artificial recharge of the aquifer, negotiations were being conducted with various local and national authorities in France. The aim was to engage in a collaborative effort to fund the work and to establish a joint water management system. Although, in the end, the entire operation was financed by the Swiss, the setting up of a cross border committee allowed for the identification of the roles and responsibilities of each side and determined the financial modalities governing the use of the resource. An agreement was signed to that effect in 1978 and a revised version was adopted in 2007, attesting to the success of the joint management plan.

Key words: transboundary aquifer, aquifer recharge, Geneva, aquifer use agreement

1. INTRODUCTION

Geneva's drinking water is provided from the Lake of Geneva (roughly 80% of total supply) and about a dozen wells (accounting for around 20% of supply) by pumping from Genevese groundwater. The aquifer straddles the canton of Geneva in Switzerland and the French department of Haute-Savoie (Upper Savoy) and is currently used on the Swiss side for ten wells and for five wells across the French border (Fig. 1). During the 1960's and 1970's, as a result of uncontrolled over pumping and the lack of coordination among distributing and beneficiary entities, groundwater levels fell drastically, to the point where certain dried out wells had to be closed. That was when the warning bell was sounded in the face of this over exploitation of groundwater resources.

The decision was then taken to set up an artificial aquifer recharge plant so as to recover use of the wells and take advantage of the large volumes of water that could be stocked from the Genevese water table. An artificial recharge system was, therefore, inaugurated in 1980 to abstract water from the Arve River - which is the aquifer's main natural recharge source- treat it and channel it into the aquifer. This operation, effected via drains that are laid underground above the aquifer, ensure the maintenance of high groundwater levels as well as seasonal stockpiling of the drinking water resource. The system has been described in previous articles on artificial recharge (de los Cobos, 2002, 2007).

2. ADMINISTRATIVE MANAGEMENT AND POLICY

Although the artificial recharge plant has been functioning satisfactorily since 1980 and rapidly proved the efficiency of seasonally storing water in the aquifer, it was only after many years of careful thought, tests and experiments on the ground to come up with appropriate techniques and systems that a successful artificial recharge system was established.

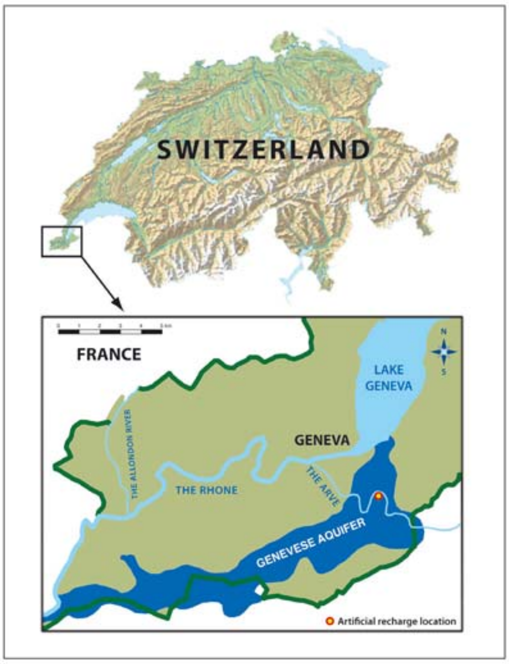

Figure 1: Location of the Genevese aquifer

The political will to develop a cross border project emerged naturally in parallel with the studies and tests that were carried out on the experimental plant. Indeed, although roughly 90% of Genevese groundwater is located in the canton of Geneva, the remaining 10% is to be found across the border in France. In the 1970's water distribution in Geneva was in the hands of two water companies (Société des Eaux de l'Arve, and Services Industriels de Genève - SIG-,), whereas on the French side a number of wells were exploited by various communities or syndicates.

Several meetings and discussions were held alongside the studies and drafting of agreements in order to:

- Impose restrictions on use for as long as the diminishing groundwater, threatened with total depletion, was not recharged artificially;
- Establish equitable cost sharing once the recharge plant was completed and operational and would then be of mutual benefit to users on both sides of the border.

From the time the first Franco-Swiss meetings were held in 1972, it was noted that groundwater resources had shrunk dramatically and continued to do so. The problem not only affected Geneva but the entire adjoining French region as well (Fig. 2).

Between 1973 and 1974, efforts were focused on drawing up an inventory of drinking water resources in the region as well as on hydrogeological issues, such as losses, natural recharge, future pumping and fees, and the whole range of factors that needed to be considered in laying the bases of a future Franco-Swiss agreement. In 1975, the French declared that they would no longer use Genevese groundwater and would be turning to other French resources but wished to retain the possibility of later participating in and benefiting from artificial recharge. This decision certainly had an impact on cost coverage because, although SIG pursued their minimum extraction policy, the financial burden fell onto the shoulders of Société des Eaux de l'Arve which pumped exclusively from Genevese groundwater. It was envisaged that the cost of artificial recharge (depreciation, interest, usage and renovation costs) would be spread among all groundwater users, irrespective of the origin of the water; whether natural or artificial recharge. The artificial recharge fee per cubic metre of water extracted could be less than 0.07 Swiss francs when the annual volume of water pumped was in excess of 20 million m^3. However, the fee could rise to 0.12 Swiss francs or more if the volume of water pumped was less than 10 million m^3.

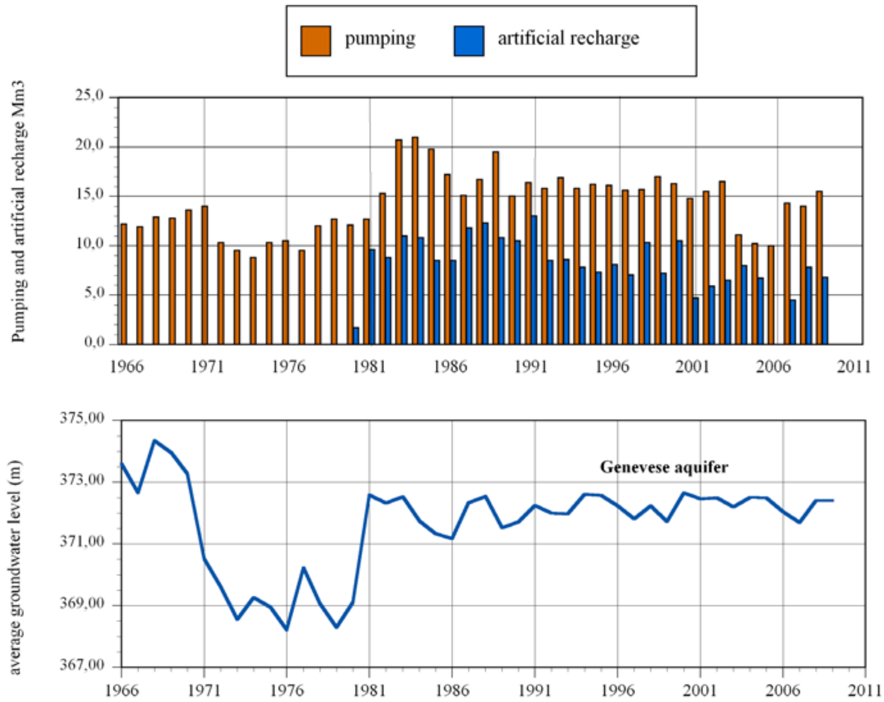

Figure 2: Impact of the artificial recharge on the Genevese aquifer

As of 1977, artificial recharge benefits for users were decided as follows:

- *Société des Eaux de l'Arve*: could continue to expand its network without having to seek out other resources (purchase of water from SIG or construction of a water pumping station to extract water from the lake).
- *SIG*: could exploit all the existing pumping wells (100,000 m^3/day) and not have to build a new plant for treating lake water (100 million Swiss francs) which would only be used for a few weeks in the year.
- *French communities*: If necessary, the French communities could extract supplementary amounts of water and pay their part of the costs beyond the annual minimum allowance of 2 million m^3 which corresponded to the volumes they extracted before artificial recharge was introduced.
- *All users*: reserves of 15 million m^3 of drinking water would be stored in the best possible conditions (underground) to be constantly available in the case of acute shortage in one of their other plants.

Finally, an arrangement between the State of Geneva and Haute-Savoie (Upper Savoy) in France was signed on 19 June 1978 for thirty years. The French authorities obtained an annual allowance of 2 million m^3. Once this quota was surpassed, the price per m^3 would be calculated on the basis of an equation comprising the following factors:

- the costs of operating the plant (SIG expense): ***E***
- depreciation: ***A***
- total pumping (Swiss +French): ***VE***
- share in natural recharge (7.5 Mm3/yr): ***AN***
- volume pumped by the French authorities minus the quota: ***Vefp***

French participation: ***Pf*** = (***A*** + ***E***) * ***Vefp*** / ***VE-AN***

Following approval of the arrangement between the canton of Geneva and the prefecture of Haute Savoie, an advisory committee was set up to oversee the management of the recharge of Genevese groundwater which would also be responsible for dealing with problems relating to the use, maintenance and monitoring of the system as a whole. The committee would regularly assess the status of the resource in terms of pumping and artificial recharge. Stocked volumes of water (the amount of water each user was expected to use for the coming year) were discussed and accepted on the basis of conditions pertaining to water quantity and quality and the operation of the artificial recharge plant.

Initially, from the Swiss side, the committee was comprised of two State Council designated representatives, one representative from the cantonal committee for water conservation and one representative for each water company (SIG and Société des Eaux de l'Arve). Committee members could be accompanied by experts. One of the State Council designated representatives would chair the committee.

The committee would be mainly responsible for reviewing the annual artificial recharge programme (drawn up on the basis of groundwater levels and forecasts of water user needs), the budget that was prepared in line with the recharge programme, the operating costs and the results of water quality control tests. Provisions governing quantities reserved for each party for the coming year, water quality and the warning system in the event of accidental pollution were also matters that would be discussed and adopted by the committee. The committee would meet once to twice per year, alternatively in France and in Switzerland. It could also meet more frequently, if necessary.

In 1988, the water company Société des Eaux de l'Arve was bought out by SIG, as of which point, Geneva had one single water supplier.

3. 2008: EXTENSION OF THE 1978 ARRANGEMENT FOR 30 ADDITIONAL YEARS

Between 2007 and 2008, the groundwater committee found itself facing new challenges, namely, the extension of the 1978 arrangement, after almost 30 years of being in force, and, particularly, on the Swiss side, the transfer of Geneva State assets to SIG and, thus, the sale of the recharge plant to SIG. In view of these important events, a sub-working group of the committee was formed and met several times during 2007. This Franco-Swiss working group, equipped with the necessary legal support, produced a basic document outlining the management of Genevese groundwater for the next 30 years. It was to be ensured, in particular, that the technical specificities agreed on by the parties would be placed within a global context that was recognised at administrative and political levels.

3.1. The new agreement

The first steps consisted of setting up the cross border legal bases for the new agreement. The 1978 arrangement did not have a legal premise that was grounded in cross border cooperation instruments, for the simple reason that there were no such instruments in existence at the time. Several instruments of this type appeared as of 1980 and were ratified by both Switzerland and France (Fig. 3). There were three conventions on which a new agreement governing Genevese groundwater usage could be based, namely:

- the European Outline Convention on Transfrontier Co-operation Between Territorial Communities or Authorities (hereinafter the Madrid convention) of 21 May 1980 (entry into force 21 December 1981);
- the Convention on the Protection and Use of Transboundary Watercourses and International Lakes of 17 March 1992 (hereinafter the Helsinki convention);
- The Karlsruhe agreement on transboundary cooperation between local communities and local state entities of 23 January 1996.

These three international legal instruments do not pursue the same objectives:

- the Madrid convention contains a standard inter-state agreement on transboundary cooperation among local authorities and a standard contract for service supply among "public law" cross border local communities.
- the Helsinki convention lays down the obligations of States parties to cooperate without directly creating institutions or operational structures. The transboundary river contracts, to which Geneva associated itself, after signing the transboundary memorandum of understanding in 1997 to revitalise Franco-Genevese rivers, might have had its origins in this convention.
- the Karlsruhe agreement, for its part, provides for the establishment of operational structures between local communities and/or local public authorities with legal personality.

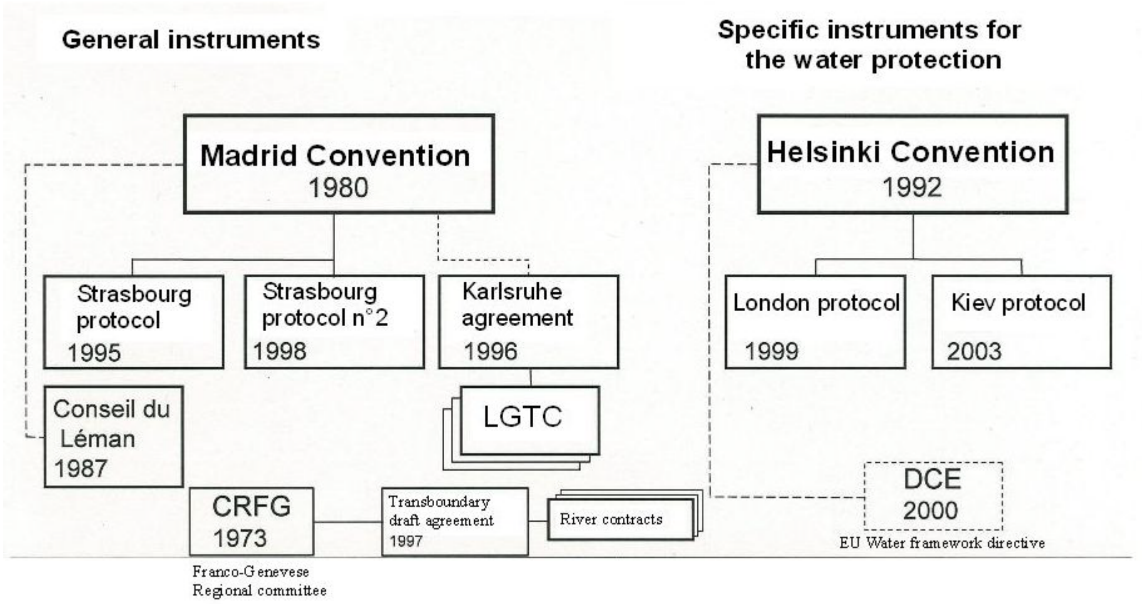

Figure 3: Transboundary cooperation Instruments

Before choosing a transboundary cooperation instrument, therefore, it was necessary to decide on the objective to be achieved. If the aim was to replace the 1978 arrangement, a Local Grouping of Transboundary Cooperation (LGTC), bringing together the local communities of Geneva, the State of Geneva and SIG, seemed to be the way forward. However, when it came to water management, the French entities and the State of Geneva would be the main interlocutors, with SIG's role being restricted to artificial recharge exploitation. In fact, a simple solution, which was limited to groundwater use and recharge, was advanced in the form of a transboundary agreement among the local communities concerned. On the basis of the Karlsruhe agreement, particularly the possibility stipulated in its article 5 of delegating a mission to one of the local communities, an agreement was subsequently reached between the State of Geneva and the three French communities involved (the greater Annemasse region, the Community of Genevese communes and the commune of Viry). This option was less burdensome and more appropriate than setting up an LGTC. Furthermore, in accordance with the Swiss federal constitution, cantons could sign treaties with foreign bodies within the areas of their competence. Cantons were thus free to act autonomously and themselves conclude international agreements of this type.

Consequently, an agreement relating to the use, recharge and monitoring of Franco-Swiss Genevese groundwater was signed between, on the one hand, the communes of the greater Annemasse region, the Genevese communes and the commune of Viry and, on the other hand, the State Council of the Republic and the canton of Geneva, on 18 December 2007. This new agreement succeeded the 1978 arrangement and entered into force on January 1, 2008 for 30 years. The agreement is a rare example of an aquifer management transboundary agreement between a Swiss canton and European Union communities.

3.2. The asset transfer project

Meanwhile, the recharge plant which, from the outset, had been placed under the responsibility of Services Industriels de Genève (SIG) for technical design and operation was included in the transfer of assets between the State of Geneva and SIG.

The asset transfer project consisted of transferring fixed assets belonging to the State of Geneva to public autonomous establishments. The transfer was both industrial and financial in nature while SIG was allowed to assume complete control of the activity it had previously executed under State authority. SIG thus became the owner of the recharge plant as the State preferred to deal solely with sovereign tasks. As far as the recharge plant was concerned, in addition to the purely accounting and legal aspects, it was also necessary to provide guarantees for the agreements that had already been signed and those yet to be concluded between the State of Geneva and the French authorities (extension of the 1978 arrangement and the new agreement being drafted).

There was need, therefore, to amend the agreement for the use and maintenance of the recharge facilities and related works between the State of Geneva and SIG. The amendment led to the State of Geneva conceding use of the artificial recharge plant to SIG. Lastly, whereas SIG used to pay annual rentals for the use of the Geneva State-financed plant, once the assets were transferred at their book value, annual rentals in SIG's accounts were replaced with financing costs and accounting depreciation. The law on asset transfer came into force on January 1, 2008.

4. CONCLUSIONS

In 30 years of operation, the Geneva artificial recharge system contributed over 250 million m^3 of water filtered from the Genevese water table. The choice made in the 1970's between a new plant for treating lake water and the creation of a recharge plant proved to be a judicious one, not only from a financial point of view, but also in terms of water resources management. Transboundary groundwater management, coupled with the technical success of the aquifer recharge system, have guaranteed safe drinking water for Geneva and the surrounding region by diversifying and optimising the quantitative and qualitative potential of existing water resources.

Due to the radical change in demographics over the past five years and the economic attractiveness of the Geneva region, there is an ever greater trend towards establishing a cross border approach. A committee on a "transboundary water community" was even formed in 2007. This water community will be included in the Franco-Valdo-Genevese regional project which will serve to create an environmental common strategic vision across the territory and which will include patrimonial, social and economic aspects.

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The Law of Transboundary Aquifers and the Berlin Rules on Water Resources (ILA): Interpretive Complementarity

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ABSTRACT

The 2008 *Draft Articles* on "The law of transboundary aquifers", annexed to UNGA Resolution 63/124, are at present the most accurate set of rules regulating the utilization of transboundary aquifers or aquifer systems. The *Articles* attest the duty of States to protect and preserve transboundary aquifers or aquifer systems while utilizing them in an equitable and reasonable manner. Hence, the *Articles* reaffirm the pivotal customary rule of equitable utilization of shared resources embedding the obligation not to cause significant harm to other States, which stands out as the primary rule for the utilization of international shared resources. On a different and scholarly exercise, the International Law Association (ILA) adopted in 2004 the *Berlin Rules on Water Resources*, a more complete instrument than the *Helsinki Rules* that the ILA finalized in 1966, which addresses groundwater in a special chapter. The provisions on Groundwater included in the *Berlin Rules*, though somehow concise, are worth analyzing. In fact, each instrument starts from a different concept, the clue that makes the comparison attractive. Even considering their different perspectives and nature, both instruments share the common target of consolidating international law rules towards a cooperative, sound, protective and sustainable management of water. A conjunctive read of both instruments, then, will help to expose their common features and their distinct elements, aiming to complement the interpretation of the Draft Articles in some points that will be briefly highlighted *infra.* As a conclusion, the *Berlin Rules* reflect a trend for a comprehensive management and utilization of water which, as *de lege ferenda* provisions, help to construe the unwritten texts of the Draft Articles.

Key words: groundwater, equitable utilization, sustainability,

1. INTRODUCTION. GROUNDWATER PROVISIONS IN THE *BERLIN RULES*

1.1. The background the Berlin Rules on Groundwater

In 1990 the International Law Association (ILA), following the path of the *Helsinki Rules* on the Uses of the Waters of International Rivers, which it had adopted in 1966, took up again the subject of water resources law aiming to draw up a far-reaching body of rules able to encounter the vacuum of a comprehensive regulation of water. A new Water Resources Committee (WRC) was established by the ILA, whose task was crystallized with the adoption of the *Berlin Rules* in 2004. This comprehensive approach had been the target of the 1977 United Nations Mar del Plata Conference, and of its Action Plan, never revisited since. In the meantime, from 1966 onward the Helsinki Rules helped to shape international water law and became one of the most influential instruments in the field. At the same time, in the 1966-1986 period the Water Resources Law Committee of the ILA addressed specific topics, *i.e.* flood control, marine pollution of continental origin and international groundwaters, among others. On underground waters, the *Seoul Rules* were adopted in 1986, a short formulation of four provisions that made their way up to the 2004 *Berlin Rules*. In the 1966 *Helsinki Rules,* groundwater was only mentioned in the definition of 'drainage basins' in Article II as the area 'determined by the watershed limits of the system of waters, including surface and underground waters, flowing into a common terminus.'

1.2. The parallel development of the ILC and the ILA works

By the time the ILA undertook its process of dimensionally updating the task accomplished by the Helsinki Rules, a codification process of the international law rules focusing on the non-navigational uses of international watercourses had already begun at the International Law Commission of the United Nations. The ILC codification process on international watercourses culminated with the adoption of the 1997 UN Convention on the Law of the Non-Navigational Uses of International Watercourses (UN Water Convention Annex to UNGA Resolution 51/229). As may be noted, they were two differentiated processes indeed, the ILA as a scholarly body painstakingly drawing up rules stemming from conventions, customary rules, State laws, judicial decisions from international as well as national courts, enriched with the general principles of law and the relevant doctrine, in a systematic restatement of water rules, and, on the other hand, the ILC as a scholarly-political body engaged in the codification and progressive development of international law in the field of watercourse uses, imbibing from similar sources but subjected to intense review by States at the 6th Committee of the General Assembly. The ILA Committee concluded its thematically more ambitious work in 2004 with the adoption of the *Berlin Rules*, which gathered in seventy-three provisions many of the relevant rules for the management of water (International Law Association, *Report of the Seventy-First Conference, Berlin,2004,* 334-421). Though not all water topics were dealt with by the ILA work and a number of issues remained to be addressed, with the completion of the draft, adopted as *The Berlin Rules on Water Resources,* the Water Resources Law Committee was wound up.

After the adoption of the 1997 Water Convention, the ILC started the consideration of the topic of 'Shared natural resources' in 2002, which focused on the law of transboundary aquifers. This new task was readily accomplished in 2007, and the Draft Articles were annexed to UNGA Resolution 63/124 (2008). The joint lecture of the ILC's Draft Articles and the Groundwater chapter of the ILA's Berlin Rules, two bodies that are aware of each other's work, will shed some light on their respective differences and similarities. It might also help to construe the Draft Articles and support its implementation.

2. DISTINCT APPROACHES OF RELEVANT TOPICS

2.1 Rules for transboundary aquifers and for national aquifers

(a) With regard to water resources, international law has traditionally refrained from establishing rules for their management at the national level. In fact, the early conventions on navigation, the rules for drawing boundaries on rivers, the river commissions, the non-conventional Helsinki Rules on the Uses of the Waters of International Rivers, the 1992 UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes, to mention only a few relevant instruments, contain rules strictly applicable to the utilization of international or transboundary waters. The same approach was maintained in the most recent instruments on water developed by the United Nations system, *i.e,* the 1997 UN Water Convention, the 2000 UNECE Guidelines on Monitoring and Assessment of Transboundary Groundwaters, and the 2008 UNGA Draft Articles on the Law of Transboundary Aquifers. Environmental conventions, for their part, have adopted a different criterion, establishing rules and duties for States both at the national and international levels, as is the case in the 1971 Convention on Wetlands (article 3), and in the 1994 Convention to Combat Desertification (Articles 2 and 3), even when those provisions apply to water.

(b) Beyond the conventions' universe, non-mandatory instruments like the Agenda 21, adopted at the 1992 UNCED Conference, made recommendations for the Protection of the Quality and Supply of Freshwater Resources: Application of Integrated Approaches to the Development, Management and Use of Water Resources (Chapter 18) meant to impinge on national water policies. Similar recommendations were also included within the contents of the Plan of Implementation of the World Summit on Sustainable Development (2002) (Section IV. *Protecting and managing the natural resource base of economic and social development*) addressing the need of national strategies for water management in numerals 24, 25 (d) and 26 (a).

(c) It appears to be that international water conventions had only been drawn up to regulate international or transboundary waters, while environmental conventions could go further and regulate, when it is embedded in the object of the treaty, both international and national waters. The Berlin Rules strive to overcome the legal divide between international and national waters, starting from the reality that, (a) all transboundary waters are at the same time national waters, (b) national water policies have transboundary effects, and (c) the obligations of States vis a vis other States are equally mandatory at the local level. In fact, even if "States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies", such discretionary capacity is constrained with regard to foreign subjects by "the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction" (Article 3, 1992 Convention on Biological Diversity), a provision replicated in an abridged version by Article 3 of the Draft Articles (see *infra* 2.3).

2.2. The scope and content of the Berlin Rules on Groundwater

The *Berlin Rules* are a comprehensive set of rules aiming to formulate -in a non-governmental setting and looking into the future, a legal framework for the management of water resources, whether national or transboundary, surface or underground, and the concomitant rights and duties of States. This is, certainly, the innovative feature of the proposed Rules. What they state is not as important as what they intend to regulate. Then, moving aside from its previous drafts restricted to shared resources, the *Berlin Rules* move its object to water resources at large. With reference to aquifers, it is also worth considering that all aquifers, connected and not connected with surface waters, are addressed by these Rules. In this regard, it is also necessary to take into consideration the Resolution adopted in 1994 by the ILC on Confined Transboundary Groundwater, clarifying the applicability of the future UN Water Convention to groundwaters related to an international watercourse (second paragraph), and commending States to apply the principles established by the Convention to confined groundwaters as well.

Then, the *Berlin Rules* chapter on Groundwater is to be construed taking into account this comprehensive scope. When they affirm that "The Rules of this Chapter apply to all aquifers", 'all aquifers' means not only transboundary aquifers, not only aquifers contributing or receiving water from surface waters (Article 36.1 Berlin Rules) but also national aquifers. All aquifers are equally implied in the provision establishing that "States, in managing aquifers, are subject to all Rules expressed in these Articles, taking into account the special characteristics of groundwater" (Article 36.2 Berlin Rules). These special features of groundwater are, mainly, slow movement, uncertain recharge/discharge and tiniest capacity to decontaminate itself once it is polluted, aggravated with unchecked abstraction. For its part, the ILC Draft Articles point out that their provisions apply to the "utilization of transboundary aquifers or aquifer systems" (Article 1 (a) Draft Articles), adopting the scope of the UN Water Convention.

2.3 Sovereignty of aquifers States

The Draft Articles include a provision underlining that "Each aquifer State has sovereignty over the portion of a transboundary aquifer or aquifer system located within its territory. It shall exercise its sovereignty in accordance with international law and the present articles." This clause is a safeguard against the eventuality that a limit could be established to the underground sovereignty of States, an unforeseen possibility at present, taking into account that oil and gas deposits are also deep underground assets, or that underground water could be considered a 'common good of mankind' similar to the status of 'common heritage of mankind' of the deep sea bed established by the 1982 Law of the Sea Convention. The Draft Articles provision was not drafted as a legal barrier to co-aquifer States, but as a reassurance towards the international community as a whole. However, it could be invoked in relation to co-aquifer States. The factors relevant to equitable and reasonable utilization listed in Article 5 of the Draft Articles, which include "The social, economic and other needs, present and future, of the aquifer States concerned" and "The existing and potential utilization of the aquifer or aquifer system" (Article 5 (b) (e)) stress the discretion of States regarding the uses of the aquifer, an element which reinforces the sovereignty safeguard of Article 3. Although that prerogative is subject to the limits imposed by international law and the Draft Articles, States are usually powerless faced with depletion of aquifers or dewatering of recharge areas outside their territory.

There is no such a provision in the Berlin Rules, neither in the general rules listed in Chapter II – VI nor in the groundwater provisions in Chapter VIII. Certainly, sovereignty of States over their water resources was not perceived to be threatened during the elaboration of the Berlin Rules, but it is also certain that circumstances change. To claim sovereignty that is not challenged could be redundant, but it is not harmful. However, it has to be highlighted that such sovereignty should be exercised "in accordance with international law and the present articles" (Article 3 *in fine*, Draft Articles).

2.4. Protecting the aquifer

The duty "to protect and preserve ecosystems within, or dependent upon, their transboundary aquifers or aquifer systems" (Article 10 Draft Articles) incorporated in the Draft Articles is included in the *Berlin Rules* as a general duty for all waters (Article 22 Berlin Rules) and it is equally applicable to groundwater. The provisions in the Draft Articles envisage that the measures for protection of ecosystems should encompass the quality and the quantity of water in the aquifer. This is the only rule in the Draft Articles establishing an obligation that embraces quality and quantity of groundwater, an obligation established specifically for the protection and preservation of the aquifers' ecosystems. On the other hand, the *Berlin Rules* under the heading of 'Protecting Aquifers' establish that "States shall take all appropriate measures to prevent, insofar as possible, any pollution of, and the degradation of the hydraulic integrity of, aquifers" (Article 41.1 Berlin Rules), embracing both elements in the protection of the aquifers.

When addressing pollution, the Draft Articles establish that aquifer States shall, individually or jointly, "prevent, reduce and control pollution of their transboundary aquifers or aquifer systems, including through the recharge process, that may cause significant harm to other aquifer States" (Article 12 Draft Articles). It is a programmatic provision that establishes no guidance as to the actions that should be prevented, and leaves to the national environmental policies the measures to be adopted. The *Berlin Rules*, on their part, indicate that, in order to fulfill their obligation to prevent pollution of an aquifer, States "shall take special care to prevent, eliminate, reduce, or control: (a) The direct or indirect discharge of pollutants, whether from point or non-point sources; (b) The injection of water that is polluted or would otherwise degrade an aquifer; (c) Saline water intrusion; or (d) Any other source of pollution" (Article 41.2 Berlin Rules) and "shall take all appropriate measures to abate the effects of the pollution of aquifers" (Article 41.3 Berlin Rules). They also add that "States shall integrate aquifers into their programs of general environmental protection, including but not limited to: (a) The management of other waters; (b) Land use planning and management; and (c) Other programs of general environmental protection" (Article 41.4 Berlin Rules), reaffirming the concept that surface and underground waters should be managed conjunctively.

2.5. Recharge and discharge areas

Both the Draft Articles and the Berlin Rules establish the duty to protect the aquifer from pollution also including "the recharge process" (Article 12 Draft Articles) or, in other words, the "sites where groundwater is withdrawn from or recharged to an aquifer" (Article 41.5 Berlin Rules).

The Draft Articles contain a specific rule for the protection of the recharge and discharge zones of aquifers, stating that States "shall take appropriate measures to prevent and minimize detrimental impacts on the recharge and discharge processes" (Article 11.1 Draft Articles), a duty that also comprises, in a transboundary context, non aquifer States "in whose territory a recharge or discharge zone is located" (Article 11.2 Draft Articles). In a transboundary context, the *Berlin Rules* establish the duty to "cooperate in managing the recharge of the aquifer" (Article 42.5 Berlin Rules), not a special rule for the protection of aquifers but a specific rule for transboundary aquifers.

2.6. Terminology issues. Aquifers and groundwater

Law is language, words, terminology, which define legal institutions. In the case of "groundwater" and "aquifers," the shift in terminology between these terms in the instruments devoted to the subject is loud and could not remain unnoticed. In the wording of the General Assembly Resolution 63/124 the object is 'aquifers', and as such, the heading and body of the Resolution refer to 'aquifers'. In the Annex, on the other hand, the ILC Draft Articles refer to both 'groundwater' and 'aquifers' in the preliminary paragraphs and exclusively to 'aquifers' in substantive provisions. The differences are qualitative, because aquifer implies geological strata while groundwater identifies water beneath the surface of the ground, the liquid element of the aquifer. While groundwater moves, the geological strata do not and, in a transboundary context, those differences do not remain unnoticed.

In this regard, which was the approach of the doctrine? If the ILA work is reviewed, the title of the *Seoul Rules,* approved in 1986, is "The Seoul Rules on International Groundwaters", although the first provision addresses "The waters of international aquifers" and the second, dealing with hydraulic interdependence, expresses that basin States "shall take into account any interdependence of the groundwater and other waters including any interconnections between aquifers, and any leaching into aquifers caused by activities and areas under their jurisdiction". The two remaining provisions of the Seoul Rules focus on the "Protection of groundwater" and on "Groundwater management and surface waters", stressing that the content of the aquifer, groundwater, is the main object of the Rules.

Another non-governmental instrument, the 1989 Bellagio "Model Agreement Concerning the Use of Transboundary Groundwater", drafted in the context of the Mexico-United States utilization of border aquifers, defines "aquifer", "transboundary aquifer" and "transboundary waters". Its provisions address groundwater -establishing rules for 'water quantity and quality measures' (Article IV) and for the operation of a database for their 'transboundary groundwaters' (Article V), and aquifers - advancing rules for the protection of 'the quality of transboundary aquifers and their waters' (Article VI). The Model Agreement proposes to set up a Commission, to prepare a Comprehensive Management Plan and to declare a Transboundary Groundwater Conservation Area, addressing "groundwater" in general and, eventually, "aquifers".

FAO, on its part, carried out a compilation of treaties and other legal instruments under the title of "Groundwater in international law" (Legislative Study No 86, Rome, 2005) giving preference to the liquid component of the aquifer. New programs and agreements, however, prefer the term "aquifer" in their instruments on the subject, *i.e.,* the Guarani Aquifer agreement of 2 August 2010 between Argentina, Brazil, Paraguay and Uruguay. On their part, Chapter VIII of the Berlin Rules is titled, laconically, "Groundwater", though in the text of the provisions both terms, groundwater and aquifers, are used. So, elaborating on the previous and other not quoted examples, the conclusion prevails that the term 'aquifer', comprehensive and technically accurate, supersedes the previous preference for 'underground water' and should be preferred as the more adequate denomination.

3. SIMILARITIES AND DIFFERENCES. LESS IS MORE OR VICEVERSA.

1. The *Berlin Rules* are a comprehensive set of rules addressing the management of all waters, surface waters and groundwaters, national and transboundary waters. The ILA proposal looks to formulate a unified body of rights and duties of States regarding water as a resource and as a common good; the Draft Articles, on their part, address specifically transboundary aquifers or aquifer systems.

2. The core interest of the *Berlin Rules* is the decantation of the general principles and the customary rules which constitute the international legal framework for water management, thus making them applicable to each category of waters and to every use of water. Accordingly, there are no general principles in the Groundwater chapter of the Berlin Rules, there are only some principles specially underlined for this category of waters. But, the important thing is that all principles and customary rules are applicable to groundwater, and to its recharge and discharge zones, in every aspect. This approach could complement the interpretation of the Draft Articles provisions when it comes to their implementation.

3. Taking into account that the *Berlin Rules* on Groundwater address not only transboundary but also national aquifers, the general principles and customary rules dealing with the management of aquifers are also valid for non-transboundary aquifers, joining international and national rules by drawing intrusive obligations at the national level. This is a possibility that goes beyond the scope of the Draft Articles, but could support the implementation of its rules to national aquifers as well.

4. A distinctive character of the *Berlin Rules* on Groundwater is the duty to carry out a conjunctive management of surface waters and ground waters, an approach absent in the Draft Articles. However, the definition of watercourse in the 1997 UN Water Convention and the Declaration of the ILC already mentioned, have broken new grounds in this sense. Additionally, the UN Water Convention and the Draft Articles are driven by parallel general principles and customary rules, and their harmonization in concrete situations will become necessary. The Berlin Rules would be an appropriate tool to advance that harmonization.

5. The Draft Articles limit the application of the rule of 'precautionary management' to the prevention of pollution while the *Berlin Rules* stress the umbrella clause stating the 'precautionary management' of aquifers as a general safeguard principle to be applied in managing aquifers, either rechargeable or non-rechargeable. With regard to the 'principle of sustainability' to which the Berlin Rules adhere, it is not incorporated by the Draft Articles.

6. The Berlin Rules adopt as a general rule the obligation of the aquifer States of transboundary aquifers not to cause significant harm to another aquifer State (Article 42.6 BR). On the other hand, the wording of the Draft Articles establishes that this duty is directed "to prevent the causing of significant harm to other aquifer States or other States in whose territory a discharge zone is located" (Article 6.1 Draft Articles).

4. DISCUSSION. It is worth exploring the harmonization of the definition and scope of surface and underground water in the 1997 UN Water Convention, the ILC Declaration on Aquifers and the Draft Articles, as governmental instruments, between them and with the non-governmental structure of the *Berlin Rules*.

5. INTERPRETIVE COMPLEMENTARITY

The Draft Articles and the Berlin Rules implied different levels of rules. The Draft Articles, as an outcome of the process of codification of the United Nations carried out by the International Law Commission, are driven to compile the existing practice of States and, if practice is scarce or absent, to propose rules of progressive development. Codification is, in itself, a process of distilling from the past, shaping in an organic set of provisions the scattered practice of States, and filling out the gaps in State practice with new rules. It is, essentially, a process of consolidation and completion of rules already existing but not duly identified. On the other hand the Berlin Rules, as a scholarly proposal, equally starts from the existing practice of States, but with a different goal. In fact, the purpose of an academic body would not be satisfactorily fulfilled with the systematic exposition of the actual practice of the international community, but by projecting into the future what the rules might be. Hence, non-governmental proposals are a contribution for the further development of law, as a model for future agreements and national legislation, and for the elaboration of programmes of international organizations. They are also of assistance in order to construe existing legal bodies, in an active interpretive complementarity.

Regional Transboundary Groundwater Management:
A Comparative analysis between the European Union and Mercosur Normative System

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ABSTRACT

International Groundwater regulation is a very difficult task. One of the reasons lies in the fact that while the transboundary effects of the actions are evident, one cannot ignore the local nature of many of the cause/effect variables involved.In consideration of this complex scenario, we suggest the need for a multi-dimensional normative system. We propose that contemporary regional models of governance may offer the opportunity to achieve the best balance between localism and universalism in environmental, and as a consequence, water and groundwater normative structure.

I propose a 'systems' approach to compare the EU water regulation structure with MERCOSUR laws and regulations relative to water management in order to observe the goals and failures of MERCOSUR groundwater management concerns, as part of environmental regulation. It is generally recognized that, up to the present, the European Community has constructed the best pattern of regional governance in the world. Concerning the special field of water management, we can find, besides general environmental regulation, a quite complete and structured framework of regulation. Nowadays the European normative structure over water protection is unified by the EU Water Framework Directive – adopted in 2000, which works as a central document and which is related with other specific norms such as the "daughter directive" concerning groundwater protection. The success of the system can be observed to this point in time.

Concerning MERCOSUR initiatives in the area of water protection, we can find many deficiencies. In fact, even if we consider there is a specific item on water resources listed among the thematic areas of the Environmental Framework Agreement, an instrument to implement and monitor water protection is yet to be developed, and the groundwater regulation is still more far from being addressed. Although some valuable documents have been produced, such as the elaboration of an Additional Protocol to the Framework Agreement on Water Resources, not yet adopted, as well as a recently adopted agreement on the Guarani Aquifer, there is a long way before we reach an efficient normative structure in MERCOSUR.

Key words groundwater management, water normative system, European Union, Mercosur

1. INTRODUCTION

Environmental protection, water resources included, is one of the factors that play a relevant role in shaping the new world order. However, water regulation is a very difficult task. One of the reasons, common to all environmental regulation, lies in the fact that while the transboundary effects of environmental actions are evident, one cannot ignore the local nature of many of the cause/effect variables involved. In consideration of this complex scenario, we suggest the need for a multi-dimensional normative system. Boisson de Chazournes (2007) has written in support of this position as follows: "le droit international de l'eau est, on le saisit, porteur d'un jeu d'émulations et de complémentarité entre des règles d'application universelle et celles empreintes de particularismes. Ces rapports sont la clé de son enrichissement".

Despite recognized importance, international groundwater regulation is still more complicated. The reasons for this had, for a long time, "to do with lack of full understanding or awareness of the characteristics and extent of groundwater, and with the rather embryonic nature of the law in this area, which is in part a consequence of the first reason" (McCaffrey, 1999).

2. OBJECTIVES

In consideration of this complex scenario, especially the very bipolar character of the issue and the need for a multi-dimensional normative structure (without entering the controversial theoretical debate concerning the merits of regionalism versus universalism), we propose that contemporary regional models of governance may offer the opportunity to achieve the best balance between localism and universalism in the water and groundwater normative structure.

Phillippe Sands (2003) considers the same over environmental law: "In application of the principle that different environmental standards could be applied to different geopolitical regions, the role of regional organizations is likely to increase significantly. They are frequently able to provide the flexibility needed to accommodate special regional concerns."

I propose a 'systems' approach to compare the EU water regulation structure with MERCOSUR laws and regulations relative to water management in order to observe the goals and failures of Mercosur groundwater management concerns. One cannot deny that the EU and Mercosur have, especially in the environmental and water protection field, the same objectives which make comparative analysis very usable for improving Mercosur regional integration process.

3. RESULTS

It is generally recognized that, up to the present, the European Community has constructed the best pattern of regional governance in the world. Concerning environmental policy it is well based on article 174 of the Treaty establishing the European Community and on the Sixth Environment Action Programme. At the special field of water management, we can find, besides this general environmental regulation, the management of natural resources as one of the areas singled out for priority action and, on water, a quite complete and structured framework of regulation.

Nowadays the European normative structure over water protection is unified by the Water Framework Directive (Directive 2000/60/EC) – adopted in 2000 (which replaced a range of directives in the field of water policy), which works as a central document in this field and which is related with other specific and local norms such as the "daughter directive" concerning groundwater protection (Directive 2006/118/EC).

The Environment Action Programmes set the EU role on accomplishing international environmental aspirations. Both the Water Framework Directive and the Groundwater daughter directive embody the concepts of integrated river basin management and set some goals to be achieved sequentially within basin and national levels. Their main objectives are to protect all water, by preventing and controlling pollution. The innovative character of the WFD consists on a new economic component which concerns the difficult problem of internalizing external effects over water and the putting into practice of efficient instruments for water management (Cavagnac and Gouguet, 2008). Moreover, the WFD and the GDD have precise values for water quality determination, criteria to identify upward pollution trends, and specific measures to prevent and control water pollution. (Crowhurst, 2007)

Mercosur environmental governance is weak, starting with the low priority placed on this area in the Treaty of Asunción (Garabello, 2002) and all its historical development (Franca, 2010). After long-time discussion, the Mercosur adopted the Framework Agreement on the Environment of Mercosur which entered into force in June 2004.

Concerning Mercosur initiatives in the area of water protection, we can find many deficiencies. In fact, even if we consider there is a specific item on water resources listed among the thematic areas of the Environmental Framework Agreement, an instrument to implement and monitor water protection is yet to be developed, and the groundwater regulation is still more far from being addressed, even though some valuable documents have been produced. As so, the elaboration of an Additional Protocol to the Framework Agreement on Water Resources Environmental Management and the recent adoption of an Agreement on the Guarani Aquifer were not even halfway to an efficient water normative structure in Mercosur.

4. CONCLUSION

On the one hand, the success of the EU water normative system can be observed to this point in time: the majority of the essential specific norms at national and basin levels are already in place as well as effective instruments to put the system in practice, even if they are not free of criticism and always have some points that would be improved.

On the other hand, it is fair to conclude that ensuring workable water and groundwater protection is something that Mercosur needs to learn from the EU experience. It is clear that Mercosur member States have experienced difficulty in constructing normative instruments which stand the test of effectiveness.

The Guarani Aquifer agreement illustrates very well Mercosur normative gaps and institutional deficiencies in this field. The adoption of a local instrument without having a general one for all Mercosur water and groundwater resources; the framework language of this particular document without precise values for water quality determination nor criteria to identify upward pollution trends, as well as no specific measure to prevent and control water pollution, are major problems.

But it is not only a question of normative construction, but mainly a matter of governance, of institutional structure and normative enforcement. In the EU, environmental purposes are a business of various institutions and the supranationality of their norms promotes compliance and helps strengthen its institutions. Finally, the central role of European courts leaves no doubt concerning the efficacy of its normative system.

In truth, the absence of effective normative enforcement and the vulnerability of conflict resolution mechanisms within Mercosur only serve to further erode the authority and efficacy of the institution. Still, the terms of the Guarani Aquifer agreement show the erosion on Mercosur institutional structure. The dispute settlement mechanism based on negotiations, specialized commission recommendations, and arbitral procedures without attention to Mercosur judicial organs, as well as the excessive attention given to the sovereignty over natural resources instead of normative harmonization, are just some of the critical reviews that we can do.

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Strengthening Water Governance Capacity for Transboundary Aquifers

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ABSTRACT

Groundwater reserves constitute the main source of fresh water available on Earth and represent a potential solution to contemporary water challenges. However, the lack of information on the natural status of groundwater and the absence of comprehensive norms for its regulation foster an unsustainable use of aquifers which can lead to their depletion. Transboundary aquifers are subject not only to competing demands from different uses at the national level, but also to diverse national jurisdictions. Competition for water resources, including groundwater, can lead to conflict, particularly in areas affected by socio-economical problems, political instability and cultural clashes. The creation of an appropriate legal framework for managing shared aquifers remains pending in the international agenda, despite the UN General Assembly Resolution on the "Law of Transboundary Aquifers" of December 2008 (A/RES/63/124). Aquifer states should conclude proper agreements in order to strengthen groundwater governance capacity, even though it might be a long and slow process, hindered by different factors such as political unwillingness and diverging economic interests. Experience on the ground shows the benefits of managing shared aquifers through specific projects implemented by international and local organizations. These projects require the compilation of available information on the status of the resources as well as the exchange of such information between aquifer states, the creation of joint committees and the implementation of cooperative mechanisms. They intend to rationalize the exploitation of groundwater resources and guarantee equitable benefits to participant States. Such projects might represent a more rapid and simple tool to foster the respect of those international principles contained in the aforementioned Resolution and to enhance shared groundwater governance capacity. Although limited in time and funds, and led by external institutions, those mechanisms initiate cooperation between aquifer states, improve the management of shared reserves, and demonstrate the positive effects of implementing appropriate joint utilization schemes; thus promoting and developing groundwater governance capacity. This paper argues that although such a project framework does not represent a long-term solution, it offers useful foundations for the creation of a permanent institutional structure and for the adoption of agreements which provide legal certainty and strengthen groundwater governance.
Keywords: Water Governance Capacity; Transboundary Aquifers; Legal and Institutional Framework; Cooperation mechanisms.

1. INTRODUCTION

The hidden nature of groundwater reserves is a major cause of the disregard towards such a resource and its marginalization in existing international law. However, being the primary source of water on Earth, it is regarded as a potential solution to current problems of water availability. Although the general principles applicable to groundwater resources are similar to those valid for surface waters (such as sovereignty, equitable and reasonable utilization, no significant harm and cooperation)[1], international agreements that rule the latter are generally inadequate for the protection and regulation of the former. The absence of clear and comprehensive norms at the international level aggravates the difficult situation of transboundary aquifers, which are subject to competing demands from different users at the national level and to diverse national jurisdictions. Moreover, transboundary ground waters are likely to be part of a wider system and to be connected with domestic or international surface waters (Eckstein, Y. and Eckstein, G., 2005). Beyond the normative gap, the peculiar characteristics of groundwater resources and the lack of information on their exact extension and qualitative status contributes to the inappropriate use of aquifers and their depletion. Drawing up a

[1] For a detailed description of the general principles included in the A/RES/63/124, see Mechlem, K. (2009)

proper legal framework aimed at protecting and managing groundwater reserves is still pending in the international agenda. The conclusion of *ad hoc* agreements can often be a long and slow process delayed by the conflicting political and economic interests of aquifer states. Therefore, shared aquifers are often unregulated. Nevertheless, there are positive examples of projects[2] implemented by international and local organizations in order to rationalize the use of transboundary groundwater reserves and properly distribute the related benefits, initiating cross-border cooperation between the participant States. Even if such a solution is limited in time and funds and externally driven, it represents a first step to recognizing the fundamental value of those resources hidden in the ground, to monitor and safeguard their status, to rationalize their extraction and better manage them. Cooperation activities can be developed at different levels and might entail various degrees of involvement; these efforts foster new and deeper commitments, creating a cooperation continuum that is "non-directional, dynamic and iterative" (Sadoff, C., Greiber, T., Smith, M. and Bergkamp, G., 2008). This paper argues that the positive results and the administrative structure created for the project constitute the first step of the continuum, offering a basis for the development of permanent institutions and the adoption of proper agreements in order to strengthen water governance capacity in relation to transboundary aquifers management.

2. DISCUSSION

Asymmetrical distribution and access to water reserves imply the possibility of an unequal exploitation in favor of those States with more financial and technical means. In such a way, these countries adopt a securitization strategy aimed at creating a *de facto* situation that affirms and preserves their right to exploit natural resources unilaterally. They exercise a "precautionary use" of resources; hence, it can be said, they act in a non-cooperative manner (Ferragina, E. and Greco F. 2008).

Unilateral exploitation of shared natural resources, such as transboundary aquifers, can result in an irrational and unsustainable use of them, impacting on the right to an equitable use that all the other States that share such resources have. This situation must serve as an inflexion point to reflect upon the potential damages which can occur to States and their people, in order to start a dialogue towards reaching cooperative agreements that set up the basis for effective governance of the aforementioned resources.

In this context, developing an *ad hoc* project brings numerous benefits, particularly in those areas with a low endowment of surface water resources and which suffer from droughts. Africa, for example, is commonly considered the dryest continent, however, it hosts some of the major groundwater reserves on Earth: 38 aquifers, all shared between two or more States. Significant evaporation rates, caused by high temperatures, increasing desertification and climate change are adding pressures on limited fresh water resources naturally located in some African regions. The constant decrease in water supply increases the risk of conflicts, especially in areas already affected by economic and political instability, social rivalries and cultural clashes. Nevertheless, water is well known for its cooperative potential, thus, the appropriate management of groundwater resources is fundamental to avoid confrontations between those countries sharing them. Aware of the fundamental role that groundwater reserves can play as an alternative solution to water shortages, various international agencies, supported by local organizations, have been studying, elaborating and implementing projects to this end.[3] In some way, this external contribution to the improvement of groundwater sustainability and management intends to balance the scarce capacities of national governments in administering such a

[2] In this paper, the term "project" refers to a methodological strategy conceived in order to develop plans and activities aimed at properly managing groundwater resources and strengthening water governance capacity of those people who benefit from the aforementioned actions. Both funds and operational efforts required to develop such strategy belong to donors from outside the beneficiary State/States. In this context, the terms "project" and "initiative" are used as equivalent.

[3] Inter alia the International Atomic Energy Agency (IAEA) and the Global Environmental Facility (GEF).

resource[4]. In fact, the appropriate cooperative management of shared aquifers stands on an efficient administrative system developed at national level. What is needed to enhance a country's "water governance capacity" is not only national policy and law, but also competent institutions, adequate mechanisms of implementation and effective enforcement mechanisms[5].

The involvement and lead of an international organization is valuable for a variety of reasons. First of all, external interventions intend to bring the financial support and the expertise missing at the national level. Moreover, international institutions are usually considered as third parties: trustworthy and authoritative. Hence, they are perceived as capable of resolving differences between aquifer states and as competent in organizing and rationalizing the conflicting interests of various users. Where national institutions are ill-equipped or corrupted, the presence of a foreign and impartial agency with an established institutional structure can represent a guarantee of equity and effectiveness. Thus, aquifer States are encouraged to collaborate with the aforementioned third party and their engagement in the externally-led project brings a direct and consequent commitment to each other.

Ultimately, the intervention of external bodies and the implementation of a pilot project reduce the lack of trust between participant States in setting up a cooperative system that considers their demands and distributes benefits between them. These benefits include: more information on the status of the aquifer, new technology, improved knowledge on how to adapt national plans according to sustainable rates of extraction and in respect of other aquifer States' rights. Presumably, participant States would understand that a joint management of shared groundwater brings more benefits than acting unilaterally.

One of the best inputs in terms of governance capacity is that these projects try to empower local populations and involve them in the decision-making process. Public participation represents one of the pillars of water governance capacity as instrumental for an appropriate implementation of law and policy. For this reason, it has been incorporated in legal instruments and institutional procedures and it constitutes a fundamental element of pilot projects too. The engagement of local communities and representative groups is fair and fundamental, given that they know the local reality and can easily identify the essential social needs that have to be satisfied. Their involvement implies easier access to information, including technical information, and higher transparency in the decision-making process. Civil society can also play an active role in the implementation phase, participating in co-management water schemes, and in the performance of monitoring activities. In addition, bringing those people to the table gives them a sense of responsibility, strengthening their respect for the rules they contributed to forming, and enables them to take future decisions and to lead water reform[6].

Another major focus of the discussed projects is to address the open-access problem. Given the lack of precise regulation at the international and national levels, the lack of adequate knowledge about the extension and properties of groundwater reserves and the inexperience in managing them in a sustainable way, these resources are "open" to unregulated exploitation and over-extraction from anyone with sufficient financial and technical means to do it. This uncontrolled, excessive and unequal use might compromise an aquifer, particularly in cases of confined or fossil ones which have low or non-existent regeneration capacities and risk being exhausted. Specifically, in case of transboundary reserves the inappropriate behavior of one State might threaten the possibilities of other aquifer States to benefit from groundwater utilization. An *a priori* assessment of the resource, in terms of extension, qualitative and quantitative status helps in evaluating the potentiality of exploitation for each aquifer and in determining the rate and pace of utilization. It goes hand in hand with the right of all States to

[4] Lopez-Gunn (2009) talks about private environmental governance, underlying the role that private actors (from transnational corporations and microfinance institutions to non-governmental organizations and international governmental institutions) can play in order to counterbalance the reduced capacities of national governments in providing public goods.
[5] The concept of "water governance capacity" is extensively treated in Iza, A. and Stein, R. (Eds) (2009).
[6] For further details on public participation see Iza, A. and Stein, R. (Eds) (2008), pp. 86 ss.

equally exploit shared groundwater resources, but also the responsibility to protect them[7] in order to avoid the risk of pollution that might cause irreversible damage[8]. Thereafter, the water management scheme implemented during the pilot project constitutes a useful basis to learn how to deal with open access resource management in the context of transboundary aquifers.

Although the main aim of an externally-led project is the proper assessment, protection and appropriate management of groundwater resources, there are other advantages, apparently unconnected, deriving from such interventions: *in primis* a socio-economical and cultural growth in aquifer States due to external financial support, instrumental availability and knowledge-sharing; and a stronger managing capability, in terms of administrative structure and operational capacities. In relation to the latter, it is worth mentioning that the lessons learned in managing groundwater reserves can be replicated and used as examples for the appropriate utilization of other natural resources. In the end, these projects might generate successful practices and results that, as a positive loop, tend to reinforce themselves and facilitate the managerial independence of aquifer States.

Some elements introduced through pilot projects are particularly sensitive, considering the highly political and strategic characteristics of groundwater; therefore it is argued that these initiatives serve as foundations to create a governance structure for transboundary aquifers. This *ad hoc* road to a governance scheme is just one of many, and complementary to an appropriate legal framework developed according to the principles contained in the UN General Assembly Resolution on the "Law of Transboundary Aquifers". Ideally, that framework would include a universal or at least a regional convention that delineates the contours of the rights and responsibilities of all aquifer states, and would be supported as well by specific bi or multilateral agreements which take into consideration the local characteristics of each underground shared water body.

From an international perspective it is fundamental to follow up with the development of the main principles included in the Resolution of the General Assembly on the "Law of Transboundary Aquifers" and to adopt shared normative instruments that close the existing formal and material gap in groundwater law. The Resolution sets up the founding values which should constitute the basis of inter-state agreements and be adapted according to the specific circumstances of the aquifer at issue. Although limited in number, there are valid examples of groundwater instruments that could serve as model for future agreements[9]. Beyond specific groundwater norms and principles, it is essential to develop new normative instruments in respect of and in connection with international agreements on wetlands, pollutants and land use, among others, since groundwater management and sustainability cannot be detached from them.

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[7] In relation to the need of reinforcing the protection of groundwater resources through appropriate norms see Mechlem, K. (2005), p. 59.

[8] The issue of contamination of a transboundary aquifer and the related liability of the contaminant State is particularly complex and has not been directly addressed in the Resolution of the General Assembly (A/RES/63/124), which includes a provision on the "Obligation not to cause significant harm" (Art. 6), on "Prevention, reduction and control of pollution" (Art.12) and another on "Emergency situations" (Art.17). Failing specific rules, apply international norms on the matter, in particular, the conventions on specific substances or other source of contamination and the "polluter pays" principle. It is worth to underline that International environmental law allows a certain degree of contamination as demonstrated by the obligation not to cause significant harm and the principles of precaution and prevention. However, the main problem in those cases is that there are no clear criteria aimed at fixing the maximum level of damage, hence, there is a scarce opportunity to ascertain the liability for water contamination and to obtain the reparation of damage, especially in relation to groundwater reserves due to their natural peculiarities.

[9] The 1977 Agreement on the Protection, Utilization and Recharge of the Franco-Swiss Genevese Aquifer is a unique example of international cooperation in managing a transboundary aquifer. It addresses issues of quality, quantity, abstraction and recharge and creates a Management Commission that sets up annual utilization plans and decides all the other issues connected with the conservation, extraction and management of the aquifer. The 1973 Agreement on a Permanent and Definitive Solution to the Salinity of the Colorado River between Mexico and the United States limits groundwater extraction rates in the Arizona-Sonora boundary area. Other useful norms are included in the 1992 UNECE Helsinki Convention which aims at protecting transboundary ground and surface waters and reducing transboundary impacts. A satisfactory overview on existing groundwater norms is offered in Burchi, S. and Mechlem, K. (2005). See also Mechlem, K. (2005), p. 62 ss.

As for the national legal frameworks, it is also relevant to address basic issues which in the context of transboundary aquifers must be harmonized. An appropriate groundwater national regulation should address issues such as rights of abstraction and utilization; hydrological connections with surface waters and with other ecosystems (wetlands, oases, etc.); impacts of land-use and other human activities; and the inclusion of wastewater discharge licensing and other legal mechanisms aimed at protecting groundwater reserves and their recharge areas from pollution, over-exploitation and consequent exhaustion. Moreover, it is important to include normative procedures that facilitate the establishment of users' groups, enable public participation and citizens' empowerment, and to create specific and capable authorities charged with implementing groundwater law, enforcing it, adjudicating disputes and intervening in critical situations. On the one hand, the aforementioned body of norms should be clear, "flexible, enabling and enforceable", aimed at establishing the main principles and powers and complemented with detailed regulations and implementation programmes[10], on the other hand, groundwater institutions should be equipped with operational capacities. Given that within the national dimension there is an interaction of different levels of regulation and administration (local, regional, federal), an effective coordination between those instances and the pursuit of common objectives are fundamental to guarantee a cohesive and sustainable management of the aquifer. While some States are already endowed with normative instruments which regulate groundwater and other natural resources or are prepared to develop appropriate norms, there are some others that do not present such a favorable legal background. Although the latter cases might be more challenging, the delineation of an adequate national legal regime is essential, not only for the urgency of the issue at stake, but also as a prerequisite for the adoption of bilateral and multilateral agreement between countries which share groundwater reserves.

Pilot international projects constitute the basis for further and independent cooperation between aquifer States. They support the development of trust, which in turn is the basis of political will for developing different kinds of agreements for governing transboundary aquifers, which also permeate to the national legislation of the aquifer states. This relationship between international initiatives and the development of legal frameworks for managing groundwater resources is not a linear process, but a necessary-complementary one.

3. CONCLUSIONS

Groundwater reserves hold a strategic role in contemporary global water challenges. However, they are scarcely protected from a normative perspective, as international water lawdo not address specific groundwater concerns, and mismanaged for lack of knowledge and capacities. In the case of shared aquifers, the situation is particularly complicated due to the lack of specific agreements and common administrative structures. The process of developing adequate norms and institutions might be long and complicated. A possible solution is represented by the implementation of international pilot projects which set the basis for further cooperation between aquifer States and adequate management of shared groundwater resources[11].

The positive results and the administrative structure created through international projects represent the first step of the cooperation continuum, offering a basis for the development of permanent institutions and the adoption of proper agreements in order to strengthen water governance capacity in relation to transboundary aquifers management.

Shared strategies, cooperative programmes and mechanisms for the management of transboundary aquifers are set up as a result of pilot projects. They are aimed at creating a cooperative spirit between the parties involved, giving a sense of responsibility to such participants and enabling them to further establish a permanent institutional structure for managing these resources. Lack of cooperation entails

[10] For further detail on groundwater legislation see in Nanni, M., Foster, S., Dumars, C. et al. (2002-2006).
[11] A successful example is offered by the GEF-funded Guarani Aquifer Project, see Foster, S., Kemper, K. and Garduño, H. (2004).

in some way lack of capacity, hence data sharing, a common vision and joint actions are consecutive and complementary steps aimed at fostering a mutual understanding of the resources and their proper governance.

Recently, the UN General Assembly recognized the human right to water and sanitation, underlying their importance in pursuing the Millennium Development Goals. Thus, water should be universally considered a public good and adequately protected, preserved, and shared in order to ensure peace, sustainability and justice. Such a declaration also reinforces the importance of aquifers in a context of uncertainty due to climate variability and water shortage; it mainstreams the UN Resolution on Transboundary Aquifers as platform for developing agreements that establish the basis for effective and equitable governance of groundwater.

The UN General Resolution on Transboundary Aquifers is a clear statement, delivered by the international community, of the strategic relevance of groundwater resources and the need of adequate governance frameworks; however, it is not enough. In an ideal scenario, there should be a treaty that provides a general framework for regulating shared aquifers between States, complemented by specific agreements which are developed according to the unique characteristics of single groundwater bodies, following the logic of subsidiarity.

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Integrating Groundwater Boundary Matters into Transboundary Aquifer Management

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ABSTRACT

With the UN General Assembly adopting a resolution on the law of transboundary aquifers, followed by the publication of the Atlas of Transboundary Aquifers by UNESCO-IHP, the transposition of the law into action and the need to move from policies to implementation is omnipresent. Political geographers have not extensively investigated the connection between groundwater resources to the metrics of space, scale and time common to the geographic study of natural resources. While it is well known that groundwater boundaries are different from surface water boundaries, and that the groundwater boundaries are both seen and unseen, the utilization of a transboundary aquifer in an equitable and reasonable manner requires taking into consideration the many boundaries associated with equitable and reasonable use without harm, resource protection, and the associated institutions.

A previously unrecognized typology for groundwater resources and user domains determined that (1) traditional approaches to defining groundwater domains focus on predevelopment conditions, referred to herein as a "commons" boundary; (2) groundwater development creates human-caused or a "hydrocommons" boundary where hydrology and hydraulics are meshed, and (3) the social and cultural values of groundwater users define a "commons heritage" boundary acknowledging that groundwater resources are part of the "common heritage of humankind". This typology helps define a fundamental unit of analysis to aggregate demographic, social, and economic data. Delineation of these boundaries is supremely political and morphs with changing social and cultural values.

Likewise, most of the emphasis regarding groundwater boundaries is two-dimensional; distinguishing between shallow and deeper groundwater systems is also important for governance. This presentation provides a starting point for differentiating between groundwater that may be governed under surface water regimes and deeper groundwater systems that may be governed by an aquifer State or as part of the global commons.

Boundaries can create competition between competing communities and institutions that do not promote the welfare of groundwater resources. Placing boundaries around user and resource domains (1) helps reduce the uncertainty within the groundwater "infosphere" and decreases reliance on knowledge entrepreneurs, (2) builds social identity and organization with groundwater resources, (3) localizes the institutional controls to promote fairness and trust regarding the use of groundwater, and (4) provides a roadmap to incentives to preserve the integrity of an aquifer or the associated ecosystem services. "Blurring the boundaries" promotes the philosophy that "we are all in this together".

Key words: Boundary typology, boundary spanning, dispute prevention

1. INTRODUCTION

Groundwater is a resource that is found everywhere. With dramatic changes in drilling technology, pumping technology and the availability of electrical and diesel power over the past 60 years, the number of wells has increased exponentially in many parts of the world (Moench, 2004; Shah, 2009). According to Zekster and Everett (2004) and Shah (2009), groundwater is the world's most extracted raw material, with withdrawal rates approaching 800 to 1,000 km^3 per year through millions of water wells. Pumping of groundwater is among the most intensive human-induced changes in the hydrologic cycle.

Information power or the "infosphere" of Lonsdale (1999) is perhaps the most important dimension of strategy in the geopolitics of groundwater. While groundwater monitoring networks have been in place in many intensively exploited regions of the world, few have been expanded since their inception (Moench, 2007). Groundwater data collection and information dissemination has created a large industry of "knowledge entrepreneurs" as described by Conca (2006).

And yet with 97% of the world's freshwater resources stored underground, the connection between groundwater resources to the metrics of space, scale and time common to the geographic study of natural resources has not been extensively investigated by political geographers.

2. OBJECTIVES

Despite the substantial body of geographic literature surrounding the historical, cultural and political development of boundaries (e.g., Anderson, 1999), it is ironic that few political geographers have addressed the problem of how boundaries are placed around common pool resources such as groundwater. Clearly, the new world order of groundwater will focus on the delineation of resource and user domain boundaries regardless if (1) the technological options to manage groundwater quantity and quality problems employ water transfers, managed recharge, or conjunctive use, or (2) the resource governance solutions include (a) collective or community action, (b) developing instrumental approaches such treaties, agreements, rights, rules and (c) prices or other incentives such as preserving the structural and ecological integrity of groundwater systems as summarized by Giordano (2009). The goal of this chapter is to provide an overview on groundwater boundaries within catchments, particularly the social and political boundaries, which do not necessarily line up with the technical or physical hydrologic boundaries.

3. THE BOUNDARIES OF GROUNDWATER

3.1 The Boundary Conundrum

Resource domains define the fixed spatial dimensions of resources (Buck, 1998). Spatial dimensions are used to define property rights that may be held by individuals, groups of individuals, communities, corporations, or nation-states. Rights to natural resource property are not a single right, but are rather composed of a "bundle of rights" such as rights of access, exclusion, extraction, or sale of the captured resource; the right to transfer rights between individuals, communities, corporations or nation-states; and the right of inheritance (Buck, 1998). Each "right" has an implied boundary.

The spatial extent of a resource affects both the ability of users to develop information and to assess their relative ability to capture the benefits of organization (Schlager, 2007). Yet with the assumptions associated with the bundle of rights and implied boundaries comes the fact that the assumptions, knowledge and understandings that underlie the definition of the rights and associated boundaries are uncertain and often contested (Adams *et al*., 2003). For example, the question of identity and its relation to the domains of natural resources is often overlooked (Dietz *et al*., 2002). Choices about water resources are value choices that involve distinct local communities of interest (Blomquist and Schlager, 2005). Defining boundaries around water resource domains is "a supremely political act" because they represent different interpretations of key issues such as water quality, water quantity, nature, economics and history (Blomquist and Schlager, 2005). The resulting boundaries may range from the international scale, to the national, regional, local, or even the individual scale. These come from the fact that water resources are coupled with the larger reality of a region, including its environmental, social, legal, and economic characteristics.

3.2 Why Boundaries Matter

Boundaries are "inner-oriented" or created by the will of a central government, or two or more states in an international setting, with the boundary indicating the limits of a political unit. All that falls within the confines of the boundary has a common bond. According to Casati *et al.* (1998), possession of a boundary is one mark of individuality in the ontology of geographic representation. Without a boundary, there can be no separation and control, and without control, it is doubtful where sovereignty in the full sense can be enjoyed (Bisson and Lehr, 2004). The existence of a boundary is the first criterion for the individuality of an autonomous entity.

Consideration of transdisciplinarity and a broad systems approach to exploring the geopolitics of groundwater yields a typology for groundwater boundaries. As depicted in Figure 1, this work found that traditional approaches used to defining groundwater domains focus on predevelopment conditions, referred to herein as a *bona-fide* "commons" boundary. Coastlines, rivers, watersheds or catchments, or rock outcrops are good examples of *bona-fide* boundaries for groundwater resource domains. At the global scale, the International Groundwater Assessment Center (IGRAC, 2009) developed a map of global groundwater regions that differentiated 35 regions on the basis of tectonic setting, present-day geomorphology, and the spatial extent of rock formations with contrasting hydraulic properties as part of the consortia of institutions undertaking WHYMAP (2008). Building upon the IGRAC mapping, the WHYMAP further refined the hydrogeologic regions into hydrogeologic units that form over 270 transboundary aquifers. The boundaries of the groundwater resources domains are based primarily on permeability architecture. The definitions of recharge and discharge zones in the Law of Transboundary Aquifers and the boundaries of aquifers in the Atlas of Transboundary Aquifers complied by Puri and Aureli (2009) fall under this category of boundary.

Groundwater development creates human-caused or *fiat* "hydrocommons" boundary. Focusing primarily on rivers and watersheds, Weatherford (2003) defined the "hydrocommons" as the convergence of hydrology and hydraulics yielding an area defined by the linkages of common water sources. *Fiat* boundaries are subjective boundaries demarcated by humans based on judgment and "ease" and represent groundwater user domains. Borders between countries are *fiat* boundaries. According to Anderson (1999), boundaries have no horizontal dimension, and that the crucial dimension of boundaries lies in the vertical plane or subsurface beneath the boundary. Three dimensional *fiat* objects are created by subterranean volumes of land assigned rights to minerals, the ocean, or groundwater. The capture area of a wellfield is an example of three-dimensional *fiat* boundaries in groundwater user domains (Casati *et al*., 1998). Likewise, large areas can be drained of groundwater by horizontal water "mines" such as qanats or karezes, found in the tens of thousands throughout the Middle East, which capture groundwater via gravity and drain towards portals. A body of groundwater within the EU Water Framework Directive refers to a distinct volume of groundwater within an aquifer or aquifers. Aquifer storage and recovery and aquifer replenishment programs that transmit surface water hundreds of kilometers from distant river basins to intensively exploited groundwater basins form a new hydrocommons. And unitization used by the oil industry to preserve the structural integrity of reservoir by "…government-mandated unitization of groundwater…is a solution to excessive access and drawdown … [where] a single "unit operator" extracts from and develops the reservoir. All other parties share in the net returns as share holders…" as suggested by Libecap (2005) may serve as one option to dealing with the emerging issue of overlapping jurisdictions or "values" related to groundwater.

The social and cultural values of groundwater users define a *fiat* "commons heritage" boundary acknowledging that groundwater resources are part of the "common heritage of humankind". The intensive use of groundwater is causing increased awareness of potential impacts to groundwater dependent ecosystems, spiritual resources, therapeutic resources, cultural and historical resources, and geothermal resources. These are natural and human boundaries associated with groundwater.

In order to protect deep confined aquifers, as well as spring waters and mineral waters used as therapeutic waters as part of a national or common heritage, de Marsily (1994) calls for the creation of "Hydrogeological Nature Reserves". Hydrothermal features are nature reserves that are not frequently considered within the context of groundwater resource domains. Yet, many have been used for thousands of years for therapeutic purposes, are World Heritage Sites, national and state parks, and are spiritually important to some cultures. And hydrothermal features are increasingly being explored as sources for renewable energy. Boundaries for groundwater user domains associated with common heritage sites vary from no protection to controlled areas.

The significance of this typology is that it focuses more on "problemsheds"—the boundaries of a particular problem defined by the issue-network—than on watersheds or catchments as recommended for water governance and management by Molden (2007). It also acknowledges that (1) groundwater systems are "boundary objects" shared by several different communities that are viewed or used differently by each of them, and (2) that groundwater scientists need to act as "boundary spanners" or persons that look across disciplinary, institutional, geographic, temporal, and sense-making (framing) boundaries for the exchange of information between an organization and groundwater system as described by Warner *et al.* (2010).

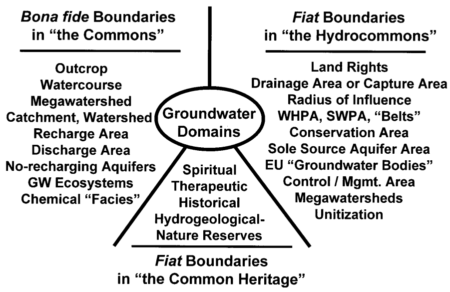

Figure 1. Inventory of groundwater domains. Adapted from Jarvis (forthcoming)

3.3 The Third Dimension

Up to this point, the discussion has focused on the planimetric boundaries associated with groundwater domains under both static and dynamic conditions. Lopez-Gunn and Jarvis (2009) synthesized the results of conceptual and numerical models of ideal groundwater systems, along with the mechanical limitations associated with pumping groundwater from great depths, to argue for a vertical dimension for distinguishing between shallow and deeper groundwater systems. Their work proposed a groundwater governance model that differentiates between shallow groundwater systems and deep groundwater systems. They found that shallow groundwater systems that are hydraulically connected to surface water resources may extend to depths approaching 305 meters. This boundary was proposed as a starting point for differentiating between groundwater that may be governed under surface water regimes and deeper groundwater systems that may be governed as part of the global commons.

4. DISCUSSION AND CONCLUSIONS

Changes in population, the world's climate, effectiveness of water treatment and conservation technologies, and social values all affect the rate of groundwater pumping, recharge, and ecological response with time. The types of spatial entities associated with groundwater resource domains not only occupy space, but also sometimes share space with other spatial entities. Governance, management, and use of shared resources such as groundwater cannot be treated independently and requires viewing the linkages between the user and resource domains as a problemshed rather than through the lens of the catchment (Molden, 2007).

Boundaries, either political or defining a resource or user domain, are obviously related to the control or the distribution of groundwater; boundaries are used to exclude some users while at the same time providing the appropriators an opportunity to develop information and capture the benefits of organizing within the boundaries (Schlager, 2004; 2007).

Social psychologist Mark van Vugt (2009) identified four conditions for the successful management of shared resources: information, identity, institutions, and incentives. Placing boundaries around user and resource domains (1) helps reduce the uncertainty within the groundwater "infosphere" and decreases reliance on knowledge entrepreneurs, (2) builds social identity and organization with groundwater resources, (3) localizes the institutional controls to promote fairness and trust regarding the use of groundwater, and (4) provides a roadmap to incentives to preserve the integrity of an aquifer or the associated ecosystem services. Clearly, boundaries can create competition and conflict between communities and institutions that do not promote the welfare of groundwater resources often times leading to "dueling expert" situations as described by Jarvis and Wolf (2010). Implementation of the Law of Transboundary Aquifers will require groundwater scientists and policy makers to become boundary spanners that acknowledge the many different ways a boundary entity like groundwater can be viewed and used. Van Vugt (2009) suggests that it is important to think of ways to "blur" the boundaries by promoting that "we are all in this together" to prevent disputes over the shared resources.

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Transboundary Water and Transboundary Aquifers in the Middle East:
Opportunities for Sharing a Precious Resource

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ABSTRACT

Surface and groundwater resources in the Middle East are to a large extent transboundary. While much attention is given to the surface water and river courses crossing national boundaries in the region little has been achieved in understanding the sometimes hydrogeological complex transboundary aquifer systems. Much political attention is given to the rivers Euphrates, Tigris, Jordan and Nile as they connect Arab and non Arab countries. However, also between the Arab countries surface and groundwater crosses political boundaries and only few regional organizations address the need for improved internal Arab cooperation on shared water resources.

An overview of confirmed and potential transboundary shared surface water and aquifers between ESCWA member countries and between ESCWA member countries and non member countries will be presented. Often detailed hydrogeological knowledge is still limited at national or trans-national level on the individual transboundary shared aquifer, some bilateral or multilateral cooperation between riparians (water course and aquifer states) have been taken place and are taking place in the region. In most cases the principles underlying the UN 1997 Convention on the Law of the Non-navigational Uses of International Watercourses and the UN General Assembly 2008 Resolution on the Law of Transboundary Aquifers as well as basic principles of IWRM applied in a transboundary context are already considered to some extend as guidance for individual cooperation mechanisms that may eventually develop into bilateral, multilateral or regional agreements and/or conventions.

ESCWA supports its member countries towards bilateral as well as regional cooperation mechanisms through a number of tools such as the cooperation through the Committee of Water Resources and activities of the ESCWA work plan, shared water resources assessments and guidance, development of negotiation skills, dispute resolution and regional advisory services responding to specific requests from member countries.

Keywords: transboundary water, transboundary aquifers, cooperation, regional organisations, regional mechanism

1. INTRODUCTION

Processes at global level led to the 1997 United Nations General Assembly resolution on the Convention on the Law of the Non-navigational Uses of International Watercourses (so-called watercourse convention, UN GA, 1997) and the 2008 United Nations General Assembly resolution on the Law of Transboundary Aquifers (UN GA, 2009). Additionally a number of regions have addressed transboundary water resources (sometimes also with direct reference to groundwater) through adapted regional legal instruments such as the water convention and related protocols of the United Nations Economic Commission for Europe (UN ECE, 1992), the revised water protocol of the Southern African Development Community (SADC, 2000) or the European Union Water Framework Directive (EU, 2000) with its EU Groundwater Directive (EU, 2006).

In the Middle East most of the larger surface water as well as groundwater systems are of transboundary nature and considered shared systems. So far no regional legal instrument is available to assist the countries in the region in the management and cooperation of these shared resources. Lately, the League of Arab States (LAS) through the Arab Ministerial Water Council (AMWC) agreed per resolution to prepare a regional legal framework to serve as a basis for cooperation and management of shared water resources within the Arab region. The present paper elaborates on the situation at the global and regional levels while discussing also possible options for a future regional legal framework applicable in the ESCWA / Arab region.

2. PROCESSES AT GLOBAL LEVEL AND IN OTHER REGIONS

Based on a number of processes and discussions, particularly the processes towards and following the 1966 Helsinki Rules on the Uses of the Waters of International Rivers (ILA, 1966) the global discussion led after thirty years to the 1997 United Nations General Assembly resolution on the Convention on the Law of the Non-navigational Uses of International Watercourses (so-called watercourse convention, UN GA, 1997). 13 years later and despite the fact that a large majority of states who initially voted for the UN GA resolution[1], the watercourse convention is one of a few multilateral environmental agreements that has still not come into force due to the fact that it has not fulfilled the required 35 ratifications by member states. A number of publications have reviewed reasons for this delay (e.g. Salman, 2007).

The definition of the term "watercourse" formulated in this convention focussed mainly on the actual water in a surface water body or in groundwater connected to a respective surface water body ("*system of surface waters and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus*", Art. 2, UN GA, 1997). It was recognised that this watercourse definition does not reflect on so-called fossil, i.e. non-renewable groundwater resources or groundwater with negligible recharge which is normally not connected to a surface water body and/or not flowing into a common terminus. Furthermore the suitability of groundwater for different uses often depends on its mineral content/composition (i.e. groundwater quality) which again is closely related to the interaction between water and rock and/or potential human interference in the natural system (i.e. pollution). This led to an additional focus on aquifers or aquifer systems comprising the groundwater within the saturated zone and its actual reservoir rock ("*container*"), instead of only the groundwater itself.

As a matter of particular interest in additionally addressing those groundwater resources which are not covered in the watercourse convention the UN International Law Commission (UN ILC) was mandated by a UN GA resolution (UN GA, 2003) to address such groundwater as part of their programme of work under the topic "shared natural resources". In fact the topic "shared natural resources" comprised groundwater, oil and natural gas, recognising some similarities between fossil, i.e. non-renewable groundwater, oil and natural gas resources. .

In a number of sessions the UN ILC decided to widen its approach towards all groundwater, and not only addressing the groundwater being excluded in the water course convention. The final UN ILC draft articles on transboundary aquifers also include provisions for the management of recharge and discharge areas of transboundary aquifers. These may actually already be covered through the provisions of the watercourse convention, esp. in the case of an international watercourse being part of the recharge or discharge zone of a transboundary aquifer. Based on the UN ILC work a list of draft articles on the law of transboundary aquifers incl. commentaries (UN ILC, 2008) was brought into debate at the UN General Assembly and led to the UN GA resolution (UN GA, 2009) to recommend the draft articles for consideration by the member countries. The resolution includes the following decisions:

"4. Takes note of the draft articles on the law of transboundary aquifers (...) and commends them to the attention of Governments without prejudice to the question of their future adoption or other appropriate action;

[1] The resolution received 103 votes in favour to 3 against with 27 abstentions.

5. *Encourages the States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers, taking into account the provisions of these draft articles;*
6. *Decides to include in the provisional agenda of its sixty-sixth session an item entitled "The law of transboundary aquifers" with a view to examining, inter alia, the question of the form that might be given to the draft articles."*

Due to the nature and content of the individual articles and their interpretation given in the commentaries of the UN ILC the law of transboundary aquifers seems to be partly overlapping with the watercourse convention. Other criticism makes explicit reference to the states' (limited) sovereignty over natural resources (McCaffrey, 2009). Hence a debate at global level might be necessary to decide how the content of both legal instruments could possibly be used in the future without causing any discrepancies or misunderstandings.

The United Nations Economic Commission for Europe (UN ECE) developed the ECE water convention (UN ECE, 1992) following similar principles of the Helsinki Rules. The convention and its protocols provide a solid basis for the management and cooperation on transboundary water for ECE member states with a particular focus on pollution prevention and a clear follow up mechanism with a secretariat and regular meetings of the parties to the convention. In 2003 the UN ECE decided to open their regional convention also to states not being members of the UN ECE (UN ECE, 2003). This amendment is currently still in the process of ratification and hence not yet in force.

Based on the global watercourse convention the Southern African Development Community (SADC) developed an adapted set of articles in the revised SADC water protocol for the southern African region (SADC, 2000). The provisions of the SADC water protocol already allow a more integrated approach to transboundary surface and groundwater in one legal framework document. The SADC water protocol was further used in the region to provide the basis for a number of specific bi- or multilateral basin agreements and commissions, addressing surface and groundwater according to the local / regional needs.

Within the European Union (EU) another rather water quality and environmental protection related approach led to the EU Water Framework Directive (EU WFD, EU, 2000). Groundwater issues were later incorporated through the EU Groundwater Directive (EU, 2006). Both instruments together constitute a comprehensive tool for the management of transboundary surface and groundwater resources for states which are organised in an interstate mechanism such as the EU. It might be worth mentioning that the EU Groundwater Directive developed a new terminology; specific groundwater or aquifer management units, i.e. aquifer sub-units, so-called "*groundwater bodies*" which do not necessarily comprise the whole aquifer or aquifer system.

Since the UN GA resolution on the law of transboundary aquifers addresses groundwater and the reservoir rock in a new, more holistic way, it remains to be seen whether amendments to the existing conventions, protocols or directives will be needed at the regional level or if the existing legal instruments may be applicable to cover these groundwater related aspects already.

3. CHALLENGES FOR WATER RESOURCES MANAGEMENT IN THE ESCWA AND ARAB REGION

The alarming situation with regard to water resources availability in most countries of the region has lead to greater reliance on: (1) external renewable surface water resources that originate outside their national borders, (2) non renewable groundwater reserves with a trend towards exhaustion of many aquifers, and (3) non-conventional water resources in the form of desalinated sea and brackish waters as well as treated wastewater. Additionally to the overall scarcity concerns, national water governance and management issues are still causing serious concerns esp. with regard to water quality protection and allocation of large water quantities to less productive and/or less socially relevant sectors.

It is estimated that the bulk of all available surface water resources in the region, represented by the major international rivers (Nile, Euphrates, Tigris, and Senegal), originate outside of the region's borders, and in some cases lead to political tensions between downstream and upstream countries. Although these major rivers represent a large percentage of the renewable water resources, there are many smaller surface water resources (rivers, streams, seasonal spate flows, renewable groundwater, etc.) that cross borders of the region's countries and as such need to be managed jointly in an integrated manner in order to maximize their socio-economic returns.

Moreover, due to the development in drilling and pumping technologies during the past four decades, countries in the region are developing and exploiting aquifers at an increasing rate, with groundwater gaining importance for domestic water supplies and increasingly for irrigation purposes. As most shallow aquifers are already extensively used, countries are investing further into the exploration and development of deeper and farther aquifers, which, in many cases are part of more extensive regional cross-boundary aquifers. Large parts of the region are further underlain by extensive rather non-renewable groundwater / aquifer systems. While renewable groundwater often links to surface water courses and may be included in their overall management, non-renewable groundwater resources require specific adapted management approaches.

Non-conventional water resources are gaining prime importance in parts of the region, particularly within the countries of the Gulf Cooperation Council. It is estimated that the desalination capacity of the Arabian Gulf region amounts to half of the world's capacity. At the same time the region faces serious limitations in industrial capacity, research and development in desalination technologies.

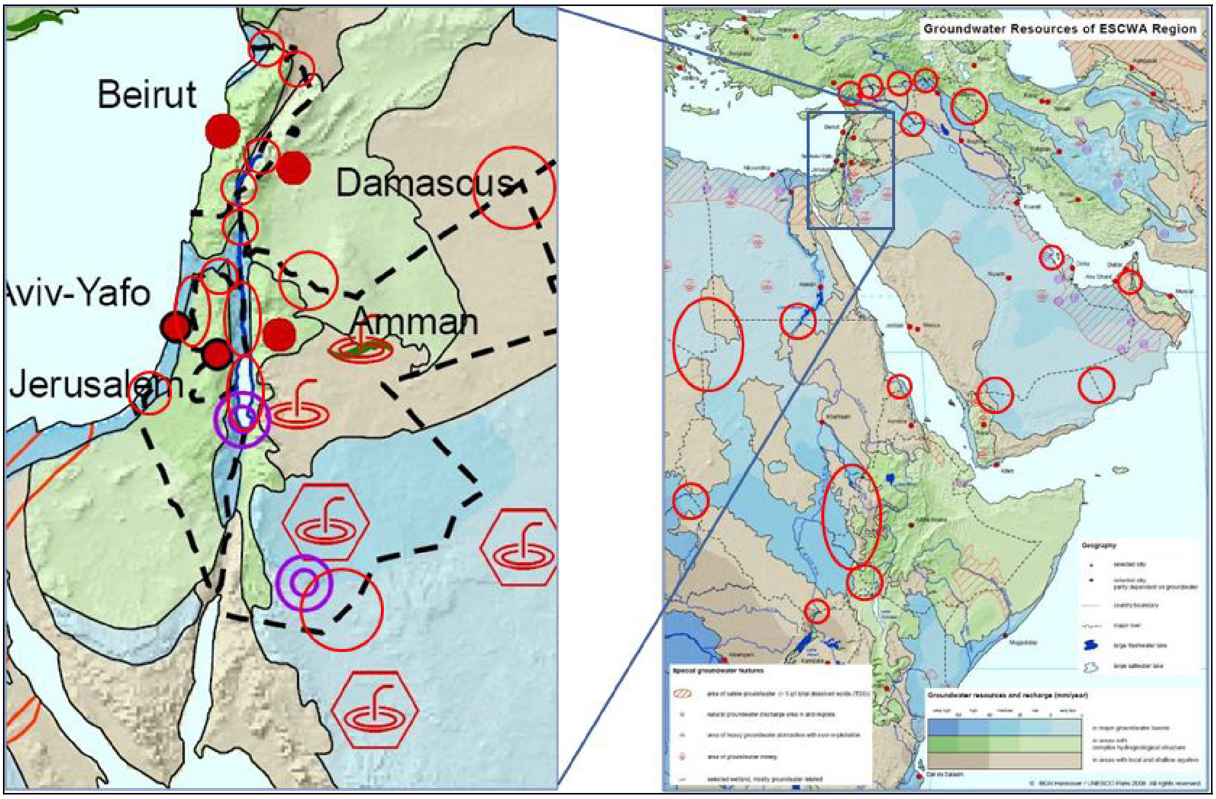

Figure 1: Proven and potential transboundary / shared aquifers between ESCWA member countries or between ESCWA member countries and neighbouring countries (presented with circles and ovals, location and size only indicative, as full horizontal extent often not fully defined), based on WHYMAP (2008)

ESCWA assists its member countries in issues related to shared water resources, based on mandates of two ministerial session resolutions; Resolution 233 (UN ESCWA, 2001) and Resolution

244 (UN ESCWA, 2003). But already since the 1990s ESCWA has continuously worked jointly with its member countries, regional and external partners (such as ACSAD, BGR, Germany and others) towards a better understanding of the hydrogeological features of transboundary aquifers in the ESCWA region. Based on a number of publications (e.g. UN ESCWA, 1992) it is possible to delineate a range of more than 20 transboundary aquifer systems in the region (Fig. 1). An ongoing study together with the German Federal Institute for Geosciences and Natural Resources (BGR) is currently undertaken to build an inventory of the most relevant transboundary water resources (surface water and groundwater / aquifers) in Western Asia. The approach and preliminary results will be presented in a separate paper (Al-Mooji and Renck, 2010).

4. TOWARDS REGIONAL LEGAL INSTRUMENTS FOR SHARING WATER RESOURCES

Realizing the pivotal role of water for sustainable development and the compounded impacts of water scarcity at the local, national and regional levels, the League of Arab States (LAS) established the Arab Ministerial Water Council (AMWC). During its first session in June 2009 the Council agreed that water security is among the key concerns facing the region and set out to prepare a regional strategy for water security in the Arab region. The Council further identified shared water resources as a regional priority and emphasized the importance of using all available international water-related legal instruments to secure and protect Arab water rights.

In this context, the Council passed a resolution during its second session in July 2010 to:

> *"Invite the Center of Water Studies and Arab Water Security and the United Nations Economic and Social Commission for Western Asia (ESCWA), in coordination with the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and the Stockholm International Water Institute (SIWI) to prepare a draft legal framework on shared waters within the Arab Region for its discussion during the next meeting of the Technical Scientific Advisory Committee of the Ministerial Council in January 2011."*
> Arab Ministerial Water Council, Session 2, Resolution 4, Item 3 (AMWC, 2010)

In the absence of other regional legal instruments, this development can be viewed as a major step towards improved legal arrangements among the Arab countries. Based on the various regional meetings related to the UN GA transboundary aquifers resolution preceding the Council decision it can also be seen in relation to the UN GA recommendation No 5 of the resolution on the law of transboundary aquifers ("*Encourages the States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers, taking into account the provisions of these draft articles*", UN GA, 2009).

The Arab region has the chance to clearly position itself with regard to the management of shared water resources not only on the wider regional level (between the region and the bordering non-Arab countries), but also between countries in the region. According to discussions with committee members and based on the wording of the above resolution, the ultimate aim of the proposed legal framework is to serve as a guide that sets the main principles upon which riparian countries / aquifer states of shared water resources can develop their specific joint management and allocation agreements. The term "shared water resources" in the context of the resolution is understood as both, surface and groundwater (renewable and non-renewable) that exist, flow across, underneath and/or along common national borders of two or more countries.

Currently the mandated organisations have started a phased approach to the implementation of the AMWC's resolution and will present the progress during the next meeting of the AMWC's Technical Scientific and Advisory Committee in January 2011 as requested. Of particular interest is the question to what extent the proposed draft Arab legal framework shall address specific factors or rules for water allocation between riparian or aquifer states, i.e. to specify rules for the implementation of one of the general principles; the equitable and reasonable utilization.

The general guiding principles most often referred to in the different international legal instruments can be summarized as follows: (1) (limited) sovereignty, (2) general obligation to cooperate, (3) equitable and reasonable utilization, and (4) obligation not to cause significant harm. Of these four general principles, it seems that the general obligation to cooperate is the least contentious. While this principle in its generality enjoys a wide consensus among the different countries, it is realized that there might be differences on the degree of details to be included in any legal instrument at the wider international level, i.e. a framework convention. The other three general principles, however, have been a source of contentious discussions.

Generally, positions of riparian countries on these principles are mostly determined by their geographical locations. Upstream countries tend to opt for the inclusion of the sovereignty principle, which gives them greater control over shared water resources. Although the sovereignty principle is aligned with the UN charter, unlike land and fixed borders, water resources are of a mobile nature distributing benefits across borders, and as such are more likely to be justifiably subject to only limited sovereignty. According to the same argument, downstream countries are usually against the inclusion of the sovereignty principle over shared water resources. On the other hand, downstream countries tend to put greater emphasis on the no significant harm principle as the overriding principle that determines water allocation between riparian countries. For the same reasoning, upstream countries are more likely to object to such interpretation and tend to align their position towards placing more weight on the sovereignty principle, or if not successful in that endeavour, towards the equitable and reasonable utilization principle thinking that this gives them an edge over downstream countries.

From the general reading of the countries position towards the equitable and reasonable utilization principle, it seems that all countries are in agreement of its notion of equity and fairness. However, the countries may differ in the weighing of the different factors that determine an equitable and reasonable utilization of a shared water resource. This is especially important when existing legal instruments include a wide range of different factors which have to be considered in defining and identifying an equitable and reasonable use and share of shared water resources. There are some arguments about the question if

- it is advisable to formulate factors determining equitable and reasonable utilization already at the stage of a regional legal framework or alternatively
- to leave the allocation rules to the development of basin-specific bi- or multilateral agreements.

By clarifying the basic factors contributing to the elaboration of allocation rules, the discussions on the principles of sovereignty and no significant harm may become less contentious. The latter approach leaves the weighing of factors which determine equitable and reasonable utilization to the countries in specific basin agreements and may see the Arab legal framework more as guidance on how to proceed in specific basin setups rather than as a prescription of rules to be applied.

5. CONCLUSIONS

While a number of legal instruments already exist at global and at various regional levels, the Arab region only recently decided per resolution of the AMWC to develop a legal framework for the management of shared water resources between its member countries. At global and regional level it might be considered necessary to review existing legal instruments in the light of the UN GA resolution on the law of transboundary aquifers. The recent developments in the Arab region, to go into the drafting of a legal framework document, allow taking into account all different legal instruments at global level and from other regions to develop the best possible set of legal principles and arrangements for the needs in the Arab world. UN ESCWA continues to serve its member countries and support the LAS in the processes towards better inter-state management and cooperation on shared transboundary surface water resources and aquifers through mandates by ESCWA Ministerial Session resolutions, its regular programme of work, meetings of the Committee on Water Resources, Expert Group Meetings and through Regional Advisor services based on requests from the member countries.

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International Shared Aquifers in the Arab Region

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ABSTRACT

The **Arab countries** are sharing many aquifers , which are in some countries one of the most important sources of water .
We will focus on the ground water resources in the Arab region between Arab – Arab countries and Arab countries with neighbouring countries , we will give case studies from the region , and the benefit of cooperation
The **" Law of Transboundary Aquifers "** and the draft convention could be , in case it is amended , an international Water Law and Convention for the benefit of all the countries especially for the Arab countries .

Keywords: Arab States, Successful agreements, Occupied Territories, Legal Instruments, Water Security Strategy, Council of Arab Ministers for Water.

1. INTRODUCTION

Twenty two **Arab States**, members of the League of the Arab States, are located in an arid and semi-arid zone, in a total area of about 14 million square kilo meters ,out of which 87% is desert .

Renewable water resources in the Arab region are estimated at about 335 Km3/year where more than 65% of which are originating outside the region mainly conveyed through international rivers. Although extensive aquifer systems are encountered, ground water contained in such systems is almost non-renewable . Renewable groundwater on the other hand is limited to specific regions where aquifers of limited extend are prevailing .

Fossil aquifers are a particularly important but fragile resource. Vast reserves underlie the Arab countries, there are about twenty deferent aquifer systems, with total reserves estimated at 143,8Km3. Eight of these aquifers are shared between countries .

At present, groundwater resources in the region, in general, are in critical condition as volumes withdrawn far exceed natural recharge, resulting in a continuous decline in groundwater levels. As reserves shrink , quality deteriorates and there is often saline or sea-water intrusion . Though the overdraft of groundwater continues in many Arab countries, especially for agricultural uses, many efforts have been undertaken throughout the region to incase groundwater recharge, and to reduce the withdrawal by relying on non-conventional water resources (desalination plants and recycling wastewater) or by water conservation measures .

Still[, the utilization of groundwater is subject to socio-economic, institutional, legal, cultural, ethical and political considerations however, its beneficial use is often constrained by weak social and institutional capacity and poor legal and policy frameworks .

Since groundwater systems are often the only source of fresh water in most of the Arab countries, where demand is rapidly increasing, water resources are contained in shared regional aquifers that represent a secure supply for all uses and are thus critical for national and regional water security .
The most important shared aquifers in the Arab region are :

1. the Nubian Sandstone Aquifer System
2. the North Western Sahara Aquifer system
3. Saudi Arabia and the Aquifers of the Arab Peninsula.
4. the basalt Aquifer .
5. the mountain aquifers : the source of life for the West Bank .
6. Chad basin
7. Dizi sandstone aquifer
8. groundwater resources under Israeli occupation .

Countries	Aquifer System	Extension (km2)	Exploitable Reserves (km3)
Egypt, Libya, Sudan, Chad	Nubian Sandstone	2 200 000	6 500
Algeria, Libya, Tunisia	North Western Sahara	1 000 000	1 280
Algeria, Libya, Niger	Murzuk Basin	450 000	60 - 80
Mauritania, Senegal, Gambia	Maastrichtian	200 000	480 - 580
Niger, Nigeria, Chad, Sudan, Cameroon, Libya	Chad Basin	600 000	170 - 350
Saudi Arabia, Bahrain, Qatar, United Arab Emirates	various including Saq Aquifer	225 000 - 250 000	500 - 2 185
Jordan (only)*	Qa Disi Aquifer	3 000	6

* extends into Saudi Arabia, where it is known as the Saq Aquifer which is included in entry above

Many Arab countries, understanding the need of the integrated management of groundwater resources, especially shared aquifers, decided to cooperate with riparian countries, toward mutually beneficial and sustainable shared aquifer development and management and they reached some form of agreement or treaty between parties sharing the aquifer system we, here, give you some examples of **successful agreements** in the Arab region between Arab – Arab countries and Arab - non-Arab countries .

2. THE NUBIAN SANDSTONE AQUIFER SYSTEM (NSAS)

It is shared by four countries, Egypt 37%, Libya 35%, Sudan %17 and Chad %11.so the total area is 2.17 million km2 .

1. A monitoring network was established of Groundwater Wells .
2. Nubian Aquifer Regional Information System was developed
3. Establishment of the Joint Authority for Study and Development of the Nubian Sandstone Aquifer in 1999 among the four countries .

Challenges and constraints

1. The flow of information between relevant partners needs to be encouraged .
2. Lack of Continual monitoring of the aquifers .
3. Financial sustainability is lacking and inability to mobilize funds by the Member states.
4. Lack of a binding legal agreement among the member states .

Figure 11. Areal distribution of the Nubian Sandstone

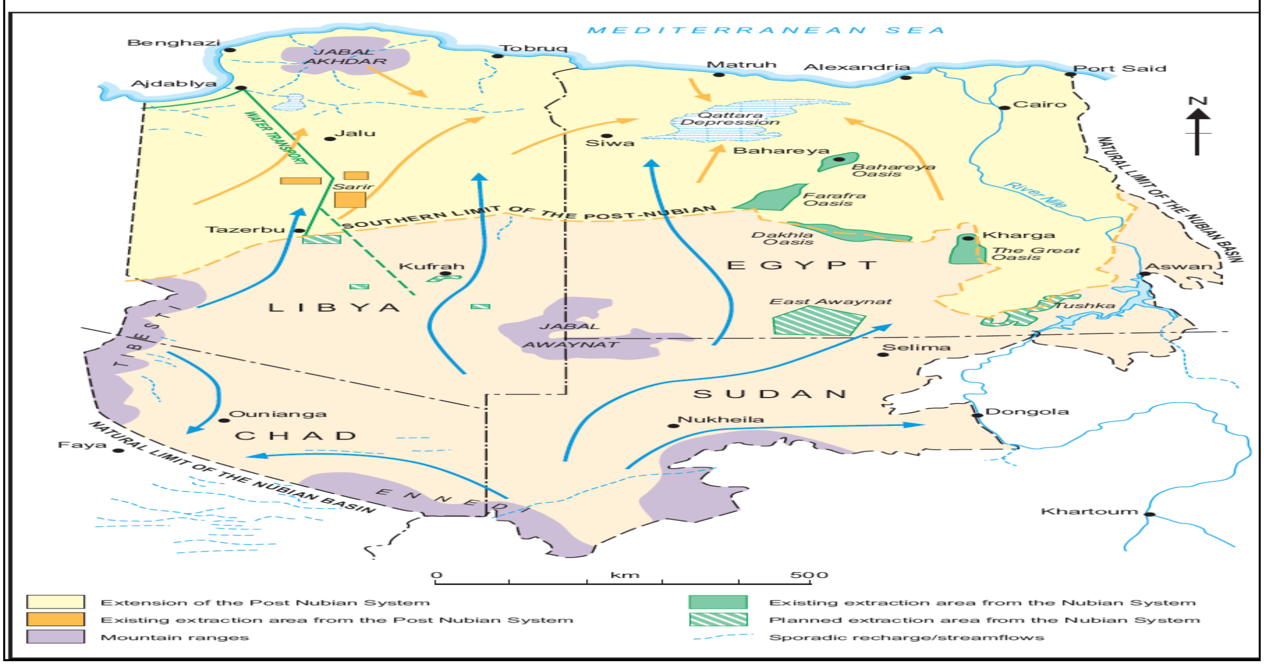


Table 3. Essential data of the Nubian Sandstone Aquifer System

Country	Nubian system (Palaeozoic and Mesozoic sandstone aquifers) Area (km²)	Nubian system Fresh water volume in storage (km³)	Post Nubian system (Miocene aquifers) Area (km²)	Post Nubian system Fresh water volume in storage (km³)	Total volume of fresh water in storage (km³) 1	Total recoverable groundwater volume (km³) 2	Present extraction from the Post-Nubian system (km³)	Present extraction from the Nubian system (km³)	Total present extraction from the NSAS (km³)
Egypt	815,670	154,720	426,480	97,490	252,210	5,180	0.306	0.200	0.506
Libya	754,088	136,550	494,040	71,730	208,280	5,920	0.264	0.567	0.831
Chad	232,980	47,810	–	–	47,810	1,630	–	0.000	0.000
Sudan	373,100	33,880	–	–	33,880	2,610	–	0.840 3	0.833
Total	2,175,838	372,960	920,520	169,220	542,180	15,340	0.570	1.607	2.170

– Not applicable
1. Assuming a storativity of 10^{-4} for the confined part of the aquifers and 7% effective porosity for the unconfined part.
2. Assuming a maximum allowed water level decline of 100 m in the unconfined aquifer areas and 200 m in the confined aquifer areas.
3. Most of this water is extracted in the Nile Nubian Basin (833 Mm^3/yr) which is not considered to be part of the Nubian Basin.

Source: CEDARE/IFAD (Programme for the development of a Regional Strategy for the Utilisation of the Nubian Sandstone Aquifer System).

3. THE NORTHWESTERN SAHARA AQUIFER SYSTEM

The Consultation Mechanism was established between the 3 Arab countries Algeria –Libya –Tunisia. This system covers 1 Million Km2, the 3 countries, with 4 M inhabitants in the aquifer area in 2000 up to 8M in 2030 this aquifer contains about 25 Milliard CM per year .

The Consultation mechanism

The Consultation mechanism presents the following features :

A- Objective

To coordinate, promote and facilitate the rational management of NWSAS water resources.

Structure

- A steering committee composed of representatives of the national agencies in charge of water resources, acting as national focal points; the committee meets in an ordinary session once a year, and in extraordinary session upon the request of one of the three states; sessions are held alternatively in each country; the committee's chairmanship is held by the representative of the host country .
- A coordination unit directed by a coordinator designated by the Sahara and Sahel Observatory (OSS)
- An ad-hoc scientific committee for evaluation and scientific guidance, to be convened when the need arises

B- Legal Status

The coordination unit is administered and hosted by the OSS.

C- ***Functions*** : among them are :

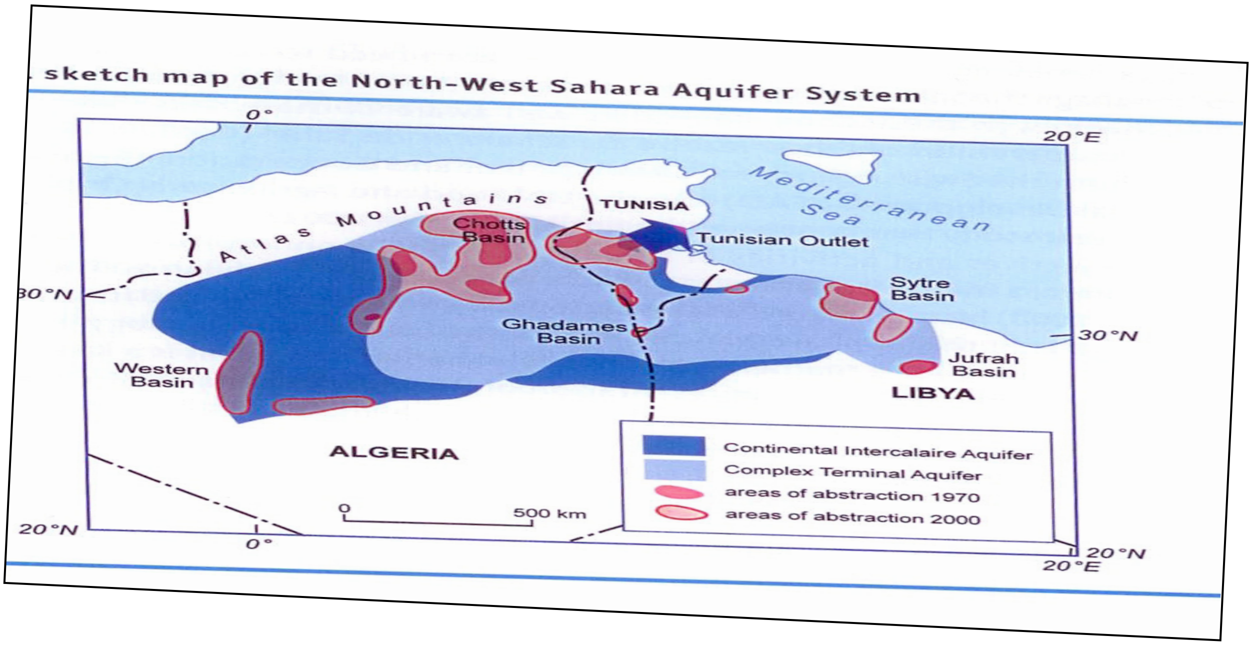
- To develop and follow-up a reference observation network ;
- To process, analyze and validate data relating to the knowledge of the resource ;
- To develop databases on socio-economic activities in the region, in relation to water uses ;
- To develop and publish indicators on the resource and its uses in three countries ;
- To promote and facilitate the conduct of joint or coordinated studies and research by experts from the three countries ;

D- Financing

Each state bears the operating costs of its own focal point . The functioning of the coordination unit is financed out of subventions and gifts granted to the OSS by the concerned states , cooperating countries, etc.

At present, The 3 countries notified an evolution and development of the aquifer resources from 0,6 Milliards CM in 1970 to 2,5 Milliards CM in 2009 per year .

complex terminal continental intercalaire



Aquifer : 1M KM2
69% Algeria
8% Tunis
Libya **23%**

4. GROUND WATER RESOURCES IN PALESTINIAN **OCCUPIED TERRITORIES**

Water resources in the West Bank and Gaza Strip consist primarily of surface water and groundwater resources. The major and permanent surface water resources is the Jordan River and flood water in wadis . However, since the Israeli occupation of the Palestinian Territories, groundwater resources have become the major source of fresh water supply in the West Bank and Gaza Strip as the Palestinians were deprived of their rightful share in the Jordan River by the Israelis .

Groundwater

Groundwater is the major source of fresh water supply in the Palestinian Territories[In the West Bank, groundwater is formed in three major basins :

the Western Basin, the Northeastern Basin and the Eastern Basin . The West Bank receives an annual average rainfall that ranges between 500 and 600 mm. With an area of 5,856 km2, this gives an average total of about 3,200 MCM of rain per year . Around[570 - 740 MCM/y as long-term annual average of this is estimated to infiltrate into the soil to replenish the aquifer. The remainder becomes surface runoff or is lost through evapotranspiration .

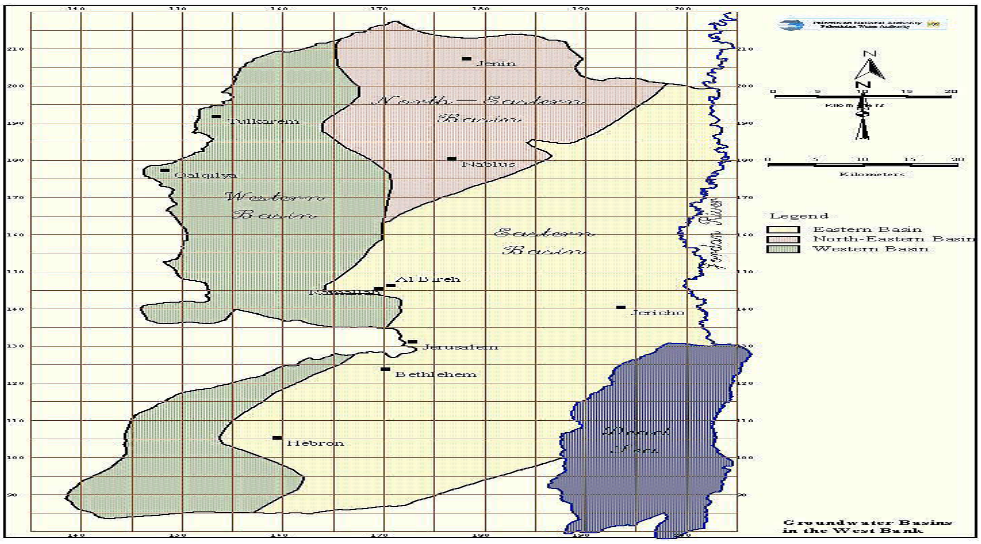
1. ***the Western Basin* :** it is the largest and most important basin among the West Bank Aquifer basins and has a Sustainable yield of 362 MCM/y but this basin is exploited by the Israelis at a rate of 340 MCM/y and some years it exceed 560 MCM/y which represents around 94% of its annual safe yield, while the Palestinians consume only 6% (22 MCM/y) of the sustainable yield .
2. ***the Northeastern Basin* :** Most of the recharge areas of this basin are located within the West Bank boundaries and it has an annual average sustainable yield of 145 MCM. In spite of this fact, the Israelis exploit the aquifer at a rate of 103 MCM/y from wells and springs , constituting around 71% of its safe yield. whereas the Palestinians allocation is only 42 MCM/y (29% of the safe yield) currently , Palestinians utilizing less than 30 MCM/y from this basin)
3. ***the Eastern Basin*:** The annual safe yield of this basin reaches 172 MCM. All the recharge areas of the basin are located within the West Bank area, giving the Palestinians the right to control its water and not to share it with Israel. However, Israel expanded its control over this basin and began to tap it to meet the Israeli water needs. It imposed several restrictions on the Palestinian water use from this basin and prevented them from digging new groundwater wells.

So the Israelis are currently controlling 100% of available water resources where they are utilizing about 82% of the annual safe yield of the groundwater basins to meet 25% of their water needs whereas the water consumption of Palestinians residing in the West Bank constitute around 17% of the annual safe yield . This Israeli prepotency over the Palestinian water resources is further illustrated by the infringement of the agreements signed between the Palestinian and Israeli sides. According to the Oslo II accord, it was agreed to provide the Palestinians with around 28,6 MCM of potable water However, Israel did not fulfill its obligations and provided the Palestinians with a water quantity of not more than 15 MCM .

In the Gaza Strip, groundwater is available in the shallow sandstone Coastal Aquifer that receives an annual average rainfall of about 400mm .

In spite of the annual safe yield of 60 MCM, the aquifer has been over-pumped at the rate of 110 MCM resulting in a lowering of the groundwater table below sea level and saline water intrusion in many areas .

The groundwater salinity in some wells amounts to 1,500 pp. Palestinians attribute the deterioration in the groundwater quality in Gaza Strip to the Israeli practices represented by the construction of dams on Wadi Gaza to divert the Wadi runoff to areas inside Israel resulting in the loss of a major source of water recharge to the aquifer .



Source: Palestininan Water Authority, 2004

The mountain aquifer system is made up of three different aquifers:

1. The western
2. The northeastern
3. The eastern

5. THE **LEGAL INSTRUMENTS**

The United Nations General Assembly has put forward two major legal instruments for managing shared surface and ground water resources .

The convention on the Law of the Non-navigational Uses of International Watercourses and the Resolution on the Law of Transboundary Aquifers, both instruments propose legal frameworks based on a number of widely accepted principles, among these principles are the equitable and reasonable utilization, the obligation not to cause significant harm, and the obligation to cooperate. Many multilateral and bilateral agreements on shared aquifer, have been signed in the Arab region that draw upon these international legal principles, considering their common socio – cultural bonds and values, and regional specificities.

Although the International Customary Rules are important, but they remain non binding and should be reviewed and adapted for the interests of the region, but regional agreements integrating the various regional factors, interests and instruments need to be agreed upon by all partners .

Most of the successful cooperation examples in the Arab region started with joint activities such as data collection, studies, monitoring programs and infrastructure projects. these activities seem to enhance communication, build trust, allow transparency and understanding of each other's interest.

Although, many regional agreements have been signed between Arab countries, and even with neighbouring non-Arab countries regarding the international shared aquifers, there is a need for regional binding legal instruments within the Arab League and especially an International law or convention within the United Nations regulating the international shared aquifers .

That's why, the League of Arab States is giving a great interest to the United Nations Law on Transboundary Aquifers and its draft convention .

The League of Arab States and especially the Center of Arab Water Security have held a meeting for representatives of the Arab concerned Ministries–high responsibles and legal and water experts at the beginning of the year2010, to study the "Law on Transboundary Aquifers" and to make amendments and suggestions about the draft convention that will make it reflect and contain all the Arab interests regarding international shared aquifers .

Given the magnitude of water scarcity that the Arab region is facing, and the fact that most available renewable water resources are shared among the Arab countries or with neighbouring non-Arab countries, the League of Arab States recognized the need for an institutional development of the water sector in the Arab region and a regional cooperation framework, that's why the Arab League established the Council of Arab Ministers for Water in 2009 which is responsible for putting a **water security strategy** in the Arab region which will be adopted in September 2010, and a series of projects for surface and ground shared water resources development and management between Arab countries, still major challenges remain on dealing with neighbouring non-Arab countries, since the majority of renewable water resources of the region originate from outside its boundaries .

Having this political umbrella, the **Council of Arab Ministers for Water** and this political will is leading to a "Shared Water Vision" since the council amended the Center of Arab Water Security with the mission of establishing a legal framework within the Arab countries about the management and cooperation of Shared Water resources which will be a binding regional water legal instrument, such as a convention or a protocol ,based on International customary Laws, and which will- we hope-solve the most challenging shared water issues in the Arab region .

Dig Deep: Conflict Prevention through Protection of Basic Water Rights

The role of international water law in conflict prevention

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ABSTRACT

Deadly disputes over access to boreholes and wells are not uncommon in drought stricken or water scarce regions. Where livelihoods are at stake, human despair can become a cause of violent conflict. The case of Darfur has demonstrated that conflicts that emanate from situations of severe shortages of water do not always remain within local or national boundaries, but can spread across borders. This paper analyzes the contribution of international water law (IWL) to the prevention of conflicts caused at least in part by water scarcity. In line with the topic of the conference, the focus is on recent developments in international groundwater law; particular attention is accorded to recent improvements of legal mechanisms promoting conflict prevention that have been introduced by the 2008 Draft Articles on the Law of Transboundary Aquifers. Where water scarcity constitutes a potential cause for inter-state conflict, the principle of equitable and reasonable utilization of transboundary water resources and associated cooperation obligations can serve as useful means to anticipate conflicts. The 2008 Draft Articles have developed the traditional conception of this principle a step further and have recast it into an increasingly forward-looking principle by putting additional emphasis on future uses and intergenerational equity. The paper argues that these small alterations as well as the special weight the Draft Articles accord to vital human water needs in determining equitable and reasonable utilization mark an important contribution to the preventive qualities of IWL. In contrast to the 1997 UN Watercourses Convention, the provisions of the Draft Articles establish legal mechanisms by which the emergence of situations that could lead to conflict is already considered before disputes between users occur. It is argued that such techniques of shaping normative content should be kept in mind in order to anticipate future conflicts when negotiating new groundwater agreements.

Key words: international groundwater law, conflict prevention, equitable utilization, cooperation, vital human needs

1. WATER CONFLICTS AND THE ROLE OF LAW

Groundwater use has expanded rapidly in developed and developing countries alike due to an increase in human water demand and improvements in pumping technology. Globally, groundwater systems meet about one fifth of total water needs for all uses and provide almost 50% of drinking water supply (WWAP, 2009; Zeckster and Everett, 2004). At the same time, overexploitation of aquifers that lead to sinking water tables or disappearance of surface water flows has increasingly put human livelihoods at risk. Where the water situation has become so precarious that water supply no longer satisfies basic human and livestock needs, this situation has become a trigger for violent conflicts. Deadly disputes over access to boreholes and wells are common occurrences in water scarce regions. The case of Darfur has demonstrated that these conflicts are not always limited to the local or national levels, but can escalate across boundaries. In order to avoid the widely predicted "future water wars" becoming a self-fulfilling prophecy, countries need to adapt to changes in demand and enhance their methods of managing water resources responsibly and peacefully.

This paper analyzes the contribution of international water law (IWL) to the prevention of conflicts caused - at least in part - by water scarcity. International law is a means employed by States to administer their interdependence and transboundary water resources management through peaceful means. It provides procedures and mechanisms for dispute resolution and a series of tools for conflict prevention, such as obligations regarding information exchange, notification, consultation and negotiation in good faith. The codification of general norms of IWL in the United Nations Convention on the Non-Navigable Uses of International Watercourses (1997) and the Draft Articles on the law of transboundary aquifers (2008) contributes to the strengthening of IWL's role in conflict prevention. It is argued that progressive evolution of the principle of equitable and reasonable utilization in the 2008 Draft Articles plays a particularly important role in this respect.

2. CODIFICATION AND SCOPE OF APPLICATION

International water law evolved over time according to the changing needs of societies and States. With expanding groundwater exploitation, the law applicable to international groundwater resources has received increasing attention over the course of the past decades. In 1973 the General Assembly (GA) asked the International Law Commission (ILC) to commence work on the progressive development and codification of customary rules of international water law. Based on the main concerns at that time, the mandate was to develop the law of non-navigational uses of international watercourses (GA Resolution 3071 (XXVIII)). The ILC elaborated a set of draft articles on that topic and recommended them to the GA for the elaboration of a convention in 1994 (ILC, 1994). These draft articles consider a large part of global groundwater resources, as does the Convention on the Law of the Non-navigational Uses of International Watercourses, which was subsequently adopted in 1997 (hereinafter "UN Watercourses Convention"). Article 2 of the UN Watercourses Convention defines "watercourses" as "system[s] of surface waters and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus". This definition excludes fossil and recharging aquifers that are not linked to surface waters, such as the Qa-Disi aquifer between by Jordan and Saudi Arabia. At the time of adopting the draft articles on the law of non-navigational uses, the ILC considered that inconclusive State practice did not allow for the inclusion of such groundwater systems and that further analysis was required (Mechlem, 2003).

The ILC took up the topic of groundwater law again in 2002 under its work program on 'shared natural resources' (ILC, 2002). The scope of the draft articles on the law of transboundary aquifers (hereinafter "2008 ILC Draft Articles" in reference to the year they were adopted by the ILC) includes freshwater resources below the surface of land that can be technically or economically extracted (ILC, 2008). Article 2 defines an "aquifer system" as two or more hydraulically connected "permeable water-bearing geological formations […] and the water contained in the saturated zone of the formation". Aquifers and aquifer systems are transboundary when their parts are situated in different States. By including the geological formation of the saturated zone in the scope of application, instead of focusing only on the water resources contained therein, the 2008 ILC Draft Articles go beyond the scope of shared resources; geological formations form part of the physical territory of States. As integrative parts of the physical territory, they are not resources that are shared among States. The inclusion of the aquifer formation can be attributed to the special characteristics of groundwater resource occurrence; yet in purely legal terms it is not conclusive. While the International Court of justice has recognized in its decision on the *Pulp Mills on the River Uruguay case* that the waters flowing in international watercourses are a shared resource, a number of States continue to voice concern about applying the 'shared natural resources' concept to transboundary waters, and in particular to groundwater (Yamada, 2008; McCaffrey, 1986).

The UN Watercourses Convention and the 2008 ILC Draft Articles have been developed on the basis of State practice and agreements concerning individual hydrographic basins, as well as on agreements of regional scope. They prove their worth in two ways; on the one hand they constitute comprehensive codifications of general norms of IWL, on the other hand, they serve as reference documents for treaties agreed on the regional and basin level (Boisson de Chazournes, 2009). Both instruments apply to groundwater resources. Their scope of application overlaps with respect to transboundary aquifers systems that are related to international watercourses. The Convention also covers groundwater resources that are captured in an aquifer located entirely in the territory of one State and are at the same time connected to international watercourses, while the Draft articles additionally regulate utilization of transboundary groundwater resources that are not related to bodies of surface water (McCaffrey, 2009).

3. STRENGTHENING OF THE PREVENTIVE FORCE OF IWL THROUGH THE 2008 ILC DRAFT ARTICLES

Codification of general norms of IWL assists in the harmonization of practices relating to sustainable management and protection of freshwater resources by way of delineation of general principles (Boisson de Chazournes, 2009).

The 2008 ILC Draft Articles follow in large part the codification of universal principles and norms contained in the UN Watercourses Convention. Most of the substantive articles of the 2008 document are based on provisions of the Convention; in addition, a number of provisions take the particular vulnerabilities and unique characteristics of aquifers into account and have refined the Convention's provisions accordingly (Eckstein, 2007; McCaffrey, 2009). These refinements strengthen the role of IWL in the prevention of conflicts. Of particular interest in this respect is the evolving definition of the principle of equitable and reasonable utilization introduced by the 2008 ILC Draft Articles.

Where water scarcity constitutes a potential cause for inter-State conflict, the principle of equitable and reasonable utilization of transboundary water resources can serve as useful means to anticipate conflicts. The implementation of this principle requires continued State cooperation. Equitable utilization of a watercourse is not a static state of affairs, it requires continuous adjustments in accordance with changes in the underlying determinants and conditions of the hydrographic system in question (McCaffrey, 2007). Cooperation obligations that emanate from this principle aim at continued engagement of concerned States and coordination of their activities through peaceful means. States are required to regularly exchange data and information and to notify other States of planned measures that might affect them. The establishment of joint management mechanisms is recommended, because experience has shown that cooperation and implementation of the principle of equitable and reasonable utilization is most effective when it is institutionalized.

3.1. A forward-looking approach

A comparison of the two documents reveals the ways by which the 2008 ILC Draft Articles have developed the traditional conception of the principle of equitable utilization a step further and have recast it into a more forward-looking principle. Additional emphasis has been put on future uses and intergenerational equity. This evolution can be explained by the fact that non-renewable groundwater resources and aquifers with very slow recharge rates are included in the scope of application of the Draft Articles. These resources are therefore particularly susceptible to over-exploitation.

As a novel enhancement, Article 4 - Equitable and Reasonable Utilization obliges States to establish a long-term utilization strategy that takes into account not only present but also future needs of aquifer States, and requires that utilization does not prevent "continuance of effective functioning" (Eckstein, 2007). The evaluation of what constitutes equitable and reasonable utilization of an individual system is the result of the consideration of a set of relevant factors, which have been identified in non-exhaustive lists (Art. 6 UN Watercourses Convention, Art. 5 2008 ILC Draft Articles). Pertinent factors include natural characteristics of the hydrographic system, social and economic needs of system States, population dependent on the system, as well as existing, potential and alternative uses and their effects on system States.

Just like the preceding provision, Article 5 of the Draft Articles adopts a forward-looking approach. Subparagraph (b) specifies that when considering social, economic and other needs of system States, it becomes necessary to take future needs into account. The consideration of future needs is not absent in the provisions of the UN Watercourses Convention; it is implied in the mandate to attain sustainable utilization of the watercourses (e.g. Article 5 (1) UN Watercourses Convention). However, the explicit references to future needs in subparagraph (b) are important. The evolution of the principle of equitable and reasonable utilization by these insertions stresses the importance of considering the dynamic characteristics of freshwater systems during the process of treaty making. Experience in some river basins has demonstrated that project related treaties which fail to take future needs of other system States into account can complicate later cooperation efforts. They establish legal facts on the ground which can become difficult to overcome in the negotiation of subsequent treaties. The consideration of future needs of system States is a key to preventing water conflicts in the medium- to long-term. By adding these specificities, the ILC enhanced the role of IWL in conflict prevention.

3.2. Consideration of vital human needs

In developing of the Draft Articles, the ILC also strengthened this role in conflict prevention by another means; consideration of vital human needs has become part of the principle of equitable and reasonable utilization. As we have seen above, the satisfaction of vital human needs contributes to the prevention of water related conflicts. The ILC defines the satisfaction of these needs as the provision of sufficient water to "sustain human life, including both drinking water and water required for production of food in order to prevent starvation" (ILC, 1994).

While the UN Watercourses Convention recognizes the importance to take vital human needs into account with respect to water utilization, it does so within the context of its provision concerning the hierarchy of uses, rather than including it in its Articles outlining the principle of equitable and reasonable utilization. Multiple competing uses of international freshwater systems are a potential source for conflict. To mitigate possible tensions, IWL does not recognize a hierarchy among uses. The Convention introduced an exception to this principle; according to Article 10 vital human needs need to be given special consideration in case of a conflict between uses. The 2008 ILC Draft Articles adopt a new perspective on the protection of vital human needs; they place their protection and consideration within the process of determining equitable and reasonable utilization. While the weight given to the factors that are pertinent in assessing equitable and reasonable utilization is determined by its importance with respect to the characteristics of each individual aquifers system, Article 5 (2) stipulates that when "weighing different kinds of utilization … special regard shall be given to vital human needs". This paragraph is remarkable with respect to the evolution of IWL tools for conflict prevention. In contrast to Article 10 (2) of the UN Watercourses Convention, vital human needs are taken into account already before a conflict between uses occurs; they are considered earlier than that, i.e. already during the process of assessing uses with respect to their impact on equitable and reasonable utilization.

The priority for the protection of vital human needs is affirmed in the Draft Articles also by the refinement of rules regarding emergency situations (Article 17). Where an emergency occurs due to natural causes or human conduct and jeopardizes vital human needs, States are for the time of the emergency allowed to take all measures that are necessary to meet these needs, notwithstanding the obligations which might arise from the principle of equitable utilization and the obligation not to cause significant harm. Such a strong protection clause is missing in the corresponding Article 28 of the Watercourses Convention of 1997.

The influence that the codification work of the ILC has had on basin level treaties and the nurturing effect of the UN Watercourses Convention and the Draft Articles with respect to these instruments can be seen in some of the most recent water treaties regulating surface as well as groundwater resources. The emerging focus on satisfaction of vital human needs as a stabilizing factor for State relations has found reflection in the 2002 Senegal Water Charter and the 2008 Niger Basin Water Charter. Both treaties include provisions prioritizing satisfaction of vital human water needs. Moreover, taking into account current developments in the sphere of human rights law, these two treaties recognize a right to water of basin populations.

4. CONCLUSION

The satisfaction of a population's basic water needs mitigates the risk of political instability and water related conflicts. International water law addresses this causal relationship by putting increasing emphasis on the necessity to respect vital human water needs in the management of transboundary water resources. The UN Watercourses Convention established an exception to the principle that there exists no hierarchy between water uses by stipulating that in the event of conflict of uses special regard shall be given to vital human water needs (Boisson de Chazournes and Tignino: 2007). The 2008 ILC Draft Articles further enhanced the protection of vital human needs. According to its provisions, the priority of utilizations which satisfy vital human needs has to be taken into account even before a conflict between uses occurs. It emphasizes the fact that for sustainable and peaceful management of transboundary freshwater resources, the consideration of the basic water needs of the population must be part of the process of evaluating equitable and reasonable utilization. Moreover, the Articles stress the importance of looking at a change in circumstances in the conditions and uses of freshwater systems. Articles 5 and 6 introduce explicit references to the future water needs of aquifer States as pertinent factors for the assessment of equitable and reasonable use. This forward-looking approach should be kept in mind when negotiating new water agreements. International treaties are characterized by their longevity. Treaties which fail to take changing conditions into account can render future development and cooperation more complicated. The preventive force of international law comes to bear only where treaties address in an adequate way potential causes of conflicts as well as likely changes in circumstances.

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Transboundary aquifers with non renewable resources call for very specific management issues

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Since early 2000, two types of aquifer systems have increasingly focused the attention of many hydrogeologists and have been a subject of numerous debates, notably at the level of several international instances such as the United Nations (i.e; UNESCO/PHI) or the European Union. These are, on the one hand, the aquifer systems with "non-renewable water resources" and, on the other hand, the aquifer systems which extend beyond the political borders, or what is now commonly called "trans-boundary aquifer systems". The debates carried on several aspects ranging from scientific considerations to economic and geopolitical standpoints.

The first type of aquifers, those with « non-renewable water », addressed and studied since the 1980's (cf. Margat and Saad 1982, 1983; Issar 1988, Llamas 2001, Abderrhaman 2003, the 1999 Tripoli International Conference in Libya-Collectif/UNESCO 2001) are linked to both the "fossil water" – *most of the water being ancient water which accumulated in the groundwater reservoir during past wetter time periods* - and the "groundwater mining" concepts – *abstraction rates exceeding recharge rates in a systematic or chronic way*. These aquifer systems whose annual recharge is most often small compared to the volume of water held in their reservoir – *the term "non-renewable water" means here that great periods of time are required to renew their water* - were particularly studied by UNESCO and the World Bank (Expert Group Meeting/GWMATE) who made a series of recommendations in 2002, and later an "ad hoc" guidebook for water resources managers (Foster and Louck, UNESCO, 2005).

It now starts to be recognized and understood by many water resources managers that the exploitation of aquifer systems with "non-renewable water" most of the time represents non-sustainable situations, and that groundwater mining is by definition a "non-sustainable concept", meaning that soon or later the water resource could dry out, at least from an socio-economical standpoint. Exploitation strategies for these water resources therefore require that choices be made with regard to the intensity and the duration of the exploitation, taking into account aquifer characteristics, inter- generation criteria and constraints, as well as alternative water supply sources, ecosystem or biodiversity considerations, and possibilities for socio-economic transformations and policies adaptation which would allow for a continued economic development in the area.

The second type of aquifers – *trans-boundary* - has only been addressed more recently, and has benefited since 2000 from the extension to groundwater of the specific analyses and rules which were elaborated and applied to trans-boundary water courses, notably through the work of the INBO Group. In the case of aquifer systems, this work was for a large part prompted by UNESCO-IHP with the support of IAH (International Association of Hydrogeologists) with the program known as ISARM (Internationally Shared Aquifer Resources Management) (Cf. Puri et al., 2001, ISARM-Africa /UNESCO, 2005, and Atlas of trans-boundary aquifers - UNESCO /IHP 2009).

It is in fact now recognized that trans-boundary aquifers which are numerous throughout the world and whose inventory is still far from being completed, raise problems many of them being similar to those of trans-boundary rivers and lakes, such as how to share the water resource in an equitable manner, or how to keep the pollution plumes and contaminants from crossing borders, or yet how to preserve ecosystems on all sides of the boundaries, etc. At the same time, more specific problems are brought along with trans-boundary aquifers which are inherent to their intrinsic properties, such as how to constraint or limit the propagation of influence – *linked to pressure transfer properties* – across the borders. Indeed, experience has shown for example that in the case of deep confined aquifers, over-pumping or even simply pumping wellfields in one country often engenders drawdowns – *lowering of water levels* - which can spread over great distances and across the frontiers, which then in turn may seriously hampers water production in the neighbouring countries, creating socio-economic problems which in the long run can trigger serious political conflicts.

A quick analysis focusing on semi-arid and arid zones shows that it gathers many of the world's greatest aquifer systems which often represent the main water supply source for drinking water, but also more generally for socio-economic development, including irrigation for agricultural purposes. Unfortunately, a great majority of these cumulate both of characteristics mentioned above: they have basically "non-renewable water" - *with very small on-going recharge rates, or small recharge rates compared to the water volume stored in their reservoir* – and they extend over several countries as shown by the world map for groundwater resources – *WHYMAP (*UNESCO/IAH/CGMW/BGR, 2006).

Most of the semi-arid and arid climate trans-boundary aquifer systems with non-renewable water resources are in fact located both in Africa and in the Middle East, the North Saharan Aquifer System – *SASS* – and the Nubian Sandstone in Africa being typical examples. Details are shown and given in Figure 1 and in Table 1 below.

Several of these great aquifer systems have been addressed and studied to various extent, sometimes from the « non-renewable water » standpoint, sometimes from the « trans-boundary » standpoint, more rarely from both, which may have lead to some redundancies and sometimes to separate or diverging visions. Nevertheless, there still remain a great amount of shadow zones for most of these aquifer systems, which vary in nature and extent from one to the other, and which should be seriously addressed according to the needs and to the exploitation interests for socio-economic development in the concerned areas.

Thoroughly studying these water resources – *the way they behave, their functioning mode, their water budgets, their responses to external stresses such as pumping etc*. - should have been a pre-requisite before starting intensive exploitation to accompany the implementation of socio-economic development policies, however in many cases exploitation started before carrying out methodical investigations and surveys, as in the Sahara region for example, where it began with the discovery of flowing artesian wells. It is in fact the multiplication of the water supply wells and the dropping water levels and well yields which followed some time after, which triggered hydrogeological studies and aquifer system modelling to simulate exploitation scenarios, as for the Sahara region with the SASS system, the Nubian Sandstone and the Murzuk basin, or in Saudi-Arabia, basically in areas where the petroleum experience and the corresponding revenues provided the necessary technical support – *hydrodynamic data, geological logs, geophysical logs, …*- and the financial means.

Fig. 1: Main trans-boundary aquifer systems with "non-renewable water" (with small annual recharge volumes compared to stored water volumes in the reservoirs – see text for explanation)

In other areas, where population is scarce or where sedentary population represents a minority with a very low water demand, the knowledge of the aquifer systems is still deficient and poor, and is basically provided by a few geological and structural observations, coming from a small number of exploration wells as in the Taoudeni -Tanezrouft or in the Iullemeden - Irhazer basins, although recently, the latter has started to be addressed notably with the implementation of a data gathering and data exchange processes, and the building of a first preliminary groundwater flow model (OSS 2007 a-c).

Today, this situation leads to uneven exploitation of the trans-boundary aquifer systems with non-renewable water resources in the semi-arid and arid regions; some of them are under-exploited, but others, on the contrary, already undergo intensive groundwater abstraction, and this has been going on in some cases for several decades inducing serious water level drops, particularly where extensive irrigation occurs. Fortunately, the actual abstraction of « fossil water » is still mostly concentrated in a small number of groundwater reservoirs and countries, essentially in the Sahara region and in the Arabian peninsula: about 87% of the extracted volumes of fossil water in the world, about 32 km^3/year representing 4% of the world's global annual groundwater abstraction, are concentrated in 5 countries: Saudi Arabia, Libya, Algeria, UAE and Oman (Fig. 2).

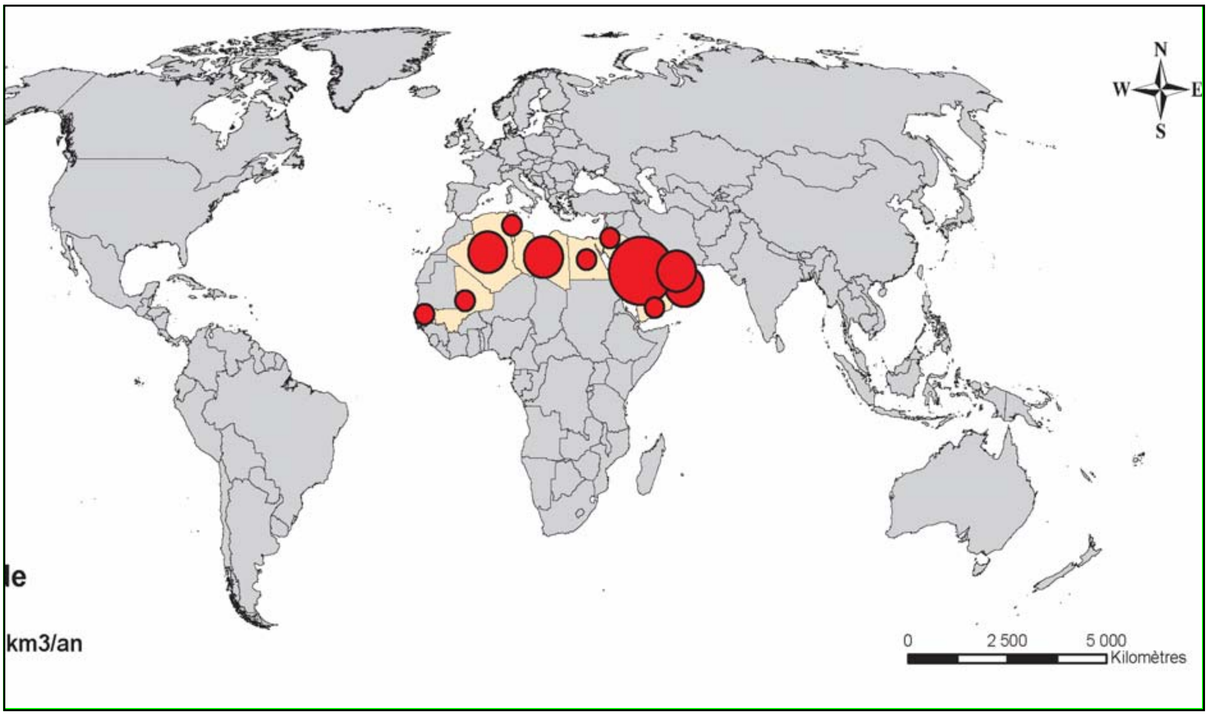

Fig. 2: Areas with major groundwater mining in the world. The total yearly groundwater mining in the world is estimated to reach about 32 km^3, most of it taking place on a large scale in North Africa and the Gulf countries – (Source : Margat, 2008)

Deep confined aquifers whose water renewal occurs on a very slow basis – *low ratio of annual aquifer recharge volume to the total water volume in the reservoir* - , and in which the greatest part of the water has a very ancient age – *several thousand years or tenth of thousands of years* - and is said to be « fossil water », often can only provide water mostly through « groundwater mining » in the extractible portion of the groundwater reservoir. Even, if water renewal in absolute terms appears to be significant in these very extensive reservoirs, water withdrawals have often little effects on the natural far away out-going water fluxes, as they often results from de-storing processes which appear as pressure drops and lowering of water levels, first on a local scale, then increasing with time in the 3-dimension (x,y,z) space, often reaching in the long run great distances from the abstraction zone.

Whatever the amplitude of this phenomenon is, such exploitation of these aquifer systems does not necessarily imply « over-exploitation » by default, at least when analysed in a global perspective – *the scale of the full aquifer system* -, as normal exploitation at equilibrium conditions in these aquifers is by nature difficult to achieve, and often in practice impossible to perform. In these cases, local groundwater abstraction can only occur for a transitional period of time whose length may vary according to the capacity of the reservoir and the pumping intensity, as it is the case for all « mining type » exploitations, and this calls for a strategic choice that must be made by the authorities in charge of water resources management, and sometimes above.

Groundwater reserves, in particular in large confined aquifers, contrarily to mineral and ore layers, are dynamic: as implied above, all groundwater withdrawals induce water level drops and exert an influence which can spread far away distances from the pumping centre. When the aquifer system happens to be trans-boundary, and even if the natural groundwater flow through the political borders is negligible, the latter – *political border* - cannot stop or prevent the propagation of the influence on the water levels triggered by a large pumping well field; indeed, pressure transfer remains by nature independent from the groundwater flow-field. This clearly means that significant groundwater exploitation performed on one side of the border can lower water levels on the other side, thereby decreasing the productivity of the well fields which are present, or the potential productivity of well fields which could be installed in the future. Exploitation anteriority on one side may in this way give an advantage over the neighbours in many cases.

In addition, heavy groundwater exploitation on one side of the border can also induce changes in the groundwater flow-field, sometimes reversing or reorienting the flow pattern and flow direction across the border. It can also trigger important modifications in the 3D distribution of groundwater bodies having different salinities or chemical compositions which, if insufficient information is available, may be difficult to predict, and which may end up spoiling the resource and the well fields used for water supply.

In the case of trans-boundary aquifer systems with "non-renewable water", it appears then that a special attention must first be paid to these cross-border transfers of influences which can engender un-equitable situations, and which must be tackled in a proper manner so as to ensure a balanced share of the groundwater resource on all sides of the political frontiers, and more generally between all parties involved. Maximum acceptable drawdowns in different areas of the neighbouring countries should be set up to become limiting constraints for groundwater withdrawal in all of the exploiting areas. This "maximum acceptable drawdown" concept, if properly applied, has the double advantage of (1) ensuring the equitable use of the available water resource among all concerned parties, and (2) setting in place a water production scheme that would in the long run preserve part of resource for future generations, thereby reaching somewhat of a sustainable state in a context where the sustainable development concept with respect to water use is difficult to achieve.

Implementing the "maximum acceptable drawdown" concept implies that sufficient knowledge of each aquifer system be acquired first, regarding its characteristics and behaviour in various conditions including climatic extremes, and that these data and information be shared among all concerned parties. This means also building a conceptual model and then a mathematical model to be able both to qualify and quantify the way the aquifer system functions and behaves in response to applied stresses such as pumping for example. When this is achieved, exploitation scenarios can be run to determine maximum pumping rates in all active well fields and a "maximum acceptable drawdown" not to be exceeded in each area of the neighbouring countries, in order to ensure both (1) that some of the water resource remains available for future generations – *by reaching a depleted but sustainable stage* - and (2) that water quality degradation does not occur for example through mixing with brackish or salt water from deep fossil water horizons, or through enhancing sea water intrusion or yet by releasing undesired polluting ions from the rock formations due to changes brought about by intense pumping to the physico-chemical context of the aquifer system.

Of course, managing trans-boundary aquifers with "non-renewable water" requires also many of the same key ingredients as do the trans-boundary aquifers with renewable water, and these notably include (from Pennequin, 2008):

- The agreement on common cross-border visions and on common supra-national objectives for the groundwater systems at the catchment scale,
- Strong cross-border political involvement, and adequate incentives and financial means for field implementation of the water resources management plans,
- The harmonisation or adaptation of the national legislations on all sides of the borders (*at least with respect to the trans-boundary groundwater resources concerned*) to avoid diverging or blocking processes,
- A proper catchment level supra-national institutional structure or mechanism empowered to enforce and supervise the groundwater management processes (*i.e; basin commission, …*),
- Common cross-boundary communication strategies (*top-down and bottom-up)*, explaining as needed the benefits of common management of the water resources, and answering all pertinent questions that may arise,

- Constructive dialogues between stakeholders showing win-to-win processes and appropriation by all of the stakes involved and of the notion of common benefits,
- Common dialogues, field actions and technical procedures involving technicians, engineers and scientists on all sides of the borders (*ie.; to monitor the water resource, to exchange data, to build and use common water resource management tools such as data bases, GIS, decision support systems – DST-, mathematical models, …, to develop indicators for management purposes, etc.*).

These different aspects of have been further illustrated and developed by several authors (Pennequin 2008, Pennequin et al. 2008, Collectif AFD 2010).

In the case of trans-boundary aquifer systems with “non-renewable water” a strong concertation between all parties on all sides of the boundaries is needed to define short-term, middle-term and long-term strategies, in order to set in place appropriate step-by-step processes to ensure the necessary gradual adaptation to a progressively less water demanding socio-economic development. These strategies may often imply to make difficult choices for prioritisation the uses of abstracted water, for example to first satisfy the needs of human consumption, instead of those for agriculture or industry, provided that the water quality is in line with the drinking water standards.

In general, groundwater mining should be regarded as being a transitional or temporary measure to implement to avoid socio-economic regression, while preparing for a less water demanding future economy more in line with the available water resources and which would allow to preserve the aquifer system for priority needs such as the drinking water supply.

It is important that the double specificity of trans-boundary aquifer systems with “non-renewable water” be well understood by all parties on all sides of the political borders, including the groundwater users and the authorities in charge of designing management and exploitation strategies for groundwater resources.

Progressive understanding of these concepts occurs in some areas, and they are even partially applied today, as it is the case for example for the SASS aquifer system shared between Algeria, Tunisia and Libya, where a data exchange structure under the supervision of OSS (Office du Sahara et du Sahel) has been set in place in 2002, along with later a consultation mechanism between the three countries, including a “steering committee”, a coordination unit and an “ad hoc” scientific council set up in 2008. A groundwater model has also been built to run exploitation scenarios. But much yet remains to be down to stop continued groundwater depletion in many trans-boundary aquifer systems with “non-renewable water”, and measures need to be rapidly implemented to re-stabilize water levels before reaching irreversible situations.

Table 1 : Main trans-boundary aquifer systems with « non-renewable water » in the world							
				Reservoir Volume			
Code Figure 1	*Aquifer*	*Country*	*Éxtent (1 000 km²)*	*Theoretical total (km³)*	*Assessed as exploitable (km³)*	*Actual Exploitation (km³/yr)*	*References*
1	Nubian Aquifer System (NAS) Nubian Sandstone Aquifer System (NSAS)	Égypt, Libya, Soudan, Chad	2 176	373 000 (soft water)	Together NA Égypt : 5 180 Libya : 5 920 Soudan : 2 610	1,38 in 2000, (~ 40 km³ abstracted 1960 – 2000)	N. Bakhbakhi, 2002 CEDARE / IFAD (FAO, 2002) Foster et al. (UNESCO 2006)
	Post-Nubian Aquifer System (PNAS)	Égypt, Libya	920	169 000 (soft water)	Chad : 1 630	0,911 in 2000	UNESCO-OSS ISARM-AFRICA-2005
	Total NAS			542 000	15 340	2,29 in 2000	
2	Système aquifère du Sahara septentrional (SASS), multilayers	Algeria, Libya, Tunisia	1 019	60 000	1 280 (Cl : 780, CT : 500)	2,56 in 2000, of which : 0,53 Tunisia, 1,77 Algeria, 0,25 iLibya	A. Mamou, 1999, Ph. Pallas et O. Salem, 1999 UNESCO-OSS, ISARM-AFRICA-2005
3	Murzuk Basin, multilayers	Algéria, Libya, Niger	450	4 800 in Libya	~ 60 to 80 in 50 years (Libya)	1,75 in 2000 in Libya	A.M. El Ghériani 2002, Ph. Pallas et O. Salem, 1999 UNESCO-OSS ISARM-AFRICA-2005
4	Taoudeni-Tanezrouft basin	Algeria, Burkina-Faso, Mali, Mauritania	~ 2 000	-	~ 2,2 in Mali + Mauritania	0,035 to 0,05 in Mali 0,07 to 0,1 in Mauritania	UNESCO-OSS 2005
5	Tindouf Basin	Algéria, Morocco, West Sahara, Mauritania	210	-	-	0,1 in Morocco	I. Zaryouhi UNESCO-OSS ISARM-AFRICA 2005
7	Sénégalo-Mauritanian basin, multilayers	Mauritania, Senegal, Gambia, Guinee-Bissau	530	1 500	Mauritania : 3 Senegal : 10 à 20	0,18 in 2000 in Senegal 0,03 in Mauritania 0,05 in Gambia and Guinee-Bissau	B. Diagana UNESO-OSS 2005
9	Iullemeden-Irhazer (IAS) basin, multilayers	Mali, Niger, Nigeria	635	10 000 to 15 000	Niger : Ci : 250 to 550, 40 to 80 Up to depth 100 m ~ 100 au Mali	~ 0,10 in 2000 (Niger et Nigeria)	A. Dodo, 1992 UNESCO/Project IAS 2003 UNESCO-OSS ISARM-AFRICA-2005
10	Chad lake basin, multilayers	Niger, Nigeria, Chad, Cameroon	1 917	600 in Niger	45 in Niger 1 850 in Chad	~ 0,10 in 2000 (Niger and Chad)	OSS/M. Terap, 1992 UNESCO/CBLT/OSS 2005 Foster et al. (UNESCO 2006)
12	Arabian Basin	Saudi Arabia - KSA, Bahreïn, Jordain, Koweit, Qatar, U. Arab Émirates, Oman, Yemen	~ 1 500	~ 2 000	870 in KSA, 2,5 in Qatar, 5 in UAE, 6,25 in Jordain (Disi)	about 20 in 2006 in KSA, 0,22 in 2005 in Qatar, ~ 2 in 2005 in UAE, 0,20 in 2003 in Bahrein, 0,20 in Jordain	Minist. of Planning (MOP) of Saudi Arabia, 2005 A.A. Ghum Alghamdi, 2002 FAO, 2009 Foster et al. (UNESCO 2006)
13	Lower Kalahari-Stampriet Basin	South Africa, Botswana, Namibia	~ 350	275	86		L. Carlsson, 1993

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Sovereignty and Cooperative Management of Shared Water Resources In a Time of Shrinking Availability: The Role of International Law

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ABSTRACT

It is a commonplace today that per capita availability of fresh water is shrinking. In addition, it is well known that some 60 per cent of global freshwater flows are contained in the 263 river basins that are shared by two or more countries, and that around 40 per cent of the human population lives in these international basins. These facts underscore the necessity of cooperation between states sharing fresh water, whether it is on the surface or underground. And yet internal political forces often lead countries to maximize their use of shared water resources without considering adequately the needs of their neighbors and co-riparians. Shrinking availability of water will only exacerbate this tendency, resulting in the potential for increased conflict.

These factors demonstrate the importance of generally accepted legal norms governing the use by states of shared freshwater resources. A set of such principles is contained in the 1997 United Nations Watercourses Convention. The Convention, which is largely a codification of customary international law, contains no provision corresponding to the general principle of "sovereignty of aquifer States" in the 2008 ILC draft articles on Transboundary Aquifers. The ILC's Aquifers articles should be harmonized with the UN Convention to provide proper guidance to states sharing transboundary groundwater.

Key words: sovereignty, Harmon Doctrine, transboundary aquifers, watercourse, UN Watercourses Convention

1. INTRODUCTION

It is a commonplace today that per capita availability of fresh water is shrinking. The math is simple: the human population continues to increase and the amount of fresh water on Earth remains the same. While we are often reminded that there is in fact enough fresh water on the planet even for the nine billion people the UN projects will inhabit the globe by 2050, its uneven distribution means that some will continue to suffer shortages – perhaps not the 1.1 billion that currently do (United Nations, Water For Life Decade), but almost certainly an unacceptably large number.

That there will be increasing competition between countries for this shrinking supply of fresh water also seems likely. It is well known that some 60 per cent of global freshwater flows are contained in the 263 river basins that are shared by two or more countries, and that around 40 per cent of the human population lives in these international basins. (UNEP Atlas, 2002.) These facts underscore the necessity of cooperation between states sharing fresh water, whether it is on the surface or underground, with a view to jointly managing the resource. In fact, most of the world's available fresh water is in the ground – "97% of all the fresh water that is potentially available for human use," according to UNEP (UNEP Vital Water Graphics; see also ILC 2008 Report, p. 31). And yet history has shown that internal political forces often lead countries to maximize their use of shared water resources without considering adequately the needs of their neighbors and co-riparians.

These factors demonstrate the importance of generally accepted legal norms governing the use by states of shared water resources. The 1997 United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses (UN Watercourses Convention or UN Convention) sets forth such principles. In 2008 the UN International Law Commission (ILC), which had prepared the draft on which the UN Convention is based, adopted a set of draft articles on the Law of Transboundary Aquifers (ILC Aquifers articles). These draft articles were annexed to a UN General Assembly resolution later that year (UNGA Aquifers resolution). Unfortunately, the ILC Aquifers articles overlap with the UN Watercourses Convention and, perhaps more seriously, introduce the novel and potentially counterproductive concept that a state has sovereignty over the portion of a transboundary aquifer located within its territory.

In this paper I will suggest that any agreement between states based on the ILC Aquifers articles should eliminate both the overlap with the UN Watercourses Convention and the notion of sovereignty over shared groundwater. I will not go into detail in this short piece on matters I have developed elsewhere (e.g., McCaffrey 2009; McCaffrey and Neville, 2010) but will focus on the main points.

2. THE 1997 UN WATERCOURSES CONVENTION AND THE TRANSBOUNDARY AQUIFERS DRAFT

2.1. The UN Convention

The scope of the UN Convention is defined as: "uses of international watercourses . . . for purposes other than navigation and . . . measures of protection, preservation and management related to the uses of those watercourses . . . ." (UN Watercourses Convention, Article 1(1).) The term "watercourse" is defined as "a system of surface waters and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus;". Thus the UN Convention applies to groundwater that is hydrologically related to surface water – a connection that characterizes much of the world's groundwater.

In adopting its draft articles on international watercourses, on which the UN Convention is based, the ILC recognized that the draft did not cover groundwater that is not hydrologically connected to surface water – for example, so-called "fossil water". The Commission therefore adopted a Resolution on Confined Transboundary Groundwater (ILC Groundwater Resolution) when it approved the final version of its draft articles on international watercourses. By "confined" groundwater the ILC had in mind that which is "not related to an international watercourse," and therefore is not covered by the draft articles (and thus by the UN Watercourses Convention). In the resolution the ILC notes "its view that the principles contained in its draft articles on the law of the non-navigational uses of international watercourses may be applied to transboundary confined groundwater". The resolution "*Commends* States to be guided by the principles contained in the draft articles on the law of the non-navigational uses of international watercourses, where appropriate, in regulating transboundary groundwater." Thus the UN Convention itself covers a large percentage of the world's transboundary groundwater and the ILC commended the principles reflected in the watercourses articles to states for the regulation of both transboundary groundwater covered by the draft articles and that which is not so covered – i.e., what the ILC referred to as "confined" transboundary groundwater. One could argue, therefore, that no further action by the ILC was necessary on transboundary groundwater. But the preamble of the resolution recognized "the need for continuing efforts to elaborate rules pertaining to confined transboundary groundwater." Hence the ILC's draft articles on the Law of Transboundary Aquifers.

2.2. The ILC's Aquifers articles

The ILC's Aquifers articles, however, apply not only to what the Commission referred to as "confined" transboundary groundwater, but also that which receives recharge from land surfaces. For example, the articles define "recharge zone" as "the zone which contributes water to an aquifer, consisting of the catchment area of rainfall water and the area where such water flows to an aquifer by run-off on the ground and infiltration through soil" (ILC Aquifers articles, article 2(g).) Since the UN Convention also covers groundwater that is recharged from the surface, there is a clear overlap between the two instruments. This could be troublesome for water managers in states for which both instruments were in force, since the Convention and the draft articles contain different – though not necessarily contradictory – rules. And because so much groundwater interacts with surface water, the likelihood that both instruments would be applicable is high. Even if the UN Convention were in force for a state but the Aquifers articles were not, the latter could be used as a means of interpreting the provisions of the former relating to groundwater. This is where the notion of "sovereignty of aquifer states" becomes particularly troublesome and mischievous.

3. SOVEREIGNTY AND INTERNATIONAL WATER LAW

3.1. The Relevant Provisions of the ILC's Aquifers Articles

Article 3 of the ILC's Aquifers articles provides as follows:

> *"Article 3*
> *Sovereignty of aquifer States*
>
> *Each aquifer State has sovereignty over the portion of a transboundary aquifer or aquifer system located within its territory. It shall exercise its sovereignty in accordance with international law and the present articles."*

(ILC Aquifers articles.) The UN Watercourses Convention contains no equivalent provision. The Aquifers draft defines "aquifer State" to mean "a State in whose territory any part of a transboundary aquifer or aquifer system is situated;". (ILC Aquifers articles, Article 1(d).) "Aquifer" is defined as "a permeable water bearing geological formation underlain by a less permeable layer and the water contained in the saturated zone of the formation", while "aquifer system" is defined as "a series of two or more aquifers that are hydraulically connected". (ILC Aquifers articles, Article 1 (a) and (b).) A "transboundary aquifer" or "aquifer system" is one, "parts of which are situated in different States". (ILC Aquifers articles, Article 1(c).)

Thus we have one or more geologic formations, spanning two or more states, that bear water. While the geologic formation – the "rock" – does not move, and is part of the land territory of the state in which it is situated, the water it contains ordinarily does move, particularly if – as would often be the case – the aquifer receives recharge, or if the water is pumped by one of the states sharing the aquifer. Subject to what is said below, it may thus be appropriate, if tautological, to speak of a state as having "sovereignty" over the portion of the geologic formation that is situated within its territory; however, it is wholly inappropriate, even pernicious, to speak of a state as having "sovereignty" over the water contained in the geologic formation. I will attempt to explain briefly the reasons for this in the following paragraphs.

3.2. The Concept of Sovereignty

"Sovereignty" is a concept whose meaning is ambiguous and often indeterminate in international law. Whether it even has a place in describing the relations between states has been questioned. Louis Henkin, one of the world's leading authorities on international law over the past half-century, has said the following in a paper entitled "The Mythology of Sovereignty": "As applied to states in their relations with other states, 'sovereignty' is a mistake. Sovereignty is essentially an internal concept, the locus of ultimate authority in a society, rooted in its origins in the authority of sovereign princes. … Surely, as applied to the modern secular state in relation to other secular states, it is not meaningful to speak of the state as sovereign. Sovereignty, I conclude, is not *per se* a normative conception in international law." (Henkin, 1993; see also Henkin, 1994.)

Indeed the very notion of state sovereignty was conceived by its creator, Jean Bodin, in 1576 as applying to the *internal* political order of nations rather than to their relations with other states. Thus understood, a nation's sovereign, or supreme power, a single source of authority, was an essential attribute of statehood – indeed, for Bodin, the defining characteristic of a state. (Bodin, 1576.)

It is true that Article 2 of the United Nations Charter recognizes the principle of the "sovereign equality" of states. But that principle merely confirms that all nations are equal under the law; it says nothing suggesting that they are not subject to law. The principle that a state is sovereign over its territory is also unquestioned – and indeed flows from Bodin's theory. But that is of little help in determining rights in shared natural resources – whether water or migratory birds – which are typically transient things that do not remain in or form part of a state's territory.

3.3. Sovereignty and State Practice concerning International Watercourses

The idea that a state can have "sovereignty" over such resources is not only unhelpful; it can in fact be pernicious, in that it can lead to a "Tragedy of the Commons" (Hardin, 1968), or worse. The misuse of the doctrine of sovereignty is perhaps nowhere better illustrated than in the context of a dispute between the United States and Mexico over the Rio Grande in the late 19th century. Upstream agricultural development in the United States had allegedly caused water shortages in Mexico, whose uses were prior to those in the United States. The US Attorney-General, Judson Harmon, was asked for his views as to the law governing the use of the river by the two countries. In an opinion that has gained well-deserved infamy as the "Harmon Doctrine", the Attorney-General stated in part as follows: "The fundamental principle of international law is the absolute sovereignty of every nation, as against all others, within its own territory …. The immediate as well as the possible consequences of the right asserted by Mexico [to a share of Rio Grande waters] show that its recognition is entirely inconsistent with the sovereignty of the United States over its national domain …." (Harmon, 1898.)

However, governments – including that of the United States – have found that in practice, sovereignty is not a good or even a particularly advantageous organizing principle when it comes to shared freshwater resources. For example, the very dispute in which Harmon announced his opinion was resolved by a 1906 agreement between the US and Mexico entitled the "Convention concerning the Equitable Distribution of the Waters of the Rio Grande for Irrigation Purposes". This shows that the United States was not prepared to insist on Harmon's extreme position but instead sought a balanced resolution to the controversy. In 1944, the US concluded another agreement with Mexico concerning shared watercourses. During the negotiation of the treaty the State Department's Legal Adviser prepared a review of existing agreements concerning shared freshwater resources. He concluded that: "No one of these agreements adopts the early theory advanced by Attorney-General Harmon. … On the contrary, the rights of the subjacent state are specifically recognized and protected by these agreements." (Hackworth, 1942.) During the hearings on the treaty in the U.S. Senate, three executive branch officials challenged the assertion that the Harmon opinion correctly stated the law. (McCaffrey, 2007, 105-106.) One observed: "Attorney-General Harmon's opinion has never been followed either by the United States or by any other country of which I am aware." (English, 1945.) Finally, in a dispute with Canada over the Columbia River – on which the United States is downstream – the US government stated that the Harmon Doctrine "is not part of international law". (Bloomfield and Fitzgerald, 1958.) Thus, the infamous "Harmon Doctrine," which I have argued elsewhere was effectively stillborn (McCaffrey, 2007), was disavowed by the country of its creation – which in any event never followed it in practice.

3.4. Should Agreements Based on the ILC's Aquifers Articles Incorporate the Concept of Sovereignty?

It will be clear from the foregoing that I do not believe it would be either practical or wise for any agreement based on the ILC's Aquifers articles to incorporate the concept of "sovereignty of aquifer states". It would also be inconsistent with the modern law of international watercourses.

In the water disputes that have come before it recently, the International Court of Justice has emphasized that there is a "basic right to an equitable and reasonable sharing of the resources of an international watercourse" (ICJ, 1997); that there is a community of interest in internationally shared fresh water (ICJ, 1997); that adequate protection of international watercourses requires close cooperation (ICJ, 2010); and that the principle of prevention of harm to the environment of another state is now part of customary international law (ICJ, 2010). The notion of sovereignty of aquifer states would work at cross-purposes with all of these principles. Two quotations from the Court's most recent judgment regarding a water dispute, in the *Pulp Mills* case, will illustrate the point.

First, the Court stated: "[procedural] obligations are all the more vital when a shared resource is at issue, as in the case of the River Uruguay, which can only be protected through close and continuous co-operation between the riparian States." (ICJ, 2010, para. 81.) Cooperation, which connotes working together, will not be promoted by a doctrine that connotes unilateralism and exclusivity. Second, the Court also found in that case that "the principle of prevention, as a customary rule, has its origins in the due diligence that is required of a State in its territory. It is 'every State's obligation not to allow knowingly its territory to be used for acts contrary to the rights of other States.' ... A State is thus obliged to use all the means at its disposal in order to avoid activities which take place in its territory … causing significant damage to the environment of another State. The Court has established that this obligation 'is now part of the corpus of international law relating to the environment' …." (ICJ, 2010, para. 101.) Observance of these obligations of due diligence and prevention of transboundary harm will hardly be encouraged by a principle of sovereignty of aquifer states.

4. HARMONIZING THE AQUIFERS ARTICLES WITH CONTEMPORARY INTERNATIONAL WATER LAW

Two categories of revisions to the ILC's Aquifers articles are necessary to harmonize them with the contemporary law of international watercourses – including both surface water and groundwater. First, the overlaps as between the Aquifers articles and the UN Watercourses convention should be eliminated. This would require confining the scope of the articles *ratione materiae* to aquifers that do not interact with surface water, i.e., do not receive significant recharge. Second, the "general principle" of the "sovereignty of aquifer States" should be revised to emphasize the importance of cooperation among states sharing transboundary groundwater. There are several steps that should be taken to accomplish these revisions. First, the subject matter of the draft should be transboundary "groundwater" rather than transboundary "aquifers". This would be more consistent with the UN Watercourses Convention and would shift the focus of attention from the rock to the water, where it should be. Second, the Article 3 should be revised along the following lines:

Article 3
Cooperation between Groundwater States

Aquifer States shall cooperate in the protection, use and joint management of transboundary groundwater in accordance with the present articles.

And third, the very valuable material in the draft concerning shared groundwater that interacts with surface water – which, as suggested above, should be eliminated from a transboundary groundwater draft because it overlaps with the UN Convention – should be made the subject of a "practice guide" or the like, similar to that which is being prepared by the ILC on Reservations to Treaties. The ILC's work on reservations is not intended to become an international agreement. Instead, it is designed to provide guidance to states on the difficult subject of reservations to treaties. Much of what is currently contained in the Aquifers articles could form the basis of a similar practice guide for the management of shared groundwater and the protection of aquifers.

5. CONCLUSION

International law requires cooperation between states sharing freshwater resources. The International Court has said that states have a community of interest in those resources and that they must cooperate closely and continuously in their management and protection. These principles are not compatible with the notion of sovereignty of aquifer states. Not only is the concept of sovereignty inappropriate legally in this context, but it also sends precisely the wrong message: one of unilateralism and exclusive authority and control, rather than one of cooperation and joint management. The UN Watercourses Convention, whose basic principles are generally regarded as codifications of customary international law, contains no corresponding provision. The ILC's Aquifers articles should be harmonized with the UN Convention to provide states with proper guidance in the use and cooperative management of this increasingly vital resource.

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Fragmentation in International Water Resources Law: Reconciling the International Law Commission's 2008 Draft Articles on Transboundary Aquifers with the 1997 UN Watercourses Convention

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ABSTRACT

While the ILC's 2008 Draft Articles follow the same format as the 1997 UN Convention and might reasonably have been expected to adopt a similar normative approach wherever possible, the Preamble to the Draft Articles fails to make any reference to this or to other seminal instruments or codifications in the area of international water resources law and the document takes, in some respects, a radically different and less progressive stance. The principal difference in the Draft Articles, and the one giving rise to most of the other deviations, is the inclusion of an express reference to the sovereignty of aquifer States in a manner implying that this is the key guiding principle of the instrument. This emphasis on State sovereignty over migratory shared water resources appears to represent something of a retreat from the distributive equity inherent in the firmly established principle of equitable and reasonable utilization and from the intense procedural and institutional cooperation required to achieve the community of interests approach necessary to give meaning to this principle. Reliance on sovereignty implies instead a drift towards a position based more on the narrow self-interest of States. In order to avoid such an interpretation, it would have been better if the Draft Articles had sought to establish two separate but parallel regimes, one based on sovereignty and covering the static geological formation of the aquifer, and one covering the shared water resources contained therein and based on equitable and reasonable utilization.

Key words: groundwater, surface waters, sovereignty, fragmentation

1. INTRODUCTION

The key principles of international water resources law are now firmly established and increasingly well understood in terms of their practical application, at least with regard to transboundary surface waters. Although already part of customary international law, the key principle of equitable and reasonable utilisation and the related duty of States to prevent significant transboundary harm, along with various associated procedural requirements, have been endorsed under the 1997 UN Watercourses Convention and supported in recent statements of the International Court of Justice. In addition, the ongoing evolution of several emerging principles of international environmental law, including the precautionary principle and the ecosystems approach, lends some coherence to this body of rules.

The ILC has taken a further significant step by its adoption of the 2008 Draft Articles on the Law of Transboundary Aquifers. This elaboration of specific rules belatedly recognizes the vital importance of groundwater resources, their unique vulnerability, and their quite distinct geophysical characteristics. However, the current Draft Articles are likely to give rise to confusion as regards their scope of application and that of the UN Convention. This matters because the Draft Articles take a markedly different approach to the utilization and environmental protection of transboundary water resources from the UN Convention in a number of key respects. For example, due to the manner in which 'transboundary aquifers' are defined in the Draft Articles, they place emphasis on the principle of State sovereignty, which would appear to be at odds with current understanding of the principle of reasonable and equitable utilization. Further, some aspects of the Draft Articles might be regarded as rowing back on progress achieved under the UN Convention, for example, in the emphasis placed upon natural characteristics as a factor in the determination of an equitable and reasonable share of groundwater resources. Of course, other aspects of the Draft Articles can be regarded as progressive, such as the clear emphasis on the distribution of 'benefits'.

2. OBJECTIVES

This paper seeks to explore the opportunities, missed and remaining, for the 'cross-fertilisation' of ideas between the UN Convention and the ILC Draft Articles in respect of the normative content, relative significance and practical application of key principles of international water resources law. Given the dearth of State and treaty practice in relation to transboundary aquifers, it is useful to try to identify which aspects of general international water law might inform inter-State practice on groundwater resources. Conversely, the more progressive aspects of the Draft Articles can help to advance understanding of water resources law generally. At any rate, a coherent and integrated framework for State cooperation on the utilization and protection of all shared water resources must be preferable to one that is fragmented and confused.

3. DISCUSSION

3.1 Uncertainty regarding scope of application

Whereas international law relating generally to the use and environmental protection of shared freshwater resources is reasonably well developed, the accepted rules and principles have largely evolved from practice in respect of surface waters, despite the vital significance of groundwater resources for meeting human needs. There are currently over 400 international agreements relating to transboundary surface waters, including binding regional framework agreements, such as the 1992 UNECE Helsinki Convention, on which several river basin agreements have been based. Groundwater resources tended either to be completely ignored or only nominally included under such arrangements. Significantly, the law relating to the utilization of shared international 'watercourses' has been meticulously codified by the work of the ILC leading to the adoption of the 1997 UN Watercourses Convention which, though not in force, is immensely influential upon the practice of States and has provided the basis for subsequent binding regional frameworks, such as the 2000 Revised SADC Protocol on Shared Watercourses. International water resources law has received considerable attention from learned societies, including the International Law Association (ILA), which adopted an absolutely seminal early codification of the area in the form of its 1966 Helsinki Rules, which have since been overtaken by the more progressive but contentious 2004 Berlin Rules. As a high-profile environmental and developmental issue, international water resources received considerable scrutiny in the lead up to the 1992 Rio process and benefited from the guidance provided under Chapter 18 of Agenda 21, as well as from the key rules and principles set out under the Rio Declaration. In addition, international courts and arbitral tribunals have examined the practical application of a variety of aspects of international water law, with the International Court of Justice delivering two landmark judgments in recent years concerning disputes over international rivers. It is telling that in each of these cases, the dispute turned on the practical implications of existing bilateral river basin agreements. Not surprisingly perhaps, this area has recently been the subject of intense and illuminating academic scrutiny and debate.

In stark contrast, prior to the adoption of the 2008 ILC Draft Articles the specific topic of shared international groundwater resources has been quite neglected. International treaty practice consists of a mere handful of international agreements applying specifically to groundwaters, only two of which create binding substantive arrangements, while two others relate to monitoring and data sharing. In 1986, the ILA adopted its Seoul Rules on International Groundwaters, which sought to outline the application of the 1966 Helsinki Rules to shared groundwater resources, but were not widely endorsed by the practice of States. Additional non-binding guidance on national measures was provided by the 1989 UNECE Charter on Groundwater Management. Although the need for integration of surface and groundwater resources for the purposes of water quantity and quality management was stressed under Agenda 21, and a separate Chapter VIII on *Groundwater* was included in the ILA's 2004 Berlin Rules, the area remained underdeveloped.

Therefore, one might reasonably have expected that the ILC's efforts to elaborate a legal framework for transboundary aquifers would have been guided to a very significant degree by the more developed law on international watercourses, particularly as the UN Convention purports to apply to groundwaters physically linked to surface waters. In addition, the ILC's 1994 Resolution on Confined Groundwaters, adopted on completion of its 1994 Draft Articles on the Non-Navigational Uses of Transboundary Watercourses, which went on to form the basis of the UN Convention, made a clear distinction between groundwater 'related to an international watercourse', which was covered by the 1994 Draft Articles (and thus by the UN Convention), and 'confined transboundary groundwater', in relation to which it commended States to be guided by the principles contained in those Draft Articles, where appropriate. Article 42 of the ILA's 2004 Berlin Rules, for example, provides that the rules applicable to internationally shared waters apply to an aquifer that is connected to shared international surface waters or that is unconnected to international surface waters but is intersected by the boundaries of two or more States. Of course, the 1994 Resolution also recognized 'the need for continuing efforts to elaborate rules pertaining to confined transboundary groundwater' and, anyway, groundwater resources could not be so neatly divided between 'confined' groundwater and groundwater 'related to an international watercourse'. For example, neither the UN Convention nor the 1994 Resolution would apply to aquifers that are recharged solely from precipitation or that discharge either into the sea or into another aquifer. It must also be borne in mind that, during the elaboration of the ILC's 1994 Draft Articles and of the final text of the UN Convention, the drafters did not focus on the unique regulatory challenges posed by groundwater (Mechlem: 806).

Alternatively, to the extent that it is inevitable that the 2008 Draft Articles would diverge substantively from the approach taken under the UN Convention, one might have expected that this imperative ought to have been explained and the scope of the Draft Articles would have been very clearly set out, in order that conflicts with the UN Convention might have been avoided. However, this does not appear to be the case. While Article 2(a) of the UN Convention defines a "watercourse" to include '*surface waters and ground waters* constituting by virtue of their *physical relationship* a unitary whole and normally flowing into a common terminus', the corresponding provision of the Draft Articles defines an "aquifer" as 'a permeable water-bearing geological formation underlain by a less permeable layer *and the water contained in the saturated zone* of the formation', thereby declining to restrict its scope of application merely to 'confined' or non-recharging aquifers or to ground waters unconnected to surface waters. Indeed, the inclusion of "recharging aquifers", "recharge zones" and "discharge zones" within the regime proposed under the Draft Articles strongly suggests that aquifers connected to surface waters are covered. Thus, though scientific and legal uncertainty as to the nature, extent or adequacy of any connection between groundwaters and surface waters would anyway be likely to persist, the issue arises of which set of rules ought to apply to ground waters physically connected to a system of surface waters. The Commentary to the 2008 Draft Articles acknowledges that the issue of overlap, and of priority in the case of conflict, between these sets of rules would become all the more urgent in the event of the Draft Articles eventually becoming a convention and, although the Commission declined to include the proposed Article 20 on the relationship between the Draft Articles and other conventions and international agreements until the outcome of its 'two-stage approach' was apparent, this decision merely defers discussion of a difficult issue and confuses the precise scope, and thus the appropriate substantive content, of the Draft Articles.

3.2 Definition of international "aquifer"

The definition of "aquifer" contained in the 2008 Draft Articles gives rise to a number of problems. This single definition includes both the 'underground geological formation which functions as a container for water', essentially a static territorial element, and the water contained therein, which will in many cases refer to a moving natural resource which might transit from the territory of one State to that of another. Thus, it combines and confuses a geological element, in respect of which it is appropriate to think in terms of sovereignty and even property, with a migratory natural resource, in respect of which it is rather more in keeping with international practice to think in terms of sovereign rights to utilize. The important distinction is that sovereign rights to utilize are limited by the obligation to consider the sovereign rights of other States, identified by means of the process of equitable balancing of needs and benefits inherent to the principle of equitable and reasonable utilization. Though the Commentary to the Draft Articles refers to the definition of an "aquifer" provided in Article 2(11) of the EU Water Framework Directive, this definition only includes the 'geological strata' and not the water contained therein. It is not immediately clear why the Commission could not have provided separate definitions for an "aquifer", focusing on the geological formation, and for "groundwater" contained therein, and then set out parallel legal regimes for the sovereign control and protection of the functioning of the former and for the utilization and management of the latter. Though the relevant provisions of the 2004 Berlin Rules apply to all aquifers, whether or not recharging or connected to surface waters, Article 3 defines "aquifer" and "groundwater" separately and Chapter VIII provides for the precautionary management and sustainable use of each, including the taking of measures to prevent 'the degradation of the hydraulic integrity of aquifers', which relates principally to prevention of the related processes of subsidence and compaction.

3.3 Sovereignty

The assertion in Article 3 of the 2008 Draft Articles that '[e]ach aquifer State has *sovereignty* over the portion of a transboundary aquifer or aquifer system located within its territory' is without doubt the single most controversial departure from established international water resources law. While it is self-evident that a State enjoys territorial sovereignty over any geological formation located within its borders, it was not felt necessary to include such a reiteration of sovereignty in the UN Convention in relation to the portion of the bed of an international river located within the territory of a riparian State. More seriously, an attempt to extend the notion of sovereignty to cover the second element of an "aquifer", as defined in the Draft Articles, that of the shared waters contained therein, marks a significant retreat from the core principles of established international water resources law. Indeed, to do so would appear to be inconsistent with the entire historical and conceptual development of the principle of equitable and reasonable utilization, which in its most basic form can be understood as a means of limiting, on the basis of the sovereign equality of States, the application of absolute theories of territorial sovereignty to shared water resources (McIntyre: 76-78). A more sophisticated understanding of this cardinal principle appreciates that equitable and reasonable utilization requires establishment of a "community of interests" approach, normally achieved by means of cooperative institutional machinery of the type envisaged under Draft Article 7(2). The community of interests approach to the management of shared waters has been endorsed by the ICJ in both the *Gabčíkovo-Nagymaros* and *Pulp Mills on the River Uruguay* cases, and can only be understood as a diminution of individual State sovereignty over shared water resources (McIntyre: 28-40). It is totally at odds with the unfounded view expressed by certain States, and seemingly supported by the ILC, that 'water resources *belong* to the States in which they are located and are subject to the *exclusive* sovereignty of those States'.

At any rate, the ILC's Commentary to Draft Article 3 does not make a persuasive case for inclusion of an explicit reference to the sovereignty of aquifer States. Most of the instruments cited in support of the principle of sovereignty are not specifically concerned with the law of shared water resources and in the case of the few that are the Commentary's references to sovereignty are misleading (McCaffrey: 286). Further, the Commission's assertion that the explicit reference to sovereignty 'was reaffirmed by many States' does not stand up to serious scrutiny and, arguably, the support from a very limited number of States that this provision did receive reflects ‘advocacy of a position they considered supportive of their interests’ rather than State practice (McCaffrey: 289-291). As regards State practice subsequent to the adoption of the Draft Articles, the 2010 Guarani Aquifer Agreement, which defines the Guarani Aquifer System as ‘a transboundary water resource’, thereby focusing on the water resource element rather than the geological formation, reiterates that ‘[e]ach Party exercises *sovereign territorial control* over their respective portions’ after identifying the four aquifer States as ‘the *sole owners* of this resource’. However, anecdotal evidence suggests that the Parties were largely motivated by a desire to obviate concerns that the recent emergence in international law of the human right to water might confer rights to these waters upon other States. This reflects confusion as to the possible legal implications of the human right to water and it is hardly ideal to address one misunderstanding with yet more legal confusion over the meaning and implications of sovereignty over shared waters.

Further, this inappropriate assertion of sovereignty is tantamount to creating “property” in shared freshwater, which is fundamentally at odds with the development of international water resources law, as evidenced by the Commission’s earlier rejection of the doctrine of “prior appropriation”. The ILC’s Commentary explains that, during elaboration of the Draft Articles, the need for a explicit reference to sovereignty was promoted by those aquifer States which took the view that ‘groundwaters must be regarded as belonging to the States where they are located, along the lines of oil and natural gas’, suggesting that the unhelpful inclusion of Draft Article 3 might perhaps be partly due to the fact that the issue of aquifers and groundwater was originally, and somewhat inappropriately, programmed for examination by the ILC within the topic of “shared natural resources”, which was to include confined transboundary groundwaters, oil and gas. The view that a comparable approach is taken under international law to water and hydrocarbon resources is generally erroneous and fails to take account, for example, of the markedly different approach taken by international courts and tribunals to equitable sharing of water and equitable delimitation of the continental shelf and the coastal territory of States (McIntyre: 121-151). The rather more distributive approach taken to the former reflects recognition of the unique human dependence on water. Renewed emphasis on sovereignty and on viewing water resources through the prism of property might have negative implications for the practice of international water resources law generally, and particularly for emerging water resources issues, such as cooperative management of glaciers and glacial meltwater (Thorson: 514).

Though the second sentence of Draft Article 3 purports to limit the exercise of State sovereignty over transboundary aquifers ‘in accordance with international law and the present draft articles’, by listing sovereignty first among the ‘general principles’ guiding application of the instrument, by relegating the principle of equitable and reasonable utilization to the following article, and by including such a vague reference in its Commentary to the ‘other rules of general international law which remain applicable’, the Commission strongly suggests, and at least one corresponding State agrees, that sovereignty is the primary guiding principle which is to inform the interpretation and application of all others. As one leading commentator observes, ‘the first sentence of Article 3 lets the genie of sovereignty out of the bottle, and the second sentence cannot put it back in’ (McCaffrey: 291).

3.4 Progressive vs. Regressive Aspects of the ILC Draft Articles

In addition to setting out a highly specific regime for transboundary aquifers based on a sound scientific and hydrological understanding of their unique characteristics, the 2008 Draft Articles include a number of very progressive elements, which reflect the ongoing evolution of international water resources law since the adoption of the UN Convention. For example, in relation to their scope of application, Draft Article 1 sensibly includes, in addition to the ‘[u]tilization of transboundary aquifers’, ‘[o]ther activities … likely to have an impact upon such aquifers’. Similarly, recognizing that impacts may be caused or endured beyond the territory of aquifer States, Draft Articles 11, 15, 16 and 17 can apply to States other than aquifer States, though they provide few rights to States in which discharge zones are located and seek to impose only obligations on States in which recharge zones are located, making it highly unlikely that either would wish to cooperate. In relation to the articulation of the principle of equitable and reasonable utilization in the Draft Articles, Article 4 emphasizes long-term *benefits* rather than utilization, thus potentially permitting broader consideration of relevant factors leading to more efficient use of resources and optimization of human benefits. In the same vein, Draft Article 5 employs a logical reordering of the factors relevant to equitable and reasonable utilization, giving sequential priority to the 'population dependent on the aquifer' and then to the 'social economic and other needs' of the aquifer States. This corresponds with the relative priority normally accorded to such factors in the established practice of international water resources law (Fuentes: ***). Indeed, 'vital human needs' do not only enjoy a special status under Draft Article 5(2), but also in respect of emergency situations under Draft Article 17 and, implicitly, in respect of technical cooperation with developing States under Draft Article 16 and in respect of armed conflict under Draft Article 18. These latter three situations correspond with the directions set out by the Committee of Economic Social and Cultural Rights in General Comment No. 15 on the Right to Water (2002) at, respectively, para. 34, paras. 34 and 38, and paras. 21 an 22, suggesting that the Draft Article were informed by the ongoing intense international discourse on the human right to water. Draft Article 5(g) further highlights the inherent vulnerability of aquifers by emphasizing consideration of alternative sources of water supply, while Draft Article 5(i) highlights the 'role of the aquifer … in the related ecosystem'. Generally, the Draft Articles might be seen to bring some clarity to determination of equitable and reasonable utilization by declining to confuse relevant 'factors' with 'uses' as, arguably, occurred in the case of Articles 6 and 10 of the UN Convention.

However, certain aspects of the Draft Articles might be regarded as less progressive than the UN Convention. For example, in respect of the principle of equitable and reasonable utilization, Article 5(1)(d) appears to place quite considerable emphasis on 'contribution to the formation and recharge of the aquifer', which the Commentary explains 'means the comparative size of the aquifer in each aquifer State and the comparative importance of the recharge process in each State where the recharge zone is located'. Despite the fact that corresponding factors are listed first in Article 6(1) of the UN Convention, this approach is totally at odds with the very minor significance normally attributed under general international water resources law to such geophysical factors as the extent of a shared watercourse or drainage basin within the territory a riparian State or its contribution to the river's flow (Tanzi and Arcari: 124; Fuentes: 398-407), and suggests that the version of the principle adopted under the Draft Articles may be less distributive in that it is less concerned with human needs and dependence. Indeed, this emphasis on hydrological factors is more in keeping with the concepts of State sovereignty over and of property in water. Similarly, though Draft Article 15 on planned activities suggests strongly that States might conduct an EIA and links any EIA to the procedures of notification, consultation, negotiation and fact-finding, thereby anticipating to some degree the approach taken by the ICJ in the recent *Pulp Mills on the River Uruguay* case, the Draft Articles provide significantly less detail and place less emphasis on procedural obligations than Articles 11-19 of the UN Convention. This omission is hardly in keeping with the ICJ's recent findings on the central importance of procedural obligations for the general duty of cooperation, the requirements of good faith, and satisfaction of the due diligence requirements of the key substantive obligations set out in the Draft Articles. However, Draft Article 7(2) does state clearly that 'aquifer States should establish joint mechanisms of cooperation' for the purposes of the general duty to cooperate, another element stressed by the ICJ. Further, despite the travails of the Commission in its earlier work on watercourses in this regard, by declining to include a reference to compensation in Draft Article 6, it is not now implicit that the principle of equitable and reasonable utilization enjoys priority over the duty to prevent significant harm in the case of transboundary aquifers. This may again convey the impression that the Draft Articles are less concerned with distributive equity than sovereignty. Finally, though Draft Article 5 includes as relevant factors the 'development, protection and conservation' of the aquifer and its 'role … in the related ecosystem' and Draft Article 10 requires protection and preservation of ecosystems, Draft Article 12 on prevention, reduction and control of pollution might be regarded as somewhat anemic in comparison to Article 21 of the UN Convention, which provides a definition of "pollution of an international watercourse" and suggests a number of types of measures on which States might cooperate. Though Draft Article 12 requires aquifer States to 'take a 'precautionary approach', Article 21 is more explicitly eco-centric, including references to pollution causing 'significant harm to other watercourse States *or their environment*' and to 'the *living resources* of the watercourse'. Perhaps this reflects the Draft Articles' greater focus on the economic rather than the environmental dimension of shared water resources, once again stemming from a notion of property in water resources supported by that instrument's reliance on the principle of sovereignty.

4. CONCLUSIONS

It is important to note that shared international waters have traditionally been regarded as a quite unique resource in international law, and have tended to be treated in a manner that recognizes the immediate and total dependency of peoples upon water, thus placing greater emphasis on equitable distribution of benefits on the basis of needs rather than geographical or hydrological circumstances. However, the Draft Articles appear to presage a drift away from a community of interests approach and towards an approach based on sovereignty and the narrow and short-term self-interest of States. If this shift in thinking stems solely from fundamental differences in the hydrological and geophysical nature of groundwater resources, then this point should be made absolutely clear so as not to undermine decades of progressive development of international law relating to shared (surface) water resources. The fact that groundwater has been neglected under international law should not permit such regression. In order to ensure the overall coherence of international water resources law, and to reconcile the Draft Articles with the UN Convention, it may be necessary to elaborate separate yet parallel regimes for the geological formation and shared water resources making up a transboundary aquifer.

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Sustainable Development of Cross - Boundary Aquifers in Australia - the Modern Legal and Institutional Tools

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ABSTRACT

Sustainable development is expressed in a number of statements for example the UNESCO Draft Law of Trans-boundary Aquifers and the Rio Declaration. Since 1992 many Australian acts of parliament at State and federal level such as the recent Water Act 2007 (Cth) require implementation of Ecologically Sustainable Development (ESD) This was heavily influenced by the 1987 publication of Our Common Future and its definition of sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' these aims. Australian law is hence an example of a norm implementing nation state and the study of the implementation of these norms is very valuable and informative to the development of international law.

This paper focuses on groundwater and ESD implementation in cross State aquifers. It finds different legal tests in Australia under three key schemes. The first case study is the oldest dating from 1985 and is the management of a vital aquifer between South Australia and Victoria, the second case study of the Great Artesian basin dating from 2000 and is a cooperative regime between 4 states. The final case study is of the legal tests proposed under the Murray Darling Basin plan under the 2007 Water Act (Cth) This Act is innovative and has legal tests that will essentially eliminate some of the issues discussed above. For example the power to accredit or not accredit State water plans in the national interest. Conclusions will be drawn as the legal norms transmitted to international law by actual and potential Australian jurisprudence on cross border aquifer management.

Key words sustainable development, interstate aquifers, changes to water allocations water plans, social sustainability

1 Introduction

Groundwater was the Cinderella of water regulation in Australia as it was regulated last under State laws only after attention was paid to surface water (McKay, 2007). Since 1994, groundwater has been incorporated in State regional water plans which have been drafted by the seven State governments. The State governments have confined their interest to their jurisdictions with two notable exceptions. The two exceptional cases are the South east of South Australia and the Great Artesian basin and these cross boundary schemes are of great importance and are discussed in this paper.

Australian water management has been revolutionised by co-operative agreements enacted under the auspices of the Council of Australian Governments (CoAG) in 1994. This body is comprised of the heads of each of the State Governments and the commonwealth government. The commonwealth government provided fiscal incentives and sets the State government tasks. One key aspect of this fiscal federalism has been to incorporate the concept of Ecologically Sustainable Development (ESD) in to State water management laws. All of the laws in the States were amended to require this objective and the operationalising mechanism has been through regional water plans. The Intergovernmental Agreement on the environment in 1992 is the most prominent first use of the term in an official Australian context. Though both the Intergovernmental Agreement and the related National Strategy on ESD 1992 acknowledged that while the Australian regulatory authorities would do all within their power to ensure compliance, it could not bind local government authorities to observe its terms. Nevertheless, it has been held by the Land and Environment Court in New South Wales that a proper exercise of the powers of local government authorities would mean that they (and the Court on a merits appeal) would apply the ESD policy unless there were cogent reasons to depart from it.

The State governments have the legal power under the constitution to deal with water and they define the ESD concept enshrined in the water plans. The Commonwealth has provided two phases of reform and the latest, The National Water Initiative (NWI), was agreed on the 25 June 2004 (Full details of the National Water initiative can be found at http://www.coag.gov.au/ and search 'CoAG Meeting 25 June 2004'). The NWI has identified several issues of relevance to groundwater management including plantations of forestry (Water lines 2010). Forestry has expanded in the South east of South Australia and the State government has adopted an innovative policy to make forestry account for the interception of rainfall and also to regulate shallow aquifer withdrawals. This has had a flow on impact on the pre-existing agreement. This will be discussed.

Figure 1. Australia with Great Artesian Basin and Murray Darling Basin

The final case study is that of the yet to be implemented Murray Darling Basin plan under the Water Act 2007 (Cth). This act has the power to accredit or adopt State water plans produced under State laws. This power was ceded to the commonwealth government by the States under section 51(31) in 2007. The grant of power to the commonwealth states that the objective of the Water Act 2007 is to manage surface and groundwater in the National interest and to implement relevant international agreements. This broad head of power will result in revisions of State water plans. For example, to leave more water in upstream areas of rivers and in replenishment zones of aquifers to provide for biodiversity. This national approach to the Murray Darling Basin (MDB) as a catchment will mean that all surface and aquifer water in the MDB will in essence be managed as though the State boundaries do not exist. This revolution essentially eliminates the cross border issues for water plans in the region(see figure1)

A key component of all these case studies is the State based water plan. Each State has prepared these water plans with community consultation and on occasions the plans have reduced water allocations by more than half to achieve ESD..

For example in a key aquifer in I NSW, the Minister reviewed the way ground water allocations were made to over 1,000 farmers and reduced to 52% of the previous level to achieve sustainable use of an aquifer. The Minister's power to amend is covered in the New South Wales (NSW) Water Management Act 2000 (WMA), which has the requirement to 'provide for the sustainable and integrated management of the water sources of the State for the benefit of both present and future generations'. Section 392 of the WMA establishes the State's rights to the control, use and flow of all waters in rivers, lakes and aquifers, conserved by any works that are under the control or management of the Minister, and occurring naturally on or below the surface of the ground.

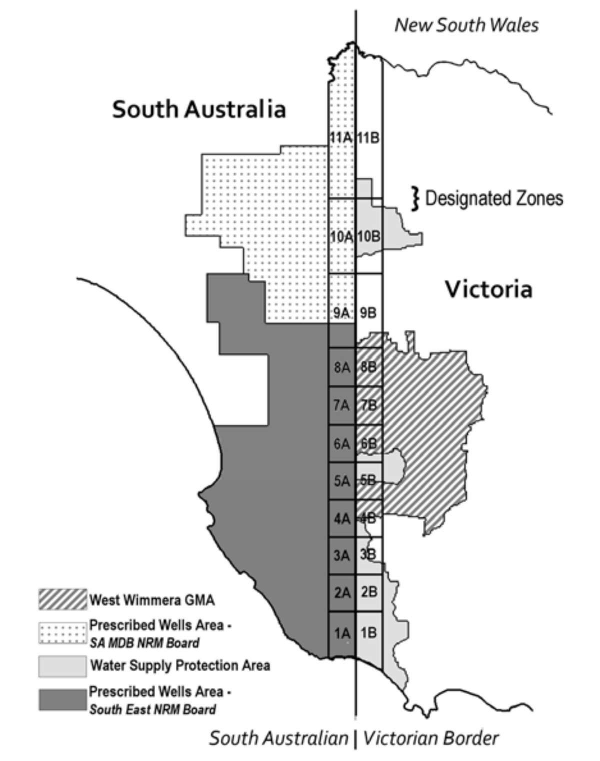
The Minister's resulting plan was challenged in Harvey v Minister Administering the Water Management Act 2000. The region covered under the challenged plan was the Murrumbidgee River which is at the very centre of the most irrigated and productive land in Australia – The Murray Darling Basin. The old Act, the Water Act 1912, had an explicit policy of over-use but this fell out of favour in the light of sustainable development principles in 1992. The judge in Harvey described the evolution of policy in NSW in these terms:

> Under the regime of the Water Act 1912 entitlements under licences within the lower Murrumbidgee area reached 512,409ML per year (according to the Murrumbidgee Groundwater Assistance Model developed by the relevant NSW Government Department). This resulted from the policy of controlled depletion of groundwater directed at addressing salinity and maximising regional economic benefits from groundwater. By the mid 1990s concerns emerged about the environmental impacts of groundwater depletion and the long-term viability of groundwater resources. In August 1997, the NSW Government released a policy document directed towards achieving sustainable use of groundwater. This led to a moratorium being placed on the grant of new licences within the area on 10 September 1997. In April 1998 the Murrumbidgee groundwater system was identified as at risk by reason of resource over-allocation. By August 1999 the moratorium imposed in 1997 became an embargo on new licence applications.
>
> *Harvey v Minister Administering the Water Management Act 2000*

2. Border agreement - South Australia implementing more aggressive polices that Victoria

The area 20 km either side of the South Australian Victorian border has been managed under a cooperative agreement since 1985 under legislation called Victoria - South Australia groundwater (Border Agreement Act 1985 Vic 1985 SA 1985). This is a very productive region with reliable water from a huge aquifer. The Agreement of 1985 between the Premiers of South Australia and Victoria had the aim of making provision to protect the Groundwater resources adjacent to the border between the State of South Australia and the State of Victoria and to provide for the cooperative management and equitable sharing of those resources and to guard against the undue depletion or degradation thereof. The Acts set up a Committee which has roles to determine "Permissible annual volume" (PAV) which means the permissible annual volume of extraction specified for each zone in the Second Schedule, or in relation to a particular zone, such other volume as has been determined by the Committee under clause 28(2). It also defined elements such as permissible salinity and "Permissible rate of potentio-metric surface lowering" which means an average annual rate of potentio-metric surface lowering of 0.05 metres, or in relation to a particular zone, such other rate as has been agreed upon by the Minister of each Contracting Government under clause 28(4).

Figure 2. Water Management Regions Along South Australian Victorian Border



The committee consists of 4 members; 2 appointed by each State. In the designated area a management plan was created under relevant state laws as this was the only power source available. The management plan for the designated area has the power to proscribe the enlarging of any bores in the area. The drilling and extraction of water from bores is regulated and licenced by each state. In 2006, the agreement was amended to provide more discretion to the Committee to vary water allocations or well licences to achieve ESD. The amendments also reflected better scientific understanding of the aquifer systems in the region. There are now several schedules listing PAV requirements for aquifers.There is also a particular issue with forestry expansion and drawdown of aquifers with impacts on bio diversity and this has been dealt with in SA see below.

In SA ,The Natural Resources Management Act 2004 (the Act), Section 76(4)(d) requires that water plans be produced for all regions. A water allocation plan (WAP) must – "Assess the capacity of the resource to meet demands for water on a continuing basis and provide for regular monitoring of the capacity of the resources to met those demands". The new Victorian Act has a similar requirement but the system of regulation is different and is managed in broader geographical areas. The principal management unit for groundwater in Victoria is the groundwater management unit (GMU), the boundaries of which often fall across more than one river basin. A GMU can be a Groundwater Management Area; Water Supply Protection Area; or Unincorporated Area.

In Victoria groundwater is managed through a range of actions:

- Licences are issued to protect the rights of licence holders; ensure that water is shared amongst users; and to ensure that environmental requirements are protected.
- Permissible consumptive volumes (PCVs) are caps that can be imposed to prevent the resource being depleted or adverse impacts such as declining groundwater levels, reduced base flows in rivers and streams, or changes to water quality. A PCV is a cap set by the Minister for Water and is the maximum volume of water that can be allocated in the area. PCVs are used in Groundwater Management Areas (GMA) and Water Supply Protection Areas (WSPA). The declaration of a PCV for an area provides certainty as to the limits of groundwater available for extraction. Currently PCVs are set for GMAs and WSPAs but caps do not currently exist in Unincorporated Areas. Many GMAs and WSPAs are already allocated to their PCV limit. In these areas new licences cannot be issued. The only way to acquire new water in these areas is to purchase a licence from an existing groundwater entitlement holder.
- Management plans and management rules can be used in WSPAs and GMAs respectively, to manage groundwater resources equitably and sustainably where there is a risk to the resource.
- Monitoring and metering is used to track groundwater use. The water levels in approximately 2500 observation bores across the state are regularly monitored to assist with responsible management of groundwater resources for long term sustainability.

In both States there has been actual and potential rapid commercial forest development and the response of the community was to request that forestry be required to account for its water use.

The outcome in South Australia was to require commercial forestry (planted for paper and pulp and for carbon credits) to account for its water use. Two polices have been proposed, accounting for rainfall interception of forests which reduced recharge, and direct extraction of water from shallow aquifers(less than 6 meters). Essentially, the recharge impact management approach is based on a dedicated minimum area of commercial forestry expansion within water resources management areas, calculated to ensure that the impact of that development on reduced recharge to the groundwater system does not affect existing water users, whilst securing sustainable management of the water resource.

Provision has been made within this dedicated minimum area of commercial forest for approximately 59,000 ha of plantation expansion in defined areas in South Australia. Further expansion of plantation forest beyond the 59,000 ha, or in water management areas where the area set aside for forest development has been reached, may be accommodated by the forest proponent offsetting the impact on the water budget by securing and quarantining an appropriate water allocation. The exclusive dedication of a share of the regional water resource to the forest industry provides for an increase in the current estate by approximately 45 percent, before there will be any need to offset further development against water allocations, except if areas are already fully utilised and there is no expansion available in the threshold area. This provides industry with significant certainty regarding its opportunities to expand.

On the 17 February 2004, the Minister for Environment and Conservation announced that the South Australian State Government would adopt a management proposal prescribing commercial forestry in the lower South East of the State as a 'water affecting activity', requiring a permit under the repealed Water Resources Act 1994. The regulation and a complementary amendment to the Development Regulations 1993 came into effect on 3 June 2004 (Published in SA Government Gazette 3 June 2004). Now the Natural Resources Management (General) Regulations 2005, Schedule 2 -Water affecting activities, 1 - Prescribed commercial forestry activities.

This innovation in South Australia has not been matched (as yet)in Victoria and these changes have put a strain on the cross border agreement. On this one aquifer, SA has also innovated in that is proposes to allow farmers to carry forward unused allocations into the next year. This policy also does not exist in Victoria to date. The carry forward policy applies in the upper cross border zones only under the plan for the Murray darling basin which is the adjacent plan to the South east plan(SA Murray darling Basin plan www.samdbnrm.sa.gov.au/nrm/boards/samdb/projects/malleepwa.html)

The rules would be:

- Maximum of 20% of their annual allocation in the following water use year (Barnett see below).
- Must first gain the water credit in previous years
- The official meter readings taken by water licensing authority (DWLBC) will be used to calculate allocation used
- Water available in any one year will not exceed 120% of the annual allocation endorsed on their licence.
- The water credit is NOT tradeable.
- The total allocations at 120% must be within the set PAV for the Mallee Prescribed Wells Area.

3 Great artesian basin plan

The Great Artesian Basin Strategic Management Plan 2000-2015 provides direction to four responsible governments; States of Queensland, New South Wales, Victoria and South Australia, regarding management of its water resources. It is the first 'whole-of-basin' management plan endorsed by all jurisdictions in the Great Artesian Basin. This is a co-operative federalism approach relying on State laws and State enforcement. In the past there have been many uncapped bores and federal funding has been given to the States to cap these and stop the waste.

The plan guides governments, water users and other stakeholders on polices, programs and actions necessary to attain optimum economic, environmental and social benefits from the existence and use of Great Artesian Basin groundwater resources. It also incorporates national policy principles on groundwater management, sustainability and biodiversity, and complements state and territory water resource legislation.
The Strategic Management Plan was developed through a consultative process involving representatives on the council, state and territory advisory bodies and community stakeholders. The vision for the NSW plan under the Water Management Act 2000 NSW as of December 2008 was to achieve the equitable, viable and sustainable management of the groundwater sources for the benefit of the community and the biodiversity of the region.

The Objectives under Water Management Act 2000 NSW:

a) improve pressures and flows in the artesian portion of the groundwater sources through efficient water use and achieve sustainable extraction in their recharge areas,
b) protect, maintain and where possible restore priority environmental assets,
c) maintain and enhance cultural and heritage values affected by the use of water from the groundwater sources,
d) enhance groundwater use for community benefit,
e) adaptively manage these groundwater sources, and
f) protect groundwater quality.

The strategies to achieve the above objectives are to:

a) phase out the use of bore drains,
b) establish environmental water rules,
c) identify water requirements for basic landholder rights,
d) identify water requirements for access licences,
e) establish rules for the granting of access licences and approvals,
f) establish rules that place limits on the availability of water,
g) establish rules for the making available water determinations,
h) establish rules for the operation of water accounts,
i) establish rules which specify the circumstances under which water may be extracted, and
j) establish access licence dealing rules.

4 Cross boundary issues and ESD under the Water Act 2007

The Water Act 2007 gives the Federal government the power to accredit or adopt regional state water plans made under state acts. The power to operate the water system remains with the States but the federal minister had a wide power to review State plans in the national interest and to implement relevant international agreements. The Act also gives the Federal government the power to create a basin plan that achieves ESD for the Murray Darling Basin, which traverses four Australian states and the Australian Capital Territory and hence change the different local plans in the national interest. This could clearly result in further reductions of allocations in some regions.

The Water Act 2007 was based on the 2007 'National Plan for Water Security'. With a change in political administration, it was amended in 2008, with these amendments giving effect to a new plan entitled 'Water for the Future'. Significantly, this new plan introduced the concept of critical human water needs into freshwater decision-making. The 2008 Water Amendment Act thus modifies the Water Act 2007 in numerous ways, most notably with the amendments designed to give effect to the intergovernmental Agreement on Murray-Darling Basin Reform, which was signed by the Prime Minister and the Premiers of New South Wales, Victoria, Queensland and South Australia and the Chief Minister of the Australian Capital Territory at the 3 July 2008 Council of Australian Governments meeting. Like the original act, the Water Amendment Act 2008 is based on a combination of Commonwealth constitutional powers and a referral of certain powers from the Basin States to the Commonwealth. The Act passed through the Commonwealth parliament following the passage of referring legislation from the Basin states - Queensland, New South Wales, Victoria and South Australia.

The following are the principles of ecologically sustainable development as used in the Water Act:

1) decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations;
2) if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures1 to prevent environmental degradation;
3) the principle of inter-generational equity--that the present generation should ensure that the health, biodiversity1 and productivity of the environment is maintained or enhanced for the benefit of future generations;
4) the conservation of biodiversity and ecological integrity should be a fundamental consideration in decision-making;
5) improved valuation, pricing and incentive mechanisms should be promoted.

Clearly the Act will change the focus of the water plans as drafted by the State and community as the national interest test could be used to change the plan and leave more water in the ground or surface system. The intersection with the GAB will mean that the GAB agreement in that region will be impacted. figure 1

5 Summary and conclusions

Australia has adopted a sophisticated water management regime aimed at achieving ESD. All of these regimes to date have been implemented with State borders forming hard barriers to policy and hence there being substantial differences between the states. The two key places of cross border aquifers have developed sharing arrangements. The policy regime since 1994 requires water plans and the community in South Australia has driven changes to water allocation policies that now impacts on the operation of the SA VICTORIA cooperative agreement. The cooperative agreement has been also influenced by better science and so has had to change and will continue to change.

The greatest potential for change is the new Water Act 2007 which essentially creates a mega plan which will revise state plans in the national interest. When implemented this will eliminate the cross border issues in that region.

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SOURCES USED FOR COMPOSITING MAPS

http://e-nrims.dwlbc.sa.gov.au/border/Default.aspx Information pertaining to the Groundwater regions and the agreed Zones of shared administration.

http://www.pir.sa.gov.au/ Maps and data detailing South Australian administrative regions, Groundwater regions, and the agreed Zones of shared administration with Victoria

http://www.anra.gov.au/ Australian Natural Resources Atlas detailed Great Artesian Basin and Murray Darling Basin Areas

http://www.dse.vic.gov.au/dse/index.htm The Department of Sustainability and Environment (DSE) Victorian groundwater, and NRM Regions.

Institutional Assessment of the Transboundary Santa Cruz and San Pedro Aquifers on the United States-Mexico Border:
UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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ABSTRACT

Shared, transboundary aquifers along the U.S.-Mexico international boundary are subject to unsustainable levels of water use and water-quality degradation resulting from rapid urban growth as well as climate change and variability. The Upper Santa Cruz and Upper San Pedro alluvial aquifers, shared by the states of Arizona, U.S. and Sonora, Mexico are essential water sources for growing cities, communities, farms, and ecosystems on both sides of the border. The U.S.-Mexico Transboundary Aquifer Assessment Act, as authorized in the U.S. as Public Law 109-448, was signed in December 2006. Continuity of programmatic and funding support for transboundary aquifer assessment is essential to collaborative initiatives. Authorities in Mexico support this initiative to collaborate on scientific assessment; however, in Mexico no similar legislation has yet been passed, given that law-making follows its own process. In the U.S., a university – federal agency partnership leads aquifer assessment activities, and prioritizes aquifers on a case-by-case basis. By contrast, in Mexico, the procedure begins at the National Water Commission, which coordinates the activities of state agencies and municipal water utilities, with university researchers playing a support role. Additional institutional complexities include the varying roles of the U.S.-Mexico International Boundary and Water Commission; the U.S. Section works to facilitate coordination and the Mexican Section sets priorities and makes decisions. A specialized binational framework for coordination and data exchange has been developed and agreed upon specifically for the binational aquifer assessment. The investment made to establish this framework has resulted in the commitment to a long-term partnership, a better understanding of transboundary aquifers, and better management of shared aquifer resources.

Key Words: groundwater management, institutions, policy, asymmetry

1.1 Introduction

Growing demands for water along with climate change and variability are placing significant stresses on aquifers along the U.S.-Mexico boundary. Recognizing the associated challenges, the United States Congress passed the U.S.-Mexico Transboundary Aquifer Assessment Act (Public Law 109-448) in late 2006 to further the assessment of "priority" shared aquifers as specified in the Act. Four were designated by the Act for study on the U.S. side: the Mesilla and Hueco Bolson aquifers along the Texas-Chihuahua and New Mexico-Chihuahua borders, and at the Arizona-Sonora border, the Upper Santa Cruz and Upper San Pedro aquifers. Beginning in 2007, academics, federal agency representatives, and officials from Arizona, New Mexico, and Texas on the U.S. side and from Sonora and Chihuahua on the Mexican side have been working collaboratively. For the Arizona-Sonora border region, these collaborative efforts have resulted in designation of the Santa Cruz and San Pedro aquifers as priority aquifers for assessment by Mexico as well. Similar developments are underway between Texas, New Mexico, and Chihuahua.

Institutional factors have been important variables in the efforts to establish a truly binational, collaborative strategy to perform the assessments required and provide the information needed for sound management of these transboundary aquifers. This paper examines some key factors that have enabled the governmental and university partners to initiate significant, multi-year assessment activities despite limited funding.

1.2 The Setting

The location of the Santa Cruz and San Pedro aquifers are shown in Figures 1 and 2. The region known as Ambos Nogales (Nogales, Arizona, and Nogales, Sonora) is the center of economic activity and water use for the Santa Cruz aquifer. The centers of economic activity for the San Pedro Aquifers are located in Cananea on the Mexican side and in the Sierra Vista-Fort Huachuca area on the U.S. side, which are separated by about 60 kilometers. While water-use decision-making at the local level is based in these urban centers, it is important to recognize the influence exerted by institutions at the state, federal, and binational levels.

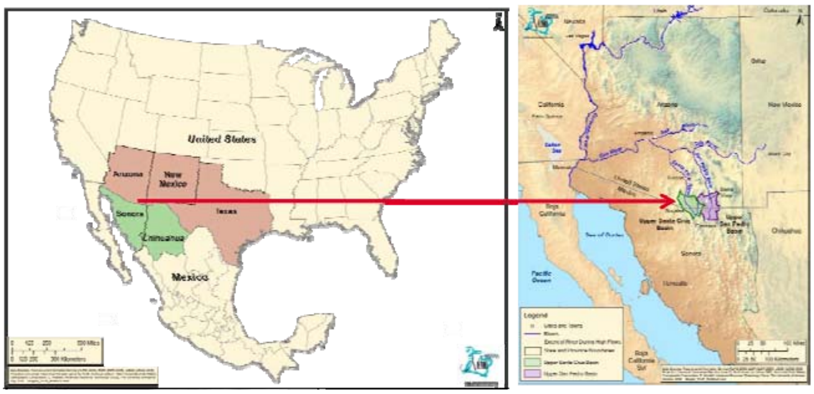

Figure 1. Location of the Santa Cruz and San Pedro Aquifers on the U.S.-Mexico Border

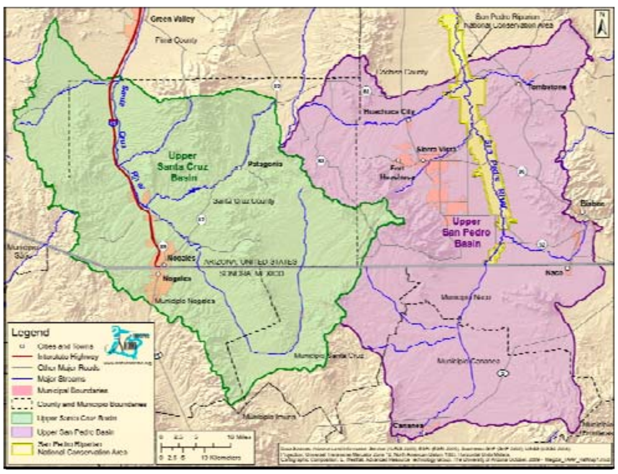

Figure 2. Detailed Map of the Santa Cruz and San Pedro Aquifers

Figure 2 shows the aquifer regions in more detail. The course of the Santa Cruz River is unusual in that it originates in Arizona, flows south into Sonora, and then flows back north into Arizona, where it meanders, dissipates, and ultimately its waters join the Gila River in Central Arizona. This Gila is also joined by the San Pedro, and ultimately flows to the Colorado River, emptying into the Sea of Cortez. The flows of the Santa Cruz River in the border area are ephemeral, occurring in direct response to precipitation events, with significant flooding events posing risks for human populations, property, and ecosystems (Norman et al., 2010). The other major and more constant source of flow is the Nogales International Wastewater Treatment Plant (NIWTP), which is located 16 km north of the border and is operated by the U.S. Section of the International Boundary and Water Commission (IBWC). Nogales, Sonora, is a much larger community than Nogales, Arizona, and so wastewater from the Mexican side accounts for approximately two-thirds of influent received by the NIWTP. Discharge from the plant, equaling approximately 17.3 MCM (million cubic meter) per year flows northward creating an "effluent-dominated" reach of the Santa Cruz River for approximately 20 km downstream (NIWTP, 2005). The economy of Nogales, Sonora, relies on maquiladoras (foreign-owned manufacturing plants) and general commerce. The border is a busy crossing for trucks with fresh produce and maquiladora-produced components.

The San Pedro River, some 100 km to the east of the Santa Cruz River, flows north from Sonora into Arizona. The Mexican town of Cananea, at the source, is the site of one of the largest copper mines in North America, which from 2007 to 2010 was idled due to a strike. The economic activity of the Sierra Vista-Fort Huachuca area centers on Fort Huachuca, a major U.S. Army base, as well as ecotourism. Sierra Vista's picturesque and climatically favorable location is also popular among retirees. The San Pedro River supports a rich riparian habitat that on the U.S. side is a National Conservation Area. The river is a key to the area's identity, and to help preserve it, members of governmental, environmental, and business organizations created the Upper San Pedro Partnership (USPP), a regional watershed association. The USPP has been tasked by the U.S. government to achieve sustainable yield of the regional aquifer by 2011.

Over the past two decades both regions have experienced population growth and expansion of economic activity, which are placing additional strains on the respective aquifers. Water management in the Santa Cruz aquifer is challenged by the existence of shallow "microbasins" in some of the most heavily used portions of the aquifer, which experience annual water levels fluctuations of up to 15 m, thereby limiting groundwater storage capacity. Climate change and variability only add to the complexities of water management for both aquifer regions, which are predicted to become hotter. Precipitation projections vary among climate models (and for the same model, according to different carbon emissions scenarios. This is partly due to uncertainty with the behavior of the North American Monsoon that strongly influences the pattern of precipitation. There is general agreement that better information and analysis are essential to developing water management strategies for these transboundary aquifers. As core members of the Arizona-Sonora group leading the effort to establish the institutional mechanisms necessary for conducting binational investigations and analyses, we have developed what we think is an effective framework for making significant progress, provided sufficient funding is available.

1.3 Institutional Asymmetries and the Roles of the Federal Agencies

The U.S. Geological Survey (USGS) is the lead U.S. federal government agency to carry out provisions of the U.S.-Mexico Transboundary Aquifer Assessment Act in the U.S. portions of the binational aquifers identified for assessment. Mexico, for its part, relies on the National Water Commission (CONAGUA, by its Spanish acronym), part of the federal executive branch charged with authority over, and administrative responsibility for, the nation's waters, to lead the scientific and technical activities associated with binational aquifer assessment. The law stipulates that the USGS work in partnership with federally recognized water centers located at public universities in each of the participating U.S. states,[1] with appropriated funding divided equally between the USGS and the university partners. The university water centers may distribute their funding to collaborators, including partners in Mexico, and the Act specified that the International Boundary and Water Commission would be consulted "as appropriate".

The partners have had to work through two major asymmetries associated with the federal legislation. First, the legislation itself pertains only to the United States. Though the Act specified four priority aquifers, the U.S. Congress could not require concurrence from Mexico regarding priority aquifers for binational assessment, nor could it mandate Mexican financial participation. It did include a requirement that any U.S funding expended in Mexico required a one-to-one match from Mexican partners, with either cash or in-kind services being an acceptable match.

The other major asymmetry relates to the roles of the federal water agencies, particularly the IBWC U.S. Section and the Mexican Section of the same binational commission, known by its name in Spanish, the Comisión Internacional de Límites y Aguas (CILA). In the U.S., water management is highly decentralized. U.S. federal water agencies have less oversight of regional water volumes and pumping than do the states, particularly in terms of groundwater, even though federal authorities regulate water quality. Additionally, the IBWC U.S. Section has had limited involvement in transboundary groundwater matters. USGS, the designated federal participant in this Act, is not a regulatory agency, but a scientific agency of the U.S. Department of the Interior. It has long-term experience researching groundwater occurrence and quality, and working with university personnel across the country. In Mexico, on the other hand, water regulation is highly centralized. CONAGUA, part of the Ministry of the Environment and Natural Resources, coordinates the activities of state agencies and municipal water utilities and conducts or coordinates water-related research throughout the country. CILA has major federal responsibilities for groundwater and surface water at the border, and only at the border. Priority-setting and decision-making for the Mexican elements of transboundary aquifer assessment have been vested in CILA. CILA, which is a branch of the Mexican ministry of foreign affairs, has requested that all transboundary aquifer assessment activities be coordinated through the diplomatic channels usually employed for IBWC-CILA water matters. The legislation clearly established the Department of Interior as the lead federal department for the U.S., with the IBWC U.S. Section playing a consultative role. However, the primary role assigned to CILA Mexican Section by the Mexican government regarding transboundary waters, along with diplomatic considerations, has put the IBWC U.S. Section in a central coordinating position.

In order to facilitate binational progress, after considerable negotiation in August 2009, the Principal Engineers for the two IBWC-CILA Sections adopted a Joint Report establishing a cooperative framework for transboundary aquifer assessment. The Joint Report calls for formation of a binational technical advisory committee to oversee the associated work efforts. Development and implementation of official binational work plans will be coordinated through IBWC-CILA, with U.S. funding flowing through both Sections. In addition, IBWC-CILA will be the official repository for the studies, which will be available in both English and Spanish.

[1] For Arizona, the Water Resources Research Center at the University of Arizona is the designated partner.

1.4 Carrying Out a Binational Work Plan

The joint cooperative framework sets out the conditions for pursuing the collaborative approach to establishing a binational work plan of the Arizona and Sonora program participants. From the start, representatives of the major partners in Arizona and Sonora have met regularly to identify priority activities. Field trips have been conducted and bilingual fact sheets were prepared by the University of Arizona team.[2] In November 2009, a binational workshop was held in Tucson, Arizona, to obtain stakeholder input into the work plans for the Santa Cruz and San Pedro aquifers. These work plans serve as the foundation for a long-term binational effort. The University of Arizona team has identified funding under the transboundary aquifer program for work to be conducted in Mexico by researchers at the University of Sonora. CONAGUA and CILA have identified funding to match the U.S. funding for assessment activities to be conducted in Mexico. Currently, scientists are working through detailed work scopes, intergovernmental/interagency agreements, and the terms of reference documents. There are institutional challenges to accomplishing the many steps along the way to binational work. The funding flow is complicated in that U.S. federal funding flows first to USGS, who then shares it with the University of Arizona through an annual grant agreement. The University of Arizona then channels the funding for Mexican work to the IBWC U.S. Section, who then transmits it to the CILA Mexican Section, who finally transfers it to the researchers doing the work in Mexico. In Mexico, CONAGUA funding is passed to CILA, who then contracts with the local scientific experts (the University of Sonora for the San Pedro and Santa Cruz shared aquifers). Each agency/participant has to follow its own protocol for funds transfer and have accountability mechanisms for financial expenditures. Developing agreement language between the agencies involved has entailed several iterations due to complications based on the asymmetries mentioned above, but also due to differing institutional mandates and administrative procedures. Nevertheless, financial resources were transferred from CONAGUA to CILA Mexican Section and this institution is independently in charge of taking necessary actions to handle project funds as required in the first phase of assessment studies. While the specific complexities we describe are unique to the U.S. and Mexico, similar asymmetries and institutional coordination challenges are likely to arise for other transboundary cases.

Significant effort has gone into developing the capacity to do work collaboratively at a foundational level. The effort acknowledges that developing a binational groundwater model is a multi-year process and that groundwater models are only as good as the data on which they rely. It further recognizes challenges of transboundary collaboration. Accordingly, transboundary aquifer assessments proceed on the basis of joint data development on both sides of the border. The scientists will synthesize and analyze existing as well as new data and reports to update the conceptual model of the hydrologic functioning and state of the aquifers (including water quantity and quality), and identify data gaps. Because cross-border hydrologic monitoring is essential and expensive; more than a few months of monitoring will be required to establish an adequate understanding of the average functioning of these aquifers on both seasonal and annual time scales. To understand annual variations, it is anticipated that a minimum of three years of monitoring will be necessary.

In addition to the hydrological studies, the parties expect to undertake socioeconomic and institutional studies as well. This will entail demographic growth projections, assessment of water use in different sectors, and characterization of organizational mandates and functions, as well as institutional and legal assessments related to groundwater management. The U.S. authorizing Act anticipated this to be a long-term investment by authorizing the U.S. program for 10 years.

[2] http://ag.arizona.edu/azwater/taap/index.html

1.5 Concluding Remarks

There are many challenges associated with transboundary aquifer assessment. This paper highlights the importance of recognizing and addressing institutional factors associated with a binational technical effort early in the process. Most binational efforts involve asymmetries in governmental functions and legal frameworks. The roles and the relative capacity and influence of non-governmental and academic institutions are likely to differ across borders. The Mexican and U.S. parties have established the foundation for genuinely collaborative, binational efforts to acquire, share and analyze data/information. Aquifer assessment will require time and financial resources, which have not yet been fully realized. The time taken to establish the cooperative framework required for the binational assessment efforts has resulted in a long-term commitment to a partnership that will result in better understanding of transboundary aquifers and thereby lead to better cross-border water management.

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Evaluación Institucional de los Acuíferos Transfronterizos Santa Cruz y San Pedro en la Frontera México-Estados Unidos:
UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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RESUMEN

Los acuíferos transfronterizos y compartidos a lo largo de la frontera internacional Estados Unidos - México están sometidos a usos no sustentables y degradación de calidad como resultado del crecimiento urbano acelerado, y también del cambio climático y su variabilidad. Los acuíferos aluviales del Alto Santa Cruz y Alto San Pedro, compartidos por los estados de Arizona, EE.UU. y Sonora, México, son fuentes esenciales de agua para las ciudades en crecimiento, las comunidades, las granjas, y los ecosistemas en ambos lados de la frontera. La Ley de la Evaluación de Acuíferos Transfronterizos Estados Unidos - México, según autorización en los EE.UU. como la Ley Pública 109-448, fue firmada en diciembre de 2006. La continuidad del apoyo financiero y para programas para la evaluación de acuíferos transfronterizos es esencial para las iniciativas de colaboración. Las autoridades en México apoyan esta iniciativa para colaborar en la evaluación científica, sin embargo, todavía en México no se ha aprobado una legislación parecida, dado que no es lo acostumbrado. En los EE.UU., la colaboración entre una universidad y una agencia federal dirige las actividades de la evaluación de los acuíferos, y da prioridad caso por caso a los acuíferos. Mientras que, en México, el procedimiento empieza en la Comisión Nacional del Agua, que coordina las actividades de las agencias estatales y servicios públicos municipales de agua, con los investigadores universitarios realizando un papel de apoyo. Complejidades institucionales adicionales incluyen un papel variable de la Comisión Internacional de Límites y Aguas entre México y Estados Unidos; la Sección Estadounidense trabaja para facilitar la coordinación mientras que la Sección Mexicana establece prioridades y toma decisiones. Un marco binacional especializado para la coordinación y el intercambio de datos ha sido desarrollado y acordado específicamente para la evaluación del acuífero binacional. Los intentos para establecer este marco han tenido como resultado un compromiso de colaboración a largo plazo, una mejor comprensión de los acuíferos transfronterizos, y una mejor gestión de los recursos de acuíferos compartidos.

Palabras Claves: manejo de aguas subterráneas, instituciones, políticas, asimetría

1.1 Introducción

Las crecientes demandas para el agua, junto con el cambio climático y su variabilidad, están poniendo bastante presión sobre los acuíferos a lo largo del limite de los Estados Unidos y México. Consciente de los retos asociados, el Congreso de los Estados Unidos aprobó la Ley de Evaluación de los Acuíferos Transfronterizos Estados Unidos- México (Ley Pública 109-448), al final de 2006, para promover la evaluación de los acuíferos compartidos de "prioridad" como se especifica en la ley. Designaron cuatro para estudiar en el lado estadounidense: los acuíferos Mesilla y Hueco Bolsón a lo largo de las fronteras Texas-Chihuahua y Nuevo México-Chihuahua, y en la región de Arizona-Sonora, las cuencas altas de los acuíferos Santa Cruz y San Pedro. Desde 2007, académicos, representantes de agencias federales, y funcionarios de Arizona, Nuevo México y Texas en el lado estadounidense y de Sonora y Chihuahua del lado mexicano, han trabajado en colaboración. Para la región fronteriza de Arizona y Sonora, estos esfuerzos de colaboración han dado como resultado la designación de los acuíferos Santa Cruz y San Pedro como los acuíferos de prioridad para la evaluación por parte de México también. Iniciativas similares se encuentran en curso entre Texas, Nuevo México, y Chihuahua. Factores institucionales han sido variables importantes en los esfuerzos para establecer una estrategia de colaboración realmente binacional para llevar a cabo las evaluaciones necesarias y proporcionar la información necesaria para una buena gestión de estos acuíferos transfronterizos. Este artículo analiza algunos factores claves que han permitido a los socios universitarios y gubernamentales iniciar actividades importantes de evaluación de varios años a pesar de los fondos limitados.

1.2 El Entorno

La ubicación de los acuíferos Santa Cruz y San Pedro se muestra en las figuras 1 y 2. La región conocida como Ambos Nogales (Nogales, Arizona y Nogales, Sonora) es el centro de la actividad económica (y el uso del agua) para el acuífero Santa Cruz. Los centros de actividad económica para los acuíferos de San Pedro se encuentran en Cananea en el lado mexicano y en Sierra Vista-Fort Huachuca en el lado estadounidense, que están separadas por unos 60 kilómetros. Mientras la toma de decisiones acerca del uso del agua a nivel local se basa en estos centros urbanos, es importante reconocer la influencia ejercida por las instituciones a nivel estatal, federal y binacional.

Figura 1. Ubicación de los Acuíferos Santa Cruz y San Pedro en la Frontera EE.UU-México

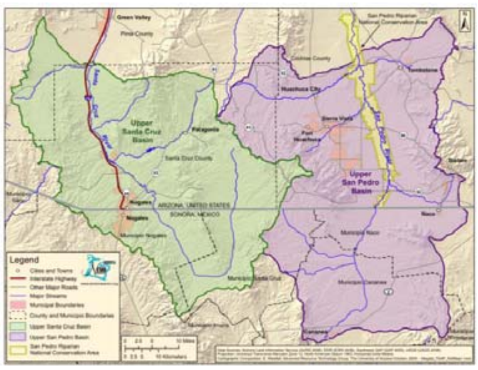

Figura 2. Mapa a Detalle de los Acuíferos Santa Cruz y San Pedro

La figura 2 muestra con mayores detalles las regiones de los acuíferos. El flujo del Río Santa Cruz es poco usual, nace en Arizona, sigue hacia el sur en Sonora, y luego regresa hacia el norte, donde da vuelta, disipa, y al final se une con el Río Gila en el centro del estado. El Río San Pedro se une también con el Río Gila, el cual, corre hacia el Río Colorado, que desemboca en el Mar de Cortés. Los flujos del Río Santa Cruz en la zona fronteriza son efímeros y ocurren después de las precipitaciones, con inundaciones fuertes que presentan riesgos para las poblaciones humanas, la propiedad, y los ecosistemas (Norman et al., 2010). La otra fuente mayor y más constante es el flujo de la Planta Internacional de Tratamiento de Aguas Residuales (PITAR) de Nogales, que está ubicado a 16 km al norte de la frontera y está operada por la Sección Estadounidense de la Comisión Internacional de Límites y Aguas (CILA), conocida por su nombre en inglés, the International Boundary and Water Commission (IBWC). Nogales, Sonora, es una comunidad mucho más grande que Nogales, Arizona, así que las aguas residuales del lado mexicano forman aproximadamente dos tercios de los afluentes recibidos por la PITAR. La descarga de la planta, lo que equivale aproximadamente a 17,3 millones de metros cúbicos / año, corre hacia el norte que crea una parte del flujo "dominado por efluentes" en el Río Santa Cruz por aproximadamente 20 Km. aguas abajo (NIWTP, 2005). La economía de Nogales, Sonora se basa en las maquiladoras (plantas de fabricación frecuentemente de propiedad extranjera) y el comercio general. Aparte, hay mucho tráfico de camiones de carga que llevan hortalizas y componentes industriales producidos en México a mercados estadounidenses.

El Río San Pedro, a unos 100 km al este del Río Santa Cruz, fluye hacia el norte desde Sonora a Arizona. En la ciudad mexicana de Cananea, ubicado cerca del nacimiento del río, se encuentra una de las minas de cobre más grandes en América del Norte, que desde 2007-2010 quedó inactivo debido a una huelga. La actividad económica del área de Sierra Vista - Fort Huachuca se concentra en la base militar "Fort Huachuca" así como en el ecoturismo. La ubicación pintoresca y el clima favorable de Sierra Vista también hacen popular esta ciudad para los jubilados. El Río San Pedro, que da sustento a un hábitat ribereño rico, es un "Área de Conservación Nacional" al lado estadounidense. El río es un elemento clave de la identidad de la zona, y para ayudar a preservarlo, los miembros de organizaciones ambientales, gubernamentales, y empresariales crearon el Consorcio del Alto San Pedro ((USPP por sus siglas en ingles), una asociación regional de cuencas hidrográficas. USPP ha sido encargado por el gobierno de los EE.UU. para cumplir con un aprovechamiento sostenible del acuífero regional en 2011.

En las últimas dos décadas ambas regiones han tenido un crecimiento demográfico y una expansión de la actividad económica, que están poniendo una presión adicional sobre los acuíferos respectivos. La gestión del agua en el acuífero Santa Cruz tiene un desafío por la existencia de las "microcuencas" de poca profundidad en algunos de los segmentos del acuífero más usados, que tienen fluctuaciones de niveles anuales hasta 15 m, lo que limita la capacidad de abastecimiento de agua subterránea. El cambio climático y la variabilidad contribuyen a la complejidad de la gestión del agua subterránea para ambas regiones, que según predicciones se volverán más calientes. Las proyecciones de la precipitación varían entre los modelos climáticos (y para el mismo modelo, según escenarios diferentes de emisiones de carbono). Este es parcialmente debido a la incertidumbre sobre el comportamiento del Monzón de América del Norte, que influye fuertemente el padrón de las precipitaciones. Existe un acuerdo general de que una mejor información y mejor análisis son esenciales para el desarrollo de estrategias de gestión del agua de estos acuíferos transfronterizos. Como miembros principales del grupo Arizona-Sonora dirigiendo el esfuerzo para establecer los mecanismos institucionales necesarios para la realización de investigaciones binacionales y los análisis, hemos desarrollado lo que pensamos es un marco eficaz para el progreso, a condición de la disponibilidad de fondos suficientes.

1.3 Las Asimetrías Institucionales y Funciones de las Agencias Federales

El Servicio Geológico de los Estados Unidos (USGS por sus siglas en inglés) es la agencia principal del gobierno federal estadounidense para llevar a cabo las provisiones de la Ley de Evaluación de Acuíferos Transfronterizos México-Estados Unidos, que cubre las partes en los Estados Unidos de los acuíferos binacionales identificados para la evaluación. México, por su parte, cuenta con la Comisión Nacional del Agua (CONAGUA) como parte del Poder Ejecutivo Federal encargada de la autoridad y administración en materia de aguas nacionales, para dirigir las actividades técnicas y científicas relacionadas con la evaluación del acuífero binacional. La ley estipula que el trabajo del USGS esté en colaboración con los institutos de investigación sobre el agua reconocidos por el gobierno federal que están ubicados en las universidades públicas para cada uno de los estados participantes de EE.UU. [1], con fondos asignados en partes iguales entre el USGS y los socios de la Universidad. Los institutos universitarios de agua pueden distribuir sus recursos financieros a los colaboradores, incluso a los asociados en México, y la Ley se especificó que la Comisión Internacional de Límites y Agua sería consultada "como sea necesario".

Los socios han tenido que trabajar a través de dos asimetrías importantes relacionados con la legislación federal. Primeramente, la legislación se refiere sólo a los Estados Unidos. Aunque la Ley especifica cuatro acuíferos prioritarios, el Congreso de los EE.UU. no podía exigir la concurrencia de México en relación con los acuíferos binacionales prioritarios para la evaluación, ni podía exigir la participación financiera de México. Se ha incluido un requisito de que cualquier financiamiento de EE.UU. gastado en México requiere una contraparte igual de los socios mexicanos, sea con dinero o en servicios.

La otra asimetría grande se refiere a los papeles de las agencias federales de agua, en particular la Sección Estadounidense de la IBWC y la Sección Mexicana de la CILA. En los EE.UU., la gestión del agua es muy descentralizada. Las agencias federales de agua de los EE.UU. tienen menos supervisión de los volúmenes regionales de agua y el bombeo que tienen los estados, en particular en términos del agua subterránea, aunque las autoridades federales regulan la calidad del agua. Además, la Sección Estadounidense de la IBWC tiene participación limitada en asuntos del agua subterránea transfronteriza. El USGS, el participante federal designado en esta Ley, no es una agencia reguladora, sino una agencia científica del Departamento del Interior. Tiene experiencia a largo plazo en la investigación de la ocurrencia y la calidad del agua subterránea, y colabora con personal académicos en todo el país. En México, por el contrario, la regulación del agua es muy centralizada. CONAGUA pertenece a la Secretaría del Medio Ambiente y Recursos Naturales y coordina las actividades de los organismos estatales y servicios públicos de agua, y lleva a cabo o coordina la investigación relacionada con agua en todo el país. La Sección Mexicana de la CILA, tiene importantes responsabilidades federales para el agua subterránea y superficial en la frontera, y sólo en la frontera. El establecimiento de prioridades y toma de decisiones para los elementos mexicanos de la evaluación de los acuíferos transfronterizos quedan con la Sección Mexicana de la CILA. CILA, que es una rama de la Secretaría de Relaciones Exteriores, ha solicitado que todas las actividades de evaluación de los acuíferos transfronterizos sean coordinadas a través de los canales diplomáticos utilizados generalmente para asuntos del agua pertinentes a CILA-IBWC. La legislación estableció claramente al Departamento del Interior como el departamento federal principal para los Estados Unidos, con la Sección Estadounidense de la IBWC jugando un papel de consulta. Sin embargo, el papel primario asignado a la Sección Mexicana de la CILA por el gobierno mexicano en relación con las aguas transfronterizas, junto con las consideraciones diplomáticas, ha puesto a la Sección Estadounidense de la IBWC en una posición central de coordinación.

Con el fin de facilitar el progreso binacional, tras una negociación considerable, en agosto de 2009 los Ingenieros Principales de las dos Secciones de IBWC-CILA aprobaron un Informe Común sobre el establecimiento de un marco cooperativo para la evaluación de los acuíferos transfronterizos. El informe común indica la formación de un comité técnico de consulta binacional para supervisar los esfuerzos del trabajo respectivo. El desarrollo y la implementación de los planes oficiales de trabajo binacional serán coordinados mediante la IBWC-CILA, con la canalización del financiamiento estadounidense a través de ambas Secciones. Además, la IBWC-CILA será el archivo oficial de los estudios, mismos que estarán disponibles en inglés y en español.

[1] Para Arizona, el socio designado es el Centro de Investigación sobre Recursos Hídricos de la Universidad de Arizona.

1.4 Realización de un Plan de Trabajo Binacional

El marco de cooperación conjunta establece las condiciones para continuar con un enfoque de colaboración para establecer un plan de trabajo binacional de los participantes del programa de Sonora y Arizona. Desde el principio, los representantes de los interlocutores principales en Arizona y Sonora se han reunido periódicamente para identificar las actividades prioritarias. Se han realizado recorridos de campo e informes bilingües fueron preparados por el equipo de la Universidad de Arizona[2]. En noviembre de 2009, hubo un taller binacional en Tucson, Arizona, para saber las opiniones de los interesados con respeto a los planes de trabajo para los acuíferos Santa Cruz y San Pedro. Estos planes de trabajo sirven como base para un esfuerzo binacional a largo plazo. El equipo de la Universidad de Arizona ha identificado recursos financieros para actividades en México del programa de acuíferos transfronterizos que se llevarán a cabo por los investigadores de la Universidad de Sonora. CONAGUA y CILA han identificado fondos para aportar en cantidad igual a los que serán aportados de parte de los EE.UU. para las actividades de evaluación que se realizarán en México. Actualmente, los científicos están desarrollando los planes de trabajo detallados, acuerdos intergubernamentales e interinstitucionales, y los términos de referencia. Hay retos institucionales para cumplir en trabajo binacional. El flujo del financiamiento es complicado porque los fondos federales de los EE.UU. van primero a USGS, que luego los comparte con la Universidad de Arizona a través de un acuerdo de subvención anual. La Universidad de Arizona luego entrega los fondos para el trabajo en México a la Sección Estadounidense de la IBWC, que luego los transmite a la Sección Mexicana de la CILA, quien finalmente los transfiere a los investigadores que realizarán el trabajo en México. En México, el financiamiento de CONAGUA pasa a CILA, que contrata los expertos científicos locales (la Universidad de Sonora para los acuíferos compartidos San Pedro y Santa Cruz). Cada agencia o participante tiene que seguir su propio protocolo para la transferencia de fondos y contar con mecanismos de rendición de cuentas por los gastos. El desarrollo de un lenguaje de acuerdo entre los organismos involucrados ha requerido varias iteraciones debido a complicaciones basadas en las asimetrías anteriormente citadas, además de los diferentes mandatos institucionales y procedimientos administrativos. Sin embargo, los recursos fueron transferidos de la CONAGUA a la CILA Sección Mexicana y esta institución es la encargada de realizar las acciones necesarias con independencia para responder a las demandas de recursos financieros que el proyecto exige para esta primera etapa de estudios. Si bien las complejidades específicas descritas son exclusivas de los EE.UU. y México, es probable que existan similares asimetrías y retos de coordinación institucional para otros casos transfronterizos.

Un gran esfuerzo ha sido puesto en el desarrollo de la capacidad de trabajar en una manera colaborativa a un nivel fundamental. El esfuerzo reconoce que el desarrollo de un modelo binacional de agua subterránea es un proceso de varios años y que los modelos de agua subterránea son sólo tan buenos como los datos en que se basan. Además, reconoce los retos de la colaboración transfronteriza. En consecuencia, la evaluación de los acuíferos transfronterizos procede sobre la base del desarrollo conjunto de datos a ambos lados de la frontera. Los científicos sintetizarán y analizarán datos existentes, así como nuevos datos e informes para actualizar el modelo conceptual del funcionamiento hidrológico y el estado de los acuíferos (incluyendo la cantidad y calidad del agua), e identificar faltas en los datos. Debido a que el monitoreo hidrológico binacional es esencial y caro, se requiere más de unos meses de seguimiento para establecer una adecuada comprensión del funcionamiento promedio de estos acuíferos en escalas de tiempo estacionales y anuales. Para comprender las variaciones anuales, se espera que un mínimo de tres años de seguimiento será necesario.

[2] http://ag.arizona.edu/azwater/taap/index.html

Además de los estudios hidrológicos, los participantes esperan llevar a cabo estudios socioeconómicos e institucionales, también. Habrá proyecciones de crecimiento demográfico, una evaluación del uso del agua en diferentes sectores, y la caracterización de los mandatos de organización y funciones, así como las evaluaciones institucionales y legales relacionadas con la gestión del agua subterránea. La Ley de los EE.UU. previó que esto sería una inversión a largo plazo cuando autorizó el programa de los Estados Unidos para 10 años.

1.5 Observaciones finales

Existen varios desafíos asociados con la evaluación de un acuífero transfronterizo. Este artículo destaca la importancia de reconocer y abordar los factores institucionales relacionados con un esfuerzo técnico binacional al principio del proceso. La mayoría de los esfuerzos binacionales implican unas asimetrías en funciones de gobierno y los marcos jurídicos. Las funciones y la capacidad relativa y la influencia de las instituciones no gubernamentales y académicas pueden diferir a través de las fronteras. Los socios mexicanos y estadounidenses han establecido las bases para esfuerzos binacionales de una verdadera colaboración para adquirir, compartir y analizar datos e información. La evaluación del acuífero requerirá el tiempo y los recursos financieros, que hasta ahora no se han realizado completamente. El tiempo requerido para establecer el marco de cooperación necesario para la evaluación de los esfuerzos binacionales se ha traducido en un compromiso a largo plazo para una asociación que se traducirá en una mejor comprensión de los acuíferos transfronterizos, y así llegar a una mejor gestión del agua transfronteriza.

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International Institutional Framework to Allocate Groundwater: US-Mexico Border

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ABSTRACT

The US-Mexico border contains several transboundary aquifers. How to preserve and allocate groundwater is one of the main issues in this area. At the international level, recommendations based on the International Law Commission's draft articles on "The law of transboundary aquifers", annexed to United Nations General Assembly Resolution 63/124 of 11 December 2008, and the United Nations Convention on the Law of Non-navigational Uses of International Watercourses 1997, would attempt to fill the legal vacuum of international and interstate groundwater management in the US-Mexico border.

Key words: international agreement, border, groundwater, legal framework.

1. INTRODUCTION

Water is a vital resource that must be managed effectively, especially in areas, such as the US South-West, where this resource is increasingly scarce, 42 USC § 1962 (2006). The study of private and public water management provides data necessary to improve decision making regarding water allocation. The area of study is located along the entire border between the US (California, Arizona, New Mexico, and Texas) and Mexico (Baja California, Sonora, Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas). It includes several aquifers: San Diego-Tijuana, Cuenca Baja del Rio Colorado, Sonoyta-Papagos, Nogales, Santa Cruz, San Pedro, Conejos Medanos-Bolson de la Mesilla, Bolson del Hueco-Valle de Juarez, Edwards-Trinity-El Burro, and Cuenca Baja del Rio Bravo/Grande, ISARM (2009).

The border contains several major cities with a rapidly increasing water demand such as San Diego (US), Mexicali (Mexico), Tijuana (Mexico), Matamoros (Mexico) Ciudad Juarez (Mexico), El Paso (US), Las Cruces (US), Laredo (US), Nuevo Laredo (Mexico), Matamoros (Mexico), and Brownsville (US), as well as large agricultural establishments, all demanding water from the aquifers located in the border region. Both the authorities and the population are concerned about the future of water supply under the increasing demand and effects of climate change, Brown (2009).

Because surface water is scarce in the border region, a solution for water allocation will most likely be based on rational groundwater use. How to preserve and allocate our groundwater is the question that many institutions such as Texas Water Development Board ask, CLE (2004). The goal of this article is to answer this question through the study of aquifers and examination of the legal framework surrounding groundwater trading. The objective is to develop an international institutional groundwater framework, where an agreement would be the solution to allocate water among the parties using the most efficient mechanism. An umbrella agreement under the United Nations General Assembly Resolution 63/124 of 11 December 2008, carrying "The law of transboundary aquifers" and the United Nations Convention on the Law of Non-navigational Uses of International Watercourses 1997 would attempt to fill the legal vacuum of international and interstate groundwater management in the US-Mexico border.

This article analyzes rationale and significance where it presents the current private and public main groundwater issues on the border. It also presents the current legal framework on the US-Mexico Border, as well as, international trends and developments in the legal and institutional dimension of shared groundwater. Moreover, this article provides guidelines to manage groundwater on the US-Mexico border. Finally, the conclusion is presented

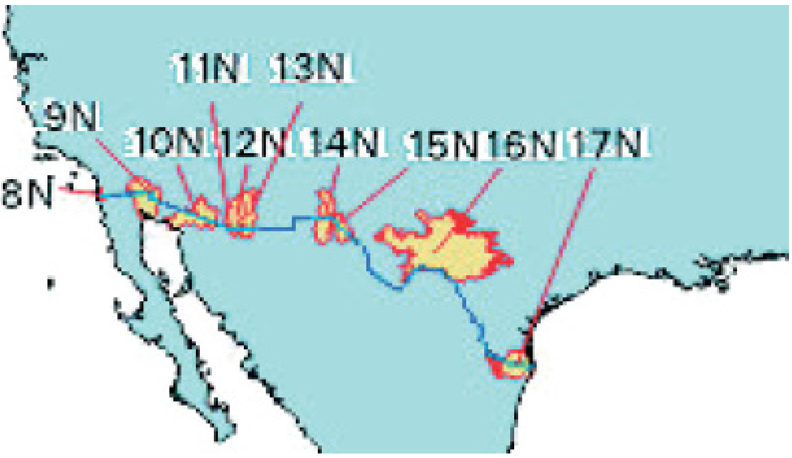
2. RATIONALE AND SIGNIFICANCE. ISSUES ON THE US-MEXICO BORDER

The purpose of this study is to provide knowledge and education to improve the management of water resources. This will support agricultural production and enhance the environment along the US-Mexico border. The increasing population of cities like San Diego, Las Cruces, El Paso, Ciudad Juarez or Nuevo Laredo, together with an inappropriate selection of crops, can seriously jeopardize the future of both agricultural and domestic supplies of water, MIS (2009).

Groundwater along the US-Mexico border has been withdrawn at high rates, EPA (2005). It has been estimated that some 18-20 shared aquifers exist, EPA (2005). This article follows the report provided by ISARM, which has studied 10 shared aquifers on the US-Mexico border (Fig. 1), ISARM (2009). The lack of a coordinated program and management framework for transboundary groundwater are the main issues in the area, EPA (2005). In addition, the lack of ground water quality data is a barrier to designed water quality standards in the international legal framework. The request of data to both countries would provide enough information to develop effective water quality standards. However, "the lack of consensus for approaches to investigations; a lack of agreement on data collection protocols; variability in laboratory methodologies, lack of data base management documentation and reporting systems; and a lack of agreement of data interpretation methods" are all main barriers to the development of appropriate water quality criteria able to be implemented among the two countries, EPA (2005).

Today, one of the major challenges is to establish a mechanism to collaborate with all levels of government and the private sector in conducting water data collection activities. Hydrologic and geologic data are important tools to manage water resources EPA (2005). They provide information about "river characteristic, interaction between ground and surface water, the amount of ground water in storage, the direction, and rate of movement, and the quality of the data," EPA (2005). This data is relevant to establish decisions for policy. For example, scientific data can reveal that a particular area contains salty water or that it is too deep. Therefore, the decision to extract water from that site will be too expensive. Decision making is directly related to the scientific information. When data is accurate, the decision will contribute to the best water allocation management.

Figure 1 Map groundwater aquifers in the US-Mexico



http://www.isarm.net/publications/324

This map shows the most relevant transboundary aquifers along the US-Mexico border, as well as interaction with surface water.

- San Diego-Tijuana (8N)

- Cuenca Baja del Rio Colorado (9N)
- Sonoyta-Papagos (10N)
- Nogales (11N)
- Santa Cruz (12N)
- San Pedro (13N)
- Conejos Medanos-Bolson de la Mesilla (14N)
- Bolson del Hueco-Valle de Juarez (15N)
- Edwards-Trinity-El Burro (16N)
- Cuenca Baja del Rio Bravo/Grande (17N)
-

The main problem in all of these aquifers is contamination. For example, Bolson del Hueco-Valle de Juarez – Colorado is suffering gradual decline in the quality of water. Today, inter-state cooperation for Bolson del Hueco-Valle de Juarez – Colorado is aimed at exchanging information and a common formulation of management strategies, ISARM (2009).

3. INTERNATIONAL LEGAL FRAMEWORK

Customary international law, and agreements among countries are the only efficient sources of international law used to manage transboundary groundwater. Today, the trend of countries to manage transboundary aquifers is through customary international law, Burchi (1999). The International Law Commission (ILC) has codified international customary rules in the UN Convention on the Law of the Non-navigational Uses of International Watercourses 1997, Resolution 51/229, fifty-first Session, Supplement No. 49 (A/51/49) (May 21, 1997). The 2008 draft articles on "The Law of Transboundary Aquifers", is annexed to United Nations General Assembly Resolution 63/124 of 11 December 2008. "Confined aquifers" is the only form of groundwater not covered by the 1997 U.N. Convention, McCaffrey (2009). Most of the aquifers in the US-Mexico border are connected to surface water. This is an interesting fact which makes the 1997 U.N. Convention applicable to most of the transboundary aquifers in the area.

The lack of a binding international instrument to manage transboundary aquifers in conjunctive use with surface water makes agreements, and customary rules, the only efficient sources of law used to manage transboundary groundwater. Despite the interest in this source, a survey of 400 freshwater treaties and agreements reveals that only 15 percent include groundwater regulation in their provisions, Jarvis (2009).

The international legal framework in the US-Mexico border contains several "Minutes" (agreements under the 1944 US-Mexico treaty) among the two countries. Minute 242.6 specifically focuses on the management of transboundary aquifers:

> "With the objective of avoiding future problems, the United States and Mexico shall consult with each other prior to undertaking any new development of either the surface or the groundwater resources, or undertaking substantial modifications of present developments, in its own territory in the border area that might adversely affect the other country." IBWC (1973)

Minute 242 echoes international water law principles codified in the UN Convention in the Law of the Non-navigational Uses of International Watercourses 1997 and in the ILC's Transboundary Groundwater draft. Under Minute 242 the United States and Mexico have the duty to "consult with each other prior to any new development." This reflects the principles of cooperation, exchange data and information, giving prior notification of planned measures, consulting and negotiating in good faith, McCaffrey (2007). Minute 242 also incorporates the principle of no significant harm, taking all appropriate measures to prevent the causing of significant harm, when a project in its own territory or in the border area "might adversely affect the other country." The principle of equitable and reasonable utilization may also be extracted from the meaning and analysis of Minute 242. Its main objective is "avoiding future problems" which implies a reasonable utilization of transboundary aquifers.

At the institutional level, the International Boundary and Water Commission, United States and Mexico (IBWC), focuses on "the operation and maintenance of Falcon and Amistad Dams on the Rio Grande; flood control projects on the Rio Grande, Colorado and Tijuana River; determination of the national ownership of the waters of the boundary rivers; water quality monitoring and salinity control; operation of international wastewater treatment plants; and mission-relevant studies and planning efforts," EPA (2005). This institution represents the key element to implement an umbrella agreement to manage transboundary aquifers in conjunctive use with surface water among the two countries.

The Bellagio Draft Treaty is a model for agreements governing the use and management of transboundary groundwater. The draft treaty proposes principles and institutional instruments for countries to address such management issues as uncontrolled drawdown, depletion, drought reserves, water quality, protection of recharge areas, and public health emergencies, along with procedures for settling disputes, Hayton and Utton (1989). This instrument provides a blueprint for international agreements on the allocation of groundwater among two countries, avoiding a tragedy of the commons, originally illustrated as a pasture open to all herdsmen, leading each to maximize his consumption and thus to the destruction of the commons. Hardin (1968); McCaffrey (2009). Similarly, the open use of an aquifer without regulation leads to the decline in the quantity and quality of groundwater and the potential destruction of the aquifer.

4. GUIDELINES TO ALLOCATE WATER IN THE US-MEXICO BORDER.

An international agreement focusing on joint management institutions for each basin would be the answer to managing groundwater in the US-Mexico border. It would be the solution to avoid future conflict and guarantee the sustainable development of the aquifers located on the US-Mexico border. Today, the main limitations for developing an agreement are the current political barriers as well as the technical difficulties in a convergence of laws from different states and countries. Another limitation is the level of uncertainty in evaluating and monitoring the quantity and quality of groundwater. This is especially problematic due to unknown underground water transport between communicating aquifers which appear to be independent from each other, EPA (2005).

The principles of international water law and an international institution such as the IBWC are essential to implement a potential transboundary groundwater management mechanism on the US-Mexico border. Under this ideal framework, special institutions for each basin would provide a mechanism for the exchange of accurate data between the two countries. This data would provide the necessary information about water quality and quantity to determine which allocation method is the most effective for that specific basin. An agreement should be flexible enough to allow its implementation. When regulations are strict and rigid, the implementation would be inefficient. Therefore, we need flexible mechanisms such as joint management mechanisms. A joint management body would be established to manage each basin. It would be the main authority managing the whole basin and determining the needs of each state along the basin. This body would study all issues trying to provide solutions in conjunction with representatives of states and the public which would participate in public meetings and hearings. According to Article 24 of the 1997 UN Convention joint management mechanisms are used to provide the implementation of any plans adopted, as well as promote the rational and optimal utilization, protection, and control of the watercourse. The ILC's draft articles on Transboundary Aquifers, in art 7, also emphasize the significance of joint mechanisms to achieve goals such as "sustainable development, mutual benefit, [...] equitable and reasonable utilization and appropriate protection of their transboundary aquifers or aquifer systems." UNGA Resolution 63/124, Annex.

In order to attain those goals, the joint management institution would establish the most appropriate mechanism for allocating water as well as determining the type of water-transfers that should be permitted, both inter-basin and intra-basin. This body would analyze relevant factors relating to each riparian state and would determine the allocation of water according to the needs and development of the regions. Ideally, the joint management body would have the authority to control, effectively implement and penalize any activity against the health of the basin. It would be assisted by other institutions such as joint supervision teams, which through monitoring control, will ensure the correct allocation of groundwater as well as good water quality. In addition, technical support institutions would provide scientific data about the basin.

In a transboundary groundwater agreement the federal governments would effectively be seen as an insurance policy, which will provide security to the local parties in case of a conflict that is unable to be resolved by the parties or the joint body. When negotiation among parties, the federal governments or mediation through a third party do not solve the conflict, the agreement would provide for a specific tribunal, such as the International Court of Justice or arbitration, to resolve potential conflicts. Article 33 of the 1997 Convention provides a very useful framework for the settlement of disputes.

Another important aspect to be included in international groundwater agreements, are specific provisions for managing groundwater in conjunctive use with surface water. This would contribute to a better allocation of water resources as well as a more efficient use of it. The holistic regulation of both sources together would protect groundwater from an excessive depletion.

The cooperation between the different levels of government facilitates the implementation of the agreement. When the federal government provides economic and technical support, the states will be more willing to collaborate and to be bound by an international agreement. International projects would be implemented according to regional water resource management and inter-state agreements developed in the basin. The success of international water regulation will depend on the level of involvement with the local governments. Only when the regulation is accepted at the local level would it be effectively implemented in the international sphere.

5. CONCLUSION

Today, transboundary aquifers on the US-Mexico border suffer contamination due to inappropriate practices. This contributes to a gradual decline in the quality and quantity of water. The implementation of the best management practices through an international groundwater agreement will ensure groundwater resource for the future. An agreement provides the legal framework able to guarantee sustainable development on the US-Mexico border. The UN Convention 1997 and the ILC's 2008 draft articles are key elements to achieve this goal. An agreement based on the provisions of both instruments would contribute to ensuring future groundwater resources and avoiding conflict among the two countries.

The UN Convention 1997 establishes an excellent framework to manage groundwater in conjunctive use with surface water. It defines "Watercourse" as a "system of surface waters and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus." Most of the aquifers on the US-Mexico border are connected with surface water. This makes aquifers part of the watercourse. Therefore, the management of both sources should be done with a view to conjunctive use. A joint management institution for each basin "watercourse" would establish the most appropriate practice and avoid potential conflict.

In conclusion, the collaboration among the different levels of government through a joint management institution, under the principles established in the UN Convention 1997 and the ILC's 2008 draft articles would be the answer to the management of groundwater on the US-Mexico border.

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Uruguay River Basin:

The Possibility of Benefit Sharing and Cooperation for Transboundary Waters Between Argentina and Uruguay

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ABSTRACT

Transboundary waters in Latin America have been and are opportunities for integration and cooperation as well as conflict threats. Many countries have instruments to deal with the joint management and use of shared water resources. Albeit drafted decades ago, these accords are early expressions of joint management of shared resources. Such an agreement is the Uruguay River Statute. The river Statute (an agreement signed between the two countries in the mid 1970s) aims at managing the boundary river (including aspects of natural resource exploitation, pollution prevention, etc.). Yet, this agreement needs to be brought up to date and needs to be made more proactive. Several issues have identified that need to be incorporated in this instrument or be part of a new one in order to successfully manage joint water resources as well as foster amicable conflict resolution. The paper will propose the generation of new overall approaches as well as the implementation of new instruments that would incorporate up to date practices through multilateral instruments.

Key words: Shared resources, international agreements, conflict resolution

1. INTRODUCTION

Transboundary waters in Latin America have been and are opportunities for integration and cooperation as well as conflict threats. Many countries have instruments to deal with the joint management and use of shared water resources. Albeit drafted decades ago, these accords are early expressions of joint management of shared resources. Such an agreement is the Uruguay River Statute. The river Statute (an agreement signed between the two countries in the mid 1970s) aims at managing the boundary river (including aspects of natural resource exploitation, pollution prevention, etc.). The Treaty itself is a key instrument to be taken into account. It is one of the first such river basin international tools in the South America region. Albeit it is a product of its times, its aspects for transboundary river management are still to some extent current and an example of early international river basin management. Nevertheless, this treaty has failed to contain a recent major conflict between the two countries that has ended in a case brought to the International Court of Justice. Following these events, there have discussions regarding how the treaty can be improved in order to be more resilient to these sorts of conflicts as well as to be a more current instrument that sustainable manages natural resources for riparian countries.

2. OBJECTIVES

The Uruguay River is one of South America's great waterways. It has a longitude of nearly 1800 kilometres, and it's an international system with a basin of some 340 000 square kilometres. A navigated river to a great extent, it has a series of direct and indirect multiple uses, including hydroelectric dams. Together with other resources is part of the La Plata Basin. For the purposes of this paper, an integrated view of water resources and water resources management will be taken, understanding that the river is a system that is part of an acquifer and it amalgamates surface and groundwater.

The main instrument that manages river – related issues is the Uruguay River Statute, as mentioned above. Nevertheless, this instrument has proven to be dated and not sufficient to contend with current issues (Giordano, 2003). As many similar treaties, it lacks forcefulness (Giordano and Wolf, 2003). Also, as in many international river agreements, this can be attributed to the vagueness in treaty's content (Brochmann and Gleditsch, 2006) as well as the lack of incorporation of more modern visions of treaty mechanisms, in particular as related to environment and development issues.

One of the matters that have been debated as part of the paper mill conflict and its relation to the Uruguay River Statute is to whether this instrument is sufficient to contain further conflicts and manage sustainably the river resources (Daneri, 2007). This work will identify and develop several issues that need be incorporated in this instrument or be part of a new one in order to successfully manage joint water resources as well as foster amicable conflict resolution. The paper will propose the generation of new overall approaches as well as the implementation of new instruments that would incorporate up to date practices through multilateral instruments. The instruments' improvement can be achieved by bringing up to date the issues and treaty-architecture it deals with and thus adding robustness to the international agreement.

2.1 Uruguay River Statute Reforms

If the Uruguay River Statute is to be brought up to date in order to meet agreed upon management of shared water resources as well as foster sustainable development associated to the river, it should incorporate new and enhanced components (Onestini, 2009). Mechanisms such as, but not limited to:

(a) improved civil society participatory processes in order to move away from state-centric outlooks and more of a multi-stakeholder method;

(b) technical and policy inclusions in the organizational architecture of treaty – derived instruments;

(c) include capacity – building mechanisms;

(d) include clearly functional governance structures;

(e) include specific joint monitoring of activities and environmental impacts.

Discussions on these and other facets of a river management instrument will be developed below.

2.2 Inclusion of all Riparian States

In order for the Statute to be inclusive as well as to appropriately fit the scale between the biophysical riverine system with management and administrative entities within an enhanced instrument, it should include all of the riparian States. Over one-third of the River is contained exclusively in Brazilian territory; over one third of its length is shared between Argentina and Brazil, while for less than one-third of its length the riparian States are Argentina and Uruguay.

The current treaty only includes the two downstream nations (Argentina and Uruguay), while Brazil (upstream nation and country where the river originates, and where two thirds of its length lies) is not part of this agreement. Therefore, a first basic reform to the Statute should be to include all of the river's riparian States in some capacity.

2.3 Civil society participation processes

The Statute does not incorporate the question of participation and civil society engagement in any way. This matter was a not an issue in national or international governance at the time the agreement was approved. Nevertheless, it cannot be circumvented that this is an issue integral to inter governmental relations, including multilateral agreements.

Conflict arising between parties to the Statute, as well as conflict between State and non – state actors, has been attributed --in part-- to a lack of transparency and participation vis-à-vis civil society, especially regarding those directly and negatively impacted by different river uses.

Therefore, the inclusion of improved civil participatory processes in order to move away from State-centric outlooks and more of a multi-stakeholder method within its institutional architecture is a needed transformation in order to bring up to date the Uruguay River mechanism (CEDEA *et* al, 2007). Following general and accepted practice of the last two decades, the Statute should incorporate participatory processes that would make the workings and decisions taken regarding river management more democratic and more equitable.

Institutional arrangements need to be made, on the one hand, to improve transparency but also to incorporate civil society's skills and points of view into sustainable river management practices. Following what nowadays is standard practice, arrangements should be made for instutionalizing matters such as the introduction of civil society knowledge, expert advice and information as well as the raising of new issues. Furthermore, civil society's input in broad consensus-building processes must also be instutionalized in order to ensure commitment by all actors in the river management and sustainable use agenda. (United Nations General Assembly, 1998)

2.4 Technical/policy incorporation to treaty – derived structures

Although some technical and policy inclusions in the organizational architecture of the treaty at hand are included, they should be strengthened in order to make this statute a more resilient and current accord. The structures that ensue from the current Uruguay River Statute need the incorporation of technical bodies that can guide and provide input to decision – making processes.

One of the contentions between the two riparian countries part of the treaty (Argentina and Uruguay) relates to impact assessment of activities in the margins. Therefore, strategic environmental evaluations, including impact assessment, should be implemented accompanied by adequate technical and scientific structures that ought to be in constant dialogue with policy governance structures.

2.5 Capacity – building mechanisms

Capacity building mechanisms in aspects of integrated and sustainable river management are not part of the Statute nor of its derived structures. This hinders adaptability of governance structures, given that new approaches, new productive endeavours and new policy situations arise, yet the structure and the organization do not have the instruments necessary to deal with these changes. Therefore, a permanent capacity – building scheme must be part of the treaty's bodies in order to keep abreast of productive and policy changes.

2.6 Clearly functional governance structures

The Treaty has neither adequate nor practical governance resilient structures, creating a situation of institutional vulnerability. In order to surpass this breach, practical and functional enforcement mechanisms must be designed and implemented as part of an overhauled agreement that has the strength to oversee issues related to the Uruguay River. These should include agile conflict resolutions provisos.

An important factor in the region is the role that sub national (local, provincial, departmental) government has in water related and riverine matters. The Uruguay River Treaty of 1976 does not fully take this into account. Therefore, it is fundamental that a new or reformed river treaty should have within its architecture stipulations recognizing this and linking with sub national structures in a responsive and proactive manner.

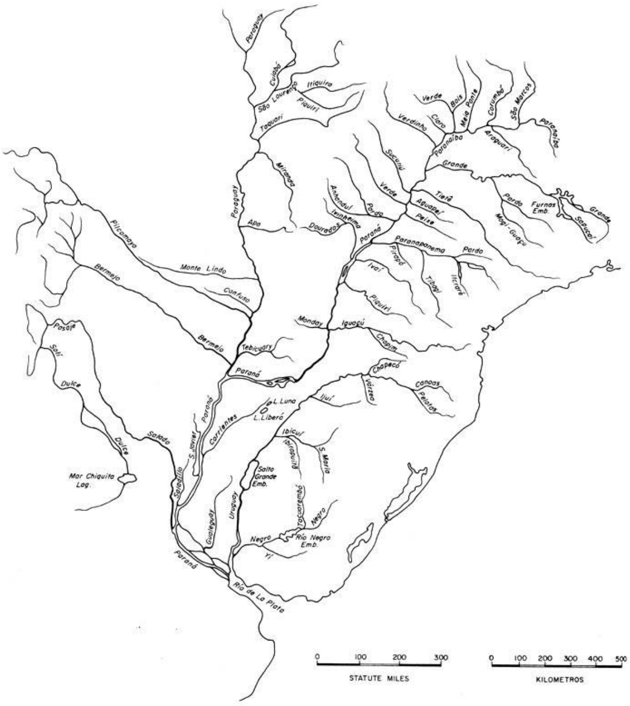
2.7 Specific monitoring of activities and environmental impacts

A reformulated or new treaty should very specifically incorporate guidelines as to the monitoring of activities, of environmental impacts, as well as other related parameters that need to be scrutinized in order to assess the impact of activities on riverine margins and influence areas. Therefore, strategic environmental evaluations, including impact assessment, should be incorporated taxatively in order to improve monitoring and evaluation.

3. CONCLUSIONS

In conclusion, looking at a situation where the Uruguay River Treaty has failed to contain a conflict between two countries, but have managed a transboundary river for three decades, policy recommendations are made in this work to improve the instrument in order to minimize conflict and manage water use issues with a developmental framework and mutually benefiting the countries and societies involved. Adaptable yet agile management structures that include clear conflict resolutions schemes and administrative arrangements, sharing of information mechanisms, as well as the participation of different stakeholders (including sub national governments and civil society) are the transformations needed to make the integrated management of the Uruguay River a cooperative endeavour.

MAP OF THE URUGUAY RIVER BASIN



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What Lessons can be learned for the Management of Non-Recharging Transboundary Groundwater from Transboundary Petroleum Law?

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ABSTRACT

Groundwater is the largest source of freshwater that is available to humanity and is the world's most mined resource. In most cases groundwater is a renewable resource which receives recharge from rainfall or surface-water resources. However in arid regions that do not receive rainfall and do not have permanent surface-water bodies non-recharging groundwaters constitute an important yet finite freshwater resource. Within a transboundary context, the finite and non-renewable nature of non-recharging groundwater has significant geo-political, economic and developmental implications. The ILC Draft Articles on the Law of Transboundary Aquifers 2008 are a notable legal advance in the development of international groundwater law. In light of the provisions found in the ILC Draft Articles on the Law of Transboundary Aquifers 2008 and the Model Bellagio Draft Treaty 1989 this article shall explore the applicability of their substantive principles and proposed institutional mechanisms on non-recharging, transboundary groundwater. Transboundary petroleum is a finite resource that is physically developed in a similar manner to non-recharging, transboundary groundwater. A number of *ad hoc* legal mechanisms such as unitisation agreements and joint development areas have been created for the management of transboundary petroleum. This article shall also examine some of the generic substantive and institutional mechanisms of transboundary petroleum agreements with a view to assessing the lessons they might provide for the management of non-recharging, transboundary groundwater. This paper suggests that the legal mechanisms of petroleum unitization and the institutional mechanisms of petroleum joint development agreements offer valuable lessons for addressing issues of allocation and the management of non-recharging, transboundary groundwater.

Keywords: Non-recharging, transboundary groundwater, ILC Draft Articles on the Law of Transboundary Aquifers 2008, Bellagio Draft Treaty 1989, Petroleum Unitisation Agreements, Joint Development Agreements

1. INTRODUCTION

This article shall expound the similarities between the geological structures that contain non-recharging transboundary groundwater and transboundary petroleum. This article shall also explain the similarities in how both resources are physically abstracted. International Water Law, as applicable non-recharging, transboundary groundwater shall be examined with a view to addressing to what extent its substantive and procedural rules offer solutions for the distributive equity in the allocation of non-recharging, transboundary groundwater. The procedures and mechanisms of transboundary petroleum shall then be presented as possible solutions to the problems emanating from the development of transboundary, non-recharging groundwater.

2. PARALLELS BETWEEN NON-RECHARGING GROUNDWATER AND PETROLEUM

Non-recharging groundwater is typically found in confined aquifers. A confined aquifer is formed when a confining layer forms between a layer of rock material whose pores are saturated with water, which is known as the saturated zone, and an impermeable rock layer beneath the saturated zone. Compaction of the sedimentary rock material above the saturated zone results in a geologically sealed layer of water that exists within a pressure system. When a well is drilled into a confined aquifer the pressure within the aquifer causes the water to rise above the uppermost level of the saturated zone. The level to which water rises in a well that is drilled into a confined aquifer is known as the piezometric1 surface. The water contained in confined aquifers is sometimes referred to as fossil water or paleowater in reference to its age which could be calculated in millennia. The origin of paleowater is precipitation that fell in regions that used to receive significant quantities of rainfall thousands of years ago and that are now arid. Many confined aquifers are found in arid parts of the world that do not receive significant amounts of rainfall and that do not have permanent surface-bodies of water.[2] The paleowater contained in these types of confined aquifers is a non-renewable resource due to the lack of a source of recharge whether through precipitation or hydraulic connection to surface-water bodies. Aquifers that contain non-recharging groundwater do not correspond to politico-legal boundaries and a number of major aquifers and aquifer systems that contain non-recharging groundwater are found beneath the territory of two or more States. Some examples of this type of aquifer include The Tindouf Aquifer between Morocco and Algeria whose size is 210,000 km^2, The Northwest Sahara Aquifer System between Algeria, Libya and Tunisia whose size is 1,019,000 km^2, The Mourzouk-Djado Basin between Chad, Libya and Niger whose size is 450,000 km^2, The Nubian Sandstone Aquifer System between Chad, Libya, Egypt and Sudan whose size is 2,199,000 km^2 as well as The Tin-Serinine Basin between Algeria and Niger and the Air Crystalline between Algeria, Mali and Niger.

The most significant characteristics of the confined aquifer for the purposes of this article are: the groundwater they contain constitutes a finite resource and the groundwater they contain exists under a pressure system which becomes altered when boreholes are drilled into the aquifer.

There are three key factors to the development of groundwater that have existed since antiquity: locating the groundwater, excavating a conduit from the earth's surface to the groundwater and transporting the groundwater from the aquifer to the earth's surface.

Drilling is one of the means through which the subsurface rock material is sampled for investigation for groundwater and is the only means through which groundwater is accessed for abstraction. Drilling results in the construction of boreholes that can then be expanded into wells. Some features of the drilling process include: the use of drilling fluids to lubricate and cool the drill bit, the removal of cuttings or crushed rock material from the borehole, and the advancement of metal casing in the well in order to prevent the collapse of the well or its contamination

Once groundwater has been accessed through drilling, the second phase of developing the resource is transporting it from the piezometric surface to the earth's surface. Mechanical pumping through submersible and turbine pumps is the contemporary means through which groundwater is transported from the aquifer to the surface for storage, treatment and consumption. Groundwater pumping is the activity that has the most physical impact on the Hydrogeological and even human environment. To this end a series of pumping tests are usually undertaken in order to examine, the effects of pumping on other wells that are extracting groundwater from the aquifer, the type of and size of pump that is required for the aquifer and the costs involved, the effects of potential long-term pumping on the surface gradient of areas that are geologically connected to the aquifer and the effects of pumping on other aquifers

Petroleum has been defined as, 'a complex mixture of hydrocarbons that occurs in the Earth in liquid, gaseous or solid forms. The term is usually restricted to the liquid form, commonly known as crude oil, bus as a technical term it also includes natural gas and the viscous or solid form known as bitumen. The liquid and gaseous phases of petroleum constitute the most important of the primary fossil fuels.'

Petroleum molecules are found under pressure in the pores and fractures of sedimentary rock in the earth's land or underwater subsurface. In order for petroleum to be exploitable the petroleum molecules must accumulate in particular geological formations in large volumes. The geological formations in which petroleum accumulations occur are known as structural traps that have been formed through the tectonic deformation of the earth's crust or lithosphere or, depositional entrapment through sedimentation. By virtue of accumulating in traps petroleum molecules exist under a pressure system sustained by the rock they underlay and the ground or seawater with which the petroleum molecules compete for space within the reservoir rock material. In the event that a wellbore is drilled into a petroleum accumulation, petroleum molecules will migrate from an area of high pressure to the area of lower pressure around the wellbore.

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[1] The piezometric surface is also known as the potentiometric surface.
[2] Non-renewable groundwater has been defined as being found in areas which receive less than 200 millimetres of rainfall per year (WHYMAP).

Petroleum accumulations exist in the geological subsurface and therefore do not correspond with politico-legal borders, raising the possibility that they may cross international boundaries whether off-shore or on-shore. Examples of developed on-shore transboundary petroleum accumulations are The Safaniya-Khafji field in the Neutral Zone between Saudi Arabia and Iraq, the Rumaila field between Kuwait and Iraq, the Fakka oil field between Iraq and Iran[3] and the Yadavaran and Adazegan fields in Khuzestan, Iran, on the Iran-Iraq border. The first three phases of the physical development of petroleum are: locating the petroleum resources, excavating a conduit from the earth's surface to the petroleum accumulation and transporting the petroleum to the location where it can be processed.

Petroleum is accessed through drilling. The precise location of where wellbores should be drilled is important in relation to the amount of petroleum that can be extracted from the accumulation due to the pressure system within which petroleum accumulations exist. The drilling of petroleum completely mirrors the drilling of groundwater. In an identical manner to the drilling of groundwater, drilling for petroleum involves the mechanical propulsion of a drill bit into a particular point in the surface rock in order to break the rock material and create a sub-surface conduit to access the petroleum resource. The features of the petroleum drilling process are also identical to those involving groundwater and include: the use of drilling fluids to lubricate and cool the drill bit, the removal of cuttings or crushed rock material from the borehole, and the advancement of metal casing in the well in order to prevent the collapse of the well or its contamination.

The similarities between petroleum accumulations and the non-recharging groundwater found in confined aquifers are: they both exist in a pressure system in similar geological formations, both resources are mobile and both resources do not conform to politico-legal international boundaries. That being the case, the non-conformity of the geological boundaries of both petroleum accumulations and confined aquifers with the areas that are administratively, legally granted to licence holders for the drilling and abstraction of the resources raises problems. Since both resources exists in pressure systems, the first licence holder to drill a well into the petroleum accumulation or confined aquifer will induce the migration of petroleum molecules from the areas of neighbouring licence holders into their area. In the case of groundwater the first licence holder to abstract water may cause the piezometric surface to drop, which would entail neighbouring licence holders to incur greater economic costs associated with drilling deeper wells in order to access the piezometric surface and pumping the groundwater up to the earth's surface from deeper distances. In legal terms, the negative consequences of the unilateral development of non-recharging, transboundary groundwater could constitute 'irreparable prejudice' to the rights of other aquifer States in the resource.

3. INTERNATIONAL GROUNDWATER LAW

There are only two international legal instruments that have been drafted to specifically deal with groundwater and that make reference to allocation which is essential to an analysis of the management of non-recharging, transboundary groundwater: The Bellagio Draft Treaty 1989 and The ILC Draft Articles[4] on the Law of Transboundary Aquifers 2008.It is essential for the management of non-recharging, transboundary groundwater that the hydro-geological specificities of confined, non-recharging groundwater are adequately addressed in the 'scope' of the Bellagio Draft Treaty and the ILC Draft Articles on the Law of Transboundary Aquifers. It is also important to assess both international legal instruments for the substantive principles that guide the utilisation of non-recharging, transboundary groundwater in order to evaluate whether the substantive principles are suited to non-recharging, transboundary groundwater which is a finite resource.

The scope of the groundwater that is covered in the Bellagio Draft Treaty can be determined by an analysis of the definitions it gives for 'aquifer' 'groundwater' and 'transboundary aquifer', 'transboundary groundwater' and 'border region'. The definition of aquifer that is made in the Bellagio Draft Treaty is: *'subsurface water bearing geologic formation(s) from which significant quantities of water may be extracted'*.[5] The Bellagio Draft Treaty defines groundwater as: '*the waters in the aquifer*'.[6] The definition of 'transboundary aquifer' that is provided in the Bellagio Draft Treaty is: '*...an aquifer intersected by a common boundary*'.[7] Transboundary groundwater is defined in the

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[3] http://www.upstreamonline.com/live/article202079.ece

[4] Draft Articles on the Law of Transboundary Aquifers, UN Doc.A/RES/63/124 (2008).

5 R. D. Hayton and A. E. Utton, Transboundary Groundwaters: The Bellagio Draft Treaty, 29 NAT. RESOURCES J., (1989) 663-676. Article I, Definitions 1.

[6] Article I, Definitions 14. Id.

[7] Article I, Definitions 20. Id.

Bellagio Draft Treaty as: '*...waters in transboundary aquifers*'.[8] Border region is defined as: '*the area within approximately kilometers from each side of the mutual boundary as set forth on the annexed map*'.[9] The definition of border region adds a politico-legal geographic component to the scope of the Bellagio Draft Treaty which is significant since hydro-geological borders do not conform to politico-legal borders. The definition of '*aquifers*' and '*transboundary aquifers*' in the Bellagio Draft Treaty does not differentiate between recharging and non-recharging aquifers and confined and non-confined aquifers. In the commentary to the Bellagio Draft Treaty it is stated that the term 'aquifer', '*comprehends all underground water-bearing strata capable of yielding water on a practicable basis*'.[10] Recharging and non-recharging aquifers are different, as recharging aquifers constitute a renewable resource that may be sustainably utilized whereas non-recharging aquifers constitute a finite resource which necessitate a specialized set of rules, particularly with regards to allocation.

The definition of 'aquifer' that is made in the ILC Draft Articles on the Law of Transboundary Aquifers is: *'a permeable water-bearing geological formation underlain by a less permeable layer and the water contained in the saturated zone of the formation'*.[11] It is important no note that transboundary non-recharging groundwater is found in a permeable water-bearing geological formation that is also: '*overlain by an impervious or almost impervious formation, in which water is stored under pressure*'. The definition of aquifer in the ILC Draft Rules on the Law of Transboundary Aquifers therefore applies more accurately to unconfined aquifers than confined aquifers that contain non-recharging groundwater. It can therefore be seen that both the Bellagio Draft Treaty and the ILC Draft Articles on the Law of Transboundary Aquifers do not specifically address non-recharging, transboundary groundwater in their scope, but include non-recharging, transboundary groundwater with recharging, transboundary groundwater.

With regards to the substantive principles that guide the allocation of transboundary, non-recharging groundwater, the Bellagio Draft Treaty contains provisions for a 'comprehensive management plan' according to which States on whose territory interconnected non-recharging groundwater exists may agree on the 'planned depletion'[12] of the aquifer over a 'defined period of time'. The specific methodology of the allocation of the non-recharging, transboundary groundwater is left to the provisions of the 'depletion plan' and not specified in the Treaty itself but expanded on in the commentary to the model Treaty. The commentary on the Bellagio Draft Treaty defines depletion as '*the withdrawal of water from an aquifer at a rate faster than it is recharged, otherwise known as "mining" the water.*'[13] The commentary on the Bellagio Draft Treaty stresses on the joint nature of planned depletion and suggests that certain water uses may have to be prioritised whilst others that are water intensive would be changed or curtailed at the behest of the Commission which would monitor the implementation of the provisions of the treaty, 'on the basis of information from the Governments'. The commentary to the Bellagio Draft Treaty further envisages the rotation of water uses and even the trading of water between States as an advance on future allocations.[14] Although the Bellagio Draft Treaty contains a substantive provision that is relevant to the management and development of non-recharging, transboundary groundwater, its status as a model treaty means that it has never been implemented. Furthermore the Bellagio Draft Treaty does not elaborate on how non-recharging, transboundary aquifers should be apportioned.

The substantive principle that governs the utilisation of transboundary aquifers in the ILC Draft Articles is enshrined in Article 4 which is entitled 'equitable and reasonable utilisation' and is comprised of 4 sub-articles. According to the ILC Draft Articles, aquifer States shall utilise their transboundary aquifers according to the principle of 'equitable and reasonable utilization' and for the '*equitable and reasonable accrual of benefits to the aquifer States concerned.*'[15] Aquifer States shall aim to maximise the long-term benefits derived from the use of water' in transboundary aquifers and shall develop individually or jointly a comprehensive utilisation plan, taking into account present and future needs and alternative water sources. The Draft Articles contain provisions on how 'equitable and reasonable utilization' is to be determined and the relevant factors include demography, social and economic needs in the present and future, existing and potential use of the aquifer as well as the

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[8] Article I, Definitions 22. Id.

[9] Article I, Definitions 2. Id.

[10] Comment 1. Id.

[11] Draft Articles on the Law of Transboundary Aquifers, UN Doc.A/RES/63/124 (2009). Article 2, Use of Terms, 2.

[12] Article X, Bellagio Draft Treaty
R. D. Hayton and A. E. Utton, Transboundary Groundwaters: The Bellagio Draft Treaty, 29 NAT. RESOURCES J., (1989) 663-676.

[13] Article I, Definitions 7. Id.

[14] R. D. Hayton and A. E. Utton, Transboundary Groundwaters: The Bellagio Draft Treaty, 29 NAT. RESOURCES J., (1989) 663-676. Comment 3 to Article X, Planned Depletion.

[15] Draft Articles on the Law of Transboundary Aquifers. UN Doc.A/RES/63/124 (2008). Article 4, Equitable and reasonable utilization, (a)

natural characteristics of the aquifer.[16] The principle of 'reasonable and equitable utilization' is the primary substantive principle that governs utilization of international surface-water resources. 'Equitable and reasonable utilization' implies a certain degree of 'sustainability' which cannot be applied to a finite resource and is more suited to guide the utilization of a renewable water resource such as an international river or recharging, transboundary aquifer as opposed to a finite water resource such as a non-recharging, transboundary groundwater. The ILC Draft Articles do not contain specific provisions which are applicable to the groundwater contained in transboundary aquifers.

4. TRANSBOUNDARY PETROLEUM LAW

The petroleum industry has managed to devise two legal mechanisms in order to offset the negative practical consequences of the disjointed drilling of a petroleum accumulation by multiple licence holders and to facilitate the development of petroleum in areas of contested sovereignty. The legal mechanism that offsets competitive drilling of a petroleum accumulation by multiple licence holders is 'unitization'. The legal mechanism that facilitates the development of petroleum in areas of contested sovereignty is the 'joint development agreement'. It should be stated that 'joint development agreements' have two contextual factors that do not apply to non-recharging, transboundary groundwater. Joint development agreements deal with offshore petroleum accumulations and areas of contested maritime sovereignty where the legal regime of the United Nations Law of the Sea applies. Notwithstanding the specificities of off-shore petroleum and the applicability of the United Nations Law of the Sea, joint development agreements contain provisions for the sharing of the economic burdens of developing the resource as well the sharing of the resource itself and its benefits. Joint development agreements also mandate the creation of institutional mechanisms that offer valuable lessons for the management of non-recharging, transboundary groundwater. The legal institutional mechanisms that have been created by joint development agreements include management by two States in a joint venture model and the creation of a joint authority comprising both States. It is worth noting that the ILC Draft Articles on the Law of Transboundary Aquifers 'encourages' States to enter into bilateral or regional arrangements[17] and states that States 'shall' establish a joint management mechanism 'wherever appropriate'.[18] The non-prescriptive or descriptive nature of the ILC's Draft Articles with regards to institutional mechanisms for the management of transboundary groundwater, coupled with few existing examples of institutional mechanisms whose scope is limited to the collection and sharing of data gives credence to the premise that lessons can be learned from transboundary petroleum law.

The concept of 'unitization' was devised in the United States to offset the economic losses incurred from the competitive drilling of neighbouring licence holders in the same petroleum accumulation. 'Unitization' is therefore sometimes referred to as 'conservation'. Petroleum 'unitization' is based on the pooling of the various licence holders interests and the development of the petroleum accumulation as a unit. Unitization has evolved from application solely in national contexts such as the United States to cross-border unitization between States that wish to develop a petroleum accumulation that straddles their international boundary.[19] Some of the main provisions of a unitization agreements are: the agreement to develop the petroleum reservoir or field as single unit, determination of the geographical scope of the unit and its corresponding area, determination of the reserves of the petroleum reservoir or field, the apportionment of production from the unit and the formation of a development plan taking into account the infrastructural facilities required for the development plan. International 'unitization' agreements involve an agreement or treaty between States to develop the petroleum accumulation that straddles their international boundary in this manner, as well as an agreement between parties that have been granted a licence to develop the resource through a 'unit operating agreement'. The parties to 'unit operating agreements' include international and national petroleum companies, independently or as consortia as they are the entities that financially invest and physically develop the resource. 'Unitization' offers a scientific method for determining the volume of

[16] Article 5, Factors relevant to equitable and reasonable utilization. Id.
[17] Article 9, Bilateral and regional agreements and arrangements. Id.
[18] Article 14, Management. Id.
[19] Norway and the United Kingdom develop the petroleum deposits that straddle their international maritime boundaries in the North Sea subject to International Unitization Agreements.
Framework Agreement Between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of Norway Concerning Cross-Boundary Petroleum Cooperation, available at http://www.og.dti.gov.uk/upstream/infrastructure/nfa_2005.doc

the resource without which an equitable apportionment cannot take place. With regards to potential conflicts over the extent of petroleum reserves, the case of cross-border unitization between Norway and the United Kingdom successfully dealt with this issue through the commissioning of an independent group of specialists to appraise the volume of petroleum reserves. 'Unitization' is therefore a logical means through which the issue of entitlement and apportionment of non-recharging, transboundary groundwater can be determined, between various States.

It should be stated that there are stark differences between the licensing systems of petroleum and groundwater. Commercial interests that involve a number of operators that are likely to be private and foreign predominate international petroleum licensing regimes whereas private international commercial institutions do not prospect for groundwater. These differences manifest themselves in the taxation and accounting provisions of unitization agreements that are not directly relevant to groundwater. Notwithstanding the commercial interests inherent in petroleum licensing regimes, the technical 'conservation' of the resource through its treatment as a unit and the more equitable outcome that is reached as a result of the processes of determination and apportionment offer valuable lessons for the development of non-recharging, transboundary groundwater particularly in the absence of any legal regime that has been specifically drafted to deal with the resource.

5. CONCLUSION

This paper has drawn attention to the similarities in the geological conditions of transboundary petroleum and non-recharging, transboundary groundwater. A parallel has been made between the negative consequences of the unilateral development of both transboundary petroleum and non-recharging, transboundary groundwater which constitutes 'irreparable prejudice' by the developing State to the rights of other aquifer States in the resource. Two of the most relevant international legal instruments dealing with transboundary groundwater law were reviewed and it was found that the Bellagio Draft Treaty contains a specific provision on 'planned depletion' which is relevant to the development of non-recharging, transboundary groundwater. It was found that the ILC Draft Articles are too wide in their scope to address the specificities of non-recharging, transboundary groundwater. The substantive rule of 'equitable and reasonable utilization' was also found to be more suited to a renewable resource than to a finite resource such as non-recharging, transboundary groundwater. The two main types of instruments that address the development of transboundary petroleum were reviewed. The legal concept and process of 'unitization' was found to be appropriate to addressing the issue of entitlement to the non-recharging, transboundary groundwater. The institutional mechanisms of joint development agreements were also found to possess a structure that can be used between aquifer States. Although petroleum is an internationally traded commodity and water is a public good and human right, the special status of non-recharging, transboundary groundwater as a finite resource necessitates a search for 'equitable entitlement' beyond the traditional scope of 'equitable and reasonable utilization' which was drafted with renewable water resources in mind.

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Effective Governance of Transboundary Aquifers through Institutions – Lessons Learned from River Basin Organizations

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ABSTRACT

While international institutions governing transboundary surface waters have been established on a large number of international rivers and lakes, transboundary aquifers have been widely neglected. Only recently, the international community has acknowledged the need for establishing institutionalized governance of shared groundwater resources. Experiences from transboundary surface water governance, however, show that the establishment of institutions is only a necessary though not a sufficient condition for effective governance of transboundary water resources. This should be acknowledged when integrating groundwater issues into existing RBOs or creating new mechanisms for groundwater governance. This paper therefore aims at drawing lessons from RBO effectiveness and applying them to shared groundwater.

Key words: Transboundary Aquifer Governance, Regional and Interstate Cooperation, Institution Building, River Basin Organizations (RBOs), Effectiveness.

1. INTRODUCTION: THE NEED FOR TRANSBOUNDARY GROUNDWATER GOVERNANCE

Transboundary water resources are of great importance for the development of societies. However, the use of water resources by one riparian state necessarily affects the opportunities of others, leading to collective action problems that spread across the borders of states. For the case of transboundary surface waters1, the international community has tried to overcome such collective action problems by developing International Water Treaties (IWTs) and establishing River Basin Organizations (RBOs) that jointly govern shared surface watercourses. Groundwater2 has, however, been widely neglected in the context of (institutionalized) transboundary water resources governance: Various international conventions and norms have been developed with regard to shared groundwater resources, namely the Helsinki Rules, incorporating groundwater in the notion of drainage basins, the Belaggio Draft Treaty (1988), the 1997 UN Convention on the Non-Navigational Uses of International Watercourses, applicable to groundwater resources as well, and, most recently, the UN General Assembly's Resolution on the Law of Transboundary Aquifers (refer to McCaffrey 1999, Eckstein/Eckstein 2005), and a number of international treaties have been signed on specific aquifers (for more details refer to Puri 2001: 20 ff., Jarvis et.al. 2005: 765). However, the number of institutionalized cooperation mechanisms on shared groundwater resources remains limited. Only very few RBOs have so far integrated groundwater issues in their mandate or their work program: For instance, the Lake Chad Basin Commission (LCBC) integrates groundwater management in its work, legally based on the 1964 Lake Chad Convention. Similarly, the International Boundary and Waters Commission between the US and Mexico provides the framework for a groundwater-specific agreement between the two countries (signed in 1973). The Orange-Senqu River Basin Commission (ORASECOM) has recently included groundwater on the basis of its IWRM strategy, extending its mandate to shared aquifers in the basin, namely the Stampriet Artesian Aquifer Basin – though not legally binding and based on a formal treaty. Even fewer independent aquifer organizations have been established, with the Genevese Aquifer Management Commission (GAMC), the Joint Authority for the Study and the Development of the Nubian Sandstone Aquifer (JANSA), or the Permanent Consultation Mechanism of the States of

[1] For consistency and simplicity, the notion of "international/transboundary/shared rivers" and, accordingly, "River Basin Organizations", captures both rivers and lakes.
[2] While the author is well aware of the terminological differences, "transboundary", "international" and "shared" aquifers are used interchangeably in this paper and refer to groundwater systems or aquifers that are part of a system that traverses an international political boundary (Eckstein/Eckstein 2005: 680).

the North Western Sahara Aquifer System (SASS), established formally in 2008, being some of the very few examples[3].

However, only institutionalized governance of shared aquifers can provide means to overcome international collective action problems related to the use of shared groundwater resources. The institutionalization of groundwater governance can thereby be achieved in two ways: In cases where river/lake basins and aquifers geographically overlap, groundwater governance can be included into the mandate and the work program of existing RBOs (as it has, for instance, been done in the case of LCBC and ORASECOM)[4]. In areas where there is no pre-existing RBO or were groundwater resources exist outside of river basins (as, for instance, in the case of the North Western Sahara Aquifer), new organizations have to be established. The establishment of such institutions alone, however, does not necessarily ensure effective groundwater governance. Instead, a proper institutional design of such organizations is the key factor for ensuring effectiveness.

2. DETERMINANTS OF GOVERNANCE EFFECTIVENESS – LEARNING FROM RBOS

Findings from research on the effectiveness of international institutions in general (e.g. Axelrod/Keohane 1995, Wettestad 1999, Koremenos et.al. 2001, Mitchell 2001, Underdal 2002) and RBOs in particular (e.g. Giodrano/Wolf 2003, Dombrowsky 2007, Schmeier 2010) provide important insights for institutionalized governance of shared aquifers as well.

One of the most obvious characteristics of RBOs is their membership structure, distinguishing between inclusive organizations, integrating all riparians into the cooperation process, and non-inclusive ones, consisting of a sub-set of riparians only. While traditional cooperation theory (Axelrod/Keohane 1985, Snidal 1985, Keohane/Ostrom 1994) argues that cooperation is easier with a smaller number of participants and thus plea for non-inclusive institutions, others, often inspired by IWRM concepts, emphasize that effective water resources governance is only possible if all riparians affecting the watercourse at stake participate in its management (GWP 2000, Kliot et.al. 2001). This indicates a trade-off between operational efficiency, more easily achieved with a limited number of members, and impact effectiveness, requiring the inclusion of all actors in the basin. This question is of particular importance with regard to the fact that river/lake basins managed by RBOs and shared aquifers often overlap, though not perfectly[5]. States sharing the aquifer but not the surface watercourse should thus ideally join the existing RBO, but might require specific management structures of forums reflecting their particular status in the system. When new organizations are created, the membership of all riparians to the aquifer is of great importance. Chad and Sudan joining the JANSA, which had originally been created by Libya and Egypt only, can be seen as an important step to the joint management of the aquifer.

The functional scope of an organization is another important determinant for effectiveness: Generally, it can be distinguished between single-issue and multi-issue institutions. In practice, most RBOs are multi-issue institutions – with exceptions such as the Lake Victoria Fisheries Organization (LVFO), the Permanent Indus Commission (PIC) and the Zambezi River Authority (ZRA) dealing with fisheries, water allocation and hydropower respectively. Similarly to what has been found with regard to the membership structure, a trade-off between the efficiency of single-issue institutions, taking on a limited amount of tasks only (Wettestad 1999, Koremenos et.al. 2001), and the need for integrated management (Bernauer 1997, Kliot et.al. 2001, Dombrowsky 2007) in order to achieve impact effectiveness can be identified. For the specific case of transboundary groundwater, the integration of groundwater issues into an existing RBO necessarily requires a multi-issue institution,

[3] A few more developments are currently ongoing, such as the development of joint principles for the Guarani Aquifer, agreed upon by Argentina, Brazil, Paraguay and Uruguay; or the recent agreement between Mali, Niger and Nigeria to develop a consultation mechanism on the Iullemeden Aquifer System.

[4] Even if overlaps are not perfect, including groundwater into existing RBO can provide several benefits, such as building on existing cooperation mechanisms and experiences or creating additional incentives for states to cooperate through issue-linkages between surface and groundwater resources.

[5] As it is, for instance, the case for the Lake Chad Aquifer, with the Central African Republic, Chad, Cameroon, Niger and Nigeria being riparians to the aquifer, Algeria, Cameroon, Central African Republic, Chad, Libya, Niger, Nigeria and Sudan being riparians to the lake, but only Cameroon, Chad, Niger, Nigeria actually being members of the LCBC.

while only for the case of alone-standing aquifers single-institutions can be considered as at least short- to medium-term solutions, especially if collective action problems in the aquifer are limited to very narrowly defined issues (such as water allocation and water quality in the Genevese Aquifer, leaving the GAMC with a very limited functional scope). However, even for independent aquifer organizations, a multi-issue scope is required if collective action problems are complex and/or IWRM principles shall be complied with (as it is, for instance, the case in JANSA, which is responsible for data collection, plan and program formulation, the implementation of joint policies as well as capacity building in member states).

Closely linked to the functional scope of an RBO is its internal structure. While most RBOs exhibit a three-fold structure consisting of a high-level ministerial decision-making body, an intermediary body operationalizing decisions into strategies, and a secretariat, some RBOs have additional bodies in place, while very few RBOs consist of a single body only (such as the PIC). With regard to effectiveness, it is argued that the degree of organizational differentiation of an RBO should match the organization's functional scope and its work program, with RBOs having a broader mandate necessarily requiring a higher degree of differentiation than single-issue RBOs. While organizations governing alone-standing aquifers can thus operate with a limited number of organizational bodies, the inclusion of groundwater in the mandate of existing RBOs requires additional organizational differentiation, e.g. through the establishment of a Groundwater Management Board or specialized Working Groups. The SASS, for instance, follows the three-fold design of most RBOs, consisting of a Council of Ministers, a Permanent Technical Committee and a Coordination Unit, complemented by National Committees and Ad-hoc Working Groups and thus being rather differentiated for its relatively limited mandate. Similar observations hold true for the GEF/World Bank Project on the Guarani Aquifer, which is managed on the basis of a Steering Committee, a Coordination Council and a Secretariat as well as National Executing Agencies (Streyer 2008: 358 ff.), thus setting the organizational structure for an aquifer organization that is still to be officially established.

Another important factor for RBO effectiveness is the degree of centralization and the organizational set-up of the organization. It can thereby be distinguished between authorities (such as the Lake Tanganyika Authority, LTA, and the Niger Basin Authority, NBA), commissions (the vast majority of RBOs) and committees (e.g. the Joint Permanent Technical Committee (JPTC) on the Limpopo or PIC), with decreasing degrees of autonomy, competences and legal authority vis-à-vis the respective member states. Although no research has so far investigated in detail the impact of the degree of institutionalization on the effectiveness of institutions, it is assumed here – by drawing from experiences from other sectors – that a relatively high degree of institutionalization (at least Commission-level) enables the organization to influence member states' decisions and thus actively shape water resources development. Organizations managing shared groundwater should therefore be sufficiently powerful vis-à-vis their members, either by increasing member states' commitments to existing RBOs that integrate groundwater in their mandate or by establishing new strong and binging institutions for shared aquifers.

In order to jointly manage shared natural resources, decisions have to be taken by the members of an RBO. Decision-making mechanisms are therefore highly relevant for effectiveness. However, while most RBOs apply some sort of consensus principle, mainly in order to minimize problem-solving complexity and increase compliance with decisions taken, cooperation theory suggests that this is not the best way to go (Wettestad 1999, Koremenos et.al. 2001, Underdal 2002): Consensus principles grant veto rights to every member, thus leading to the problem that a single reluctant laggard state might be sufficient to hinder to vast majority of states from agreeing to a regulation (Wettestad 1999: 24/25). And indeed, decision-making practice shows that many RBOs move forward slowly due to the reluctance of one of few laggard members. Integrating mechanisms for pushing forward decisions and overcoming blockage situations is therefore decisive for long-term water resources governance effectiveness. While decision-making structures of existing institutions are difficult to change, the establishment of new organizations for the management of shared aquifers provides a window of opportunity for introducing more effective mechanisms.

Information and data is required to inform decision-makers and thus ensure long-term cooperation through reducing uncertainties and prolonging the 'shadow of the future'. Hydropolitics scholars have therefore emphasized the importance of data and information exchange (GWP 2000, Grossmann 2005, Sadoff et.al. 2008). Most RBOs have indeed specific data and information management mechanisms in place – either with the RBO itself collecting, analyzing and disseminating information (as, for instance, in the Zambezi Watercourse Commission, ZAMCOM) or the RBO coordinating data and information exchange among member states based on previously defined mechanisms (e.g. in the International Commission for the Protection of the Rhine, ICPR, and the Nile Basin Initiative, NBI). Since a serious lack of information can be identified for transboundary groundwater resources, data and information management by the organization entitled to manage the particular aquifer is even more important. Moreover, institutionalized mechanisms for sharing data and information can facilitate cooperation and intensify exchange despite of the absence of formalized organizations and thus contribute to further institutionalization in the future. This is, for instance, the case with the data and information management tasks of SASS (Schmidt 2008: 225).

Nevertheless, even in a cooperative environment with institutionalized governance mechanisms in place, disputes can arise. The fact that little is known about shared groundwater while, on the other hand, pressure on the resource is increasing, makes disputes among riparians even more likely in the future. The existence of dispute-settlement mechanisms can therefore be regarded as decisive for ensuring long-term stable cooperation (Giordano/Wolf 2003, Dombrowsky 2007, Fischhendler 2008), with mechanisms having to be binding, formalized and universal. ORASECOM's dispute-resolution mechanisms, which refer disputes with regard to the basin's water resources (including groundwater) to the Southern African Development Community's (SADC) dispute-resolution mechanisms and thus a very high political level external from the RBO itself can thereby be considered as a role model – although a test case is yet to emerge that would prove the effectiveness of this well-designed mechanism in practice.

Establish and maintaining organizations governing shared groundwater – both within RBOs and as independent entities – requires the availability of financial resources. A shortage of funding can significantly reduce an organization's abilities to deal with groundwater (with a lack of funding being one of the main reasons for why implementation of groundwater policies within the LCBC is still lacking; refer to Alker 2008a: 153 ff.) or can impede the establishment of groundwater governance mechanisms at all. While this is generally acknowledged by the hydropolitics community, the mechanisms through which such organizations are funded and based on which costs are shared among members remain contested. While many RBOs rely on equal cost-sharing mechanisms, others apply specific keys for defining the contribution of each member to the organization (e.g. the LCBC calculates member contributions based on the annual national budget of each member, and the Organisation pour la Mise en Valeur du Fleuve Senegal, OMVS, defines payments on the basis of benefits each member gains from joint projects). Such cost-sharing keys are particularly helpful in regions with a great heterogeneity among riparians with regard to their financial capacity but are, however, extremely difficult to define and leave constant room for contestation. Extremely unequal cost-sharing can, however, impede the organization's effectiveness, namely since financial contributions can be regarded as a sign of serious political commitment and often come with agenda-setting and decision-making power. In this context, the funding mechanisms of JANSA can be perceived as problematic, with Libya funding the organization's entire budget (Alker 2008b: 260).

In the developing world, where riparian states often lack the financial capacities to fund an RBO, donor agencies have an important role to play. While this has been emphasized by various scholars for the case of RBOs (e.g. Kirmani/LeMoigne 1997, Gerlak 2004, Mostert 2005), donor engagement in transboundary groundwater governance remains limited: In the Lake Chad Basin, for example, only the GEF Project "Reversal of Land and Water Degradation Trends" includes groundwater aspects, while other donors continue to focus on surface waters only. Donor engagement has been important in the Guarani Aquifer as well, where riparian states have adopted a first draft declaration of joint principles for the management of the shared aquifer, largely due to the GEF's engagement in the Project on the Environmental Protection and Sustainable Development of the Guarani Aquifer System. And even in pure aquifer regions, support from donors rarely goes beyond the financing of studies, while efforts to establish well-functioning organizations remain extremely limited (one of the few exceptions is the World Bank/GEF's contribution to the establishment of a joint management mechanism for the Guarani Aquifer, with an overall budget of US-$ 28 million from 2003 to 2009 and a significant though still insufficient impact on the institutionalization of cooperation; Steyrer 2008: 356).

3. CONCLUSION

The previous analysis has demonstrated that the joint governance of shared aquifers is of great importance, but, however, the pure existence of institutionalized cooperation mechanisms is not sufficient for effective groundwater governance. Instead, the institutional design of the respective organizations is decisive. Based on lessons learned from RBOs and the application of findings to transboundary aquifer governance, it can be concluded that organizations governing shared aquifers tend to be more effective

- If all relevant riparians to the aquifer are members of the organization
- If all relevant issues are included in the functional scope of the organization
- If the organizational set-up reflects the organization's mandate and scope
- If the degree of institutionalization is sufficiently high
- If decisions are taken in a timely way without favoring laggards
- If data and information are shared timely and efficiently
- If binding, formalized and universal dispute-settlement mechanisms exist
- If sustainable funding is secured, acknowledging member's capacities and integrating donors.

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The Management of the GAS:
What Role for the Emerging International Law of Transboundary Aquifers?

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ABSTRACT

The goal of this paper is to critically assess the role that the UN-ILC draft articles on the law of transboundary aquifers may have on the regulation of specific transboundary aquifers. The GAS, shared by Argentina, Brazil, Uruguay and Brazil, will be used as a case study for this purpose.

A tentative management structure of the GAShas been laid out by the Organisation of American States / World Bank / Global Environmental Facility in their 2000-2009 *Environmental Protection and Sustainable Development of the GASProject*. Argentina, Brazil, Uruguay and Paraguay are now called to take this management structure forward. The challenge will be to develop adequate regulatory frameworks capable of securing the sustainable management of the GAS. Countries will have to decide whether the latter should be linked to any already existing regional legal frameworks, such as the *Treaty of the River Plate Basin* or any *MERCOSUR* agreements, or whether they will consider ad-hoc regional or bilateral arrangements to secure the sustainable management of the GAS.

It is against this background that this presentation will discuss the role that the UN-ILC draft articles on the law of transboundary aquifers can play in the future management of the GAS. This paper builds upon research of the Environmental Regulatory Research Group in its project "The Environmental Protection of the Guarani Aquifer: A Legal Perspective". One of the milestones of this project is an international seminar that will be held at the University of Surrey in August 2010 whose results will also be presented throughout this presentation. Finally, our study on the GASwishes to be a first case study for the forthcoming Surrey Centre for the Regulation of Transboundary Aquifers, whose future work and activities will be briefly presented at the end of this presentation.

Key words: GAS, international law, transboundary aquifers

1. INTRODUCTION

On 2 August 2010 the four countries that share the Guarani Aquifer System (GAS) – Argentina, Brazil, Paraguay and Uruguay – have signed the Guarani Aquifer Agreement (GAA) in San Juan, Argentina. While the agreement may not be perfect, it does entail a significant achievement for the four countries and it is likely to have important repercussions for the ongoing development of international law in the field of groundwater. This paper wishes to study the linkages between the regional legislative framework that has been recently set up for the GAS and the Draft Articles on the law of transboundary aquifers (Draft Articles) adopted in 2008 by the United Nations International Law Commission (UNILC). To what extent have the latter influenced the former? And will the GAA play any role in the future development of the draft articles? Both questions will accompany us throughout this paper.

2. THE GUARANI AQUIFER SYSTEM

Despite the fact that studies on the GAS had begun prior to the Guarani Project (Auge, 2009), it has been the latter that has allowed the four countries to gain greater insight on the characteristics thereof (OAS, 2009). Some of the conclusions that have been reached from a hydro-geological perspective are the following (OAS, 2009):

- The GAS is a vast rock strata (geological formations) with aquifer characteristics, forming a vast groundwater reservoir (hydro-geological basin) that stretches over 1.087.879 Km^2, 71% of which lies beneath Brazil, 20.98% under Argentina, 8.05% beneath Paraguay and 3.32% can be found under the territory of Paraguay.
- The water is renewable, but circulation is slow. Recharge zones lie principally in the outcrop regions, some of which can be found along the borders of some of the countries sharing the GAS.
- Generally, the water quality is very good and it is therefore a perfect source for the drinking needs of the population overlying the GAS, there where water can be reached. Problems of contamination and over exploitation do not seem to be present in important numbers for the time being, but change in land uses could threaten the overall quality of the GAS water.

While some studies stress the exceptional volumes of water present in the GAS suggesting that it could provide enough drinking water for a population of 5.5 billion people for the next 200 years (UNESCO-IAH, 2003), the truth is that it is very difficult to say precisely how much water is contained within the GAS. What the Project for Environmental Protection and Sustainable Development of the GAS (Guarani Project) has highlighted is that water security in the region is guaranteed by the GAS indicating that its sustainable management is paramount in the long term.

If one of the goals of the Guarani Project was to increase the knowledge on the GAS, one other goal was to suggest possible future institutional arrangements that would lead to a sustainable management of the transboundary aquifer. An immediate and future implementation stage can be found in the final Strategic Action Program, both of which rely to a lesser or a greater extent on the institutional arrangements that had been put in place throughout the project (OAS, 2009).

Of the five scenarios that were devised for the implementation of the Strategic Programme, two deserve special attention (OAS, 2009):

- Scenario 4: "Countries follow up on national Pilot Projects and implement actions identified in the SAP with a regional support structure for the GAS and other aquifers technical support, capacity building institutional strengthening and international cooperation within the La Plata River Basin Treaty / MERCOSUR.
- Scenario 5: "Same as 4, but with creation or expansion of the regional organization (CIC-Plata / MERCOSUR) with the role of collective decision making, defining policies and guidelines and approving projects and programs with regional impacts.

These two scenarios were definitely taken into account very closely by the four countries when negotiating a legislative framework for the future management of the GAS, which leads me to look at the recently signed GAA.

3. THE GUARANI AQUIFER AGREEMENT

In 2004, running parallel to the initial stage of the Guarani Project, the four countries launched negotiations aimed at an agreement that would lead to the sustainable management of the GAS. A draft agreement was negotiated, including a rather detailed annex on an arbitral procedure that would settle possible disputes. The provision in the draft agreement regarding dispute settlement proved to be the stumbling block that countries were not able to overcome. A year after the Guarani Project ended, the four countries reinitiated negotiations in June 2010 and after only one meeting held in Buenos Aires on June 23 they reached an agreement, which was formally signed by the four countries in San Juan, Argentina, on 2 August 2010 in occasion of a meeting of Heads of State of the MERCOSUR.

The text of the 2010 agreement replicates the negotiating text that was abandoned in 2005 without the annex on the arbitral procedure needed if a dispute is not solved by negotiations or through the intervention of the Commission that is foreseen in the agreement. One can only speculate as to why the countries kept the negotiating text silent until 2010 to then recuperate it almost in its entirety, but three factors could have played a role:

- States may have considered that they needed to wait for the final outcome of the Guarani Project.
- While in 2005 tension between Argentina and Uruguay was leading to the Pulp Mills dispute, in April 2010 the latter was solved by a decision of the International Court of Justice (ICJ, 2010) followed by a political agreement between the Presidents of the two countries.
- In 2005 the work of the UNILC on the law of transboundary aquifers was ongoing, while in 2010 the international community can rely on a set of draft articles annexed to a UN General Assembly resolution that can give them some guidance as to how to deal with a specific transboundary aquifer (UNGA, 2009).

Before analysing in more depth the possible influence of the work of the UNILC on the GAA, we wish to briefly highlight some of the main features of this agreement.

3.1. National sovereignty

The first characteristic that underpins the entire text is its reliance on national sovereignty. Article 2 maintains that:

> "Each Party exercises sovereign territorial control over their respective portions of the GAS, in accordance with their constitutional and legal arrangements, and in agreement with the norms of applicable international law."

Despite the fact that some commentators have argued that an international legal instrument on watercourses (be they surface or groundwater) based on national sovereignty implies a regression (Mc Caffrey, 2009), and that others have seen this negative trend in the GAA (Eckstein, 2010), one should not be too surprised from the result. The four countries sharing the GAS had made it very clear from the outset that there was no room for negotiation as to what key principle would underline the spirit of the agreement: that being national sovereignty. The Strategic Action Programme resulting from the Guarani Project highlights this common position in saying:

> "It was acknowledged that the GAS, and groundwater in general, belongs to and is under the sovereignty of the countries that overlie it, and which are responsible for its management within their territories." (OAS, 2009)

State practice in the years leading to the GAA demonstrate that the countries were not ready to relinquish their sovereignty over the portions of the GAS beneath their territory (Uruguay, 2004). One of the reasons why countries in the region are so akin to hold on to their national sovereignty in the field of water resources is that civil society has been warning over the possibility of countries from outside the region coming and depriving the countries from "their" water (Hearn, 2006). Whether these are just hydro myths or not is another account, but they do seem to have their effect on politicians.

3.2. Cooperation

The preamble of the GAA tries to balance the reliance on national sovereignty with the need to cooperate amongst the four countries in order to achieve the final goal of the agreement, which is the "conservation and sustainable utilization of the GAS transboundary water resources". However, once again this goal is qualified by saying "which is located in their territories." Cooperation in the GAA refers both to substance and to institutional arrangements.

On the one hand, cooperation comes, for example, in the form of notifying other parties about the intention to undertake activities within the GAS that could lead to negative effects to other countries (Art. 5). Countries undertaking those activities will "adopt all the necessary measures to avoid causing significant harm to the other Parties or the environment" (Art. 6). Another form in which cooperation is embedded in the GAA is through the acknowledgement that more research is needed and that countries need to work together to achieve such information and share it amongst them (Art. 8, 9 and 12).

On the other hand, just as suggested in the scenarios for the future implementation of the Strategic Action Programme of the Guarani Project, cooperation amongst the four countries will be institutionalised in the framework of the Treaty of the River Plate Basin. Article 15 of the GAA establishes that "a Commission comprised by the four Parties… shall coordinate the cooperation among such Parties for complying with the principles and objectives of this Agreement." The countries now need to work together to create such a Commission providing it with its own regulations and, possibly more importantly, staffing it and providing it with a budget.

3.3. Boundary measures that require specific measures

In my opinion one of the most important characteristics of the GAA is the acknowledgment that some areas of the GAS will require additional measures. This stems from the scientific conclusions in the Guarani Project that

> "current and potential transboundary effects of the GAS are restricted to a narrow strip of territory of no more than a few dozen kilometres depending upon local specific hydrodynamic conditions." (OAS, 2009)

In the Guarani Project two transboundary pilot projects were identified: Santana do Livramento/Rivera (Brazil/Uruguay) and Concordia/Salto (Argentina / Uruguay). These areas already have a number of ad-hoc measures put in place and institutions created that could fall under the category of "specific treatment measures" provided for in Article 15 of the GAA.

One important challenge for the four countries is to identify further hot spots on the border where the GAS may need specific treatment and assess the extent to which measures put in place in the pilot projects can be replicated elsewhere.

The acknowledgment that some areas of the GAS may need specific measures provides the GAA with a degree of flexibility, which is needed to sustainably manage such a vast groundwater reservoir with different hydro-geological characteristics. In particular, countries are likely to consider specific measures to sustainably manage recharge zones in outcrop areas of the GAS, when they may lead to trans-boundary pollution or over exploitation.

3.4. Dispute settlement

As previously mentioned, in 2005 the four countries stumbled upon an insurmountable obstacle in their negotiations towards an agreement over the GAS. That obstacle was the nature of dispute settlement. Two options were on the table: any country could have triggered the arbitral procedure annexed to the agreement or the latter could have been initiated only if the two countries at conflict agreed to.

In the GAA disputes will first be solved through negotiations (art. 16). Only if these fail, the Commission, that needs to be set up in the framework of the Treaty of the River Plate Basin, will address the situation (Art. 17). Finally, if the Commission is unable to formulate a recommendation, the dispute will be solved through an arbitration procedure, which now needs to be negotiated amongst the four countries (Art. 19). Formal negotiations need to start soon in order to complete the GAA with a much needed arbitration procedure. It is yet to be seen whether the countries will use, as they did for the rest of the GAA, the arbitration procedure present in the draft negotiating text that was abandoned in 2005.

In conclusion, through the GAA the countries sharing the GAS have kick-started a long and ongoing process. While they must be praised for restarting negotiations in 2010 and immediately reaching a consensus on the text of the GAA, countries now need to ratify the agreement, they need to operationalise the institutional arrangements provided for therein. In particular, they need to establish the Commission mentioned in Article 15 under the framework of the Treaty of the River Plate Basin. Finally, they need to launch negotiations aimed at securing an arbitration procedure that will added as a protocol to the Agreement.

While this means that the process to provide the GAS with a regional legislative framework is far from over - one could actually say that it has just started -, it still may be able to stem effects outside of the borders of the four countries.

3. THE GUARANI AQUIFER AGREEMENT AND THE UNILC DRAFT ARTICLES ON THE LAW OF TRANSBOUNDARY AQUIFERS

UN General Assembly Resolution 63/124, which endorses the UNILC Draft Articles:

> "[E]ncourages the States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers, taking into account the provisions of these draft articles."

The GAA does exactly this, and in its preamble it takes into account Resolution 63/124 of the UN General Assembly on the law of transboundary aquifers. A fertile cross fertilisation is starting to take place which goes both from the international community down to the GAS region and back up.

On the one hand, there is scope to consider that the political will to conclude the GAA has been heightened by, amongst other factors, the adoption of the above mentioned resolution that incorporates the work of the UN ILC. The four countries were well aware of the work that had been done by the UN body and they had participated actively therein. Actually, the UNILC looked closely at the ongoing efforts in the region on the GAS and acknowledged the work of the Guarani Project that took place in the period of the drafting of the articles. Taking into account the dearth of state practice on transboundary aquifers at disposal of the UNILC, one dares to consider whether the latter actually looked at what was happening in region as "state practice"…

On the other hand, the GAA joins the Genevese Aquifer Franco Swiss Agreement as the only binding international treaties on the management of specific transboundary aquifers. However, due to the size of the Genevese Aquifer and to engineering, legal and political characteristics thereof, the GAA may end up being substantially more relevant. Against this background, UN General Assembly Resolution 63/124

"[D]ecides to include in the provisional agenda of its sixty-sixth session an item entitled "The law of transboundary aquifers" with a view to examining, inter alia, the question of the form that might be given to the draft articles".

Will the international community look up at the GAA as a model for a future framework global convention on the law of transboundary aquifers? How will the UN ILC Draft Articles be read, now that a further specific agreement on a transboundary aquifer has been signed?

If the adoption of the draft articles and its dissemination has, at least partly, encouraged States in the GAS region to restart negotiations that had been interrupted in 2005, and if they have helped the States to reach an agreement, maybe a global binding convention is not even necessary. A detailed one size fits all convention is not possible. If the UN General Assembly decides to launch negotiations amongst the international community, this will be a framework convention, possibly a watered down version of the UNILC Draft Articles. Following the line of some commentators (McCaffrey, 2009), I share some of their concern on a global framework that enshrines once and for all the management of transboundary aquifers based primarily on national sovereignty. On the other hand, if the UNILC Draft Articles may have had some role to play to boost political will, a UN endorsed global convention on transboundary aquifers could have a very important political role around the world in order to speed up government's understanding of the importance to take preventive measures in the field of joint transboundary management. If the global convention is general enough, and it will be, and the reliance on national sovereignty is present, but not oppressive, then a UN global convention on the law of transboundary aquifers could be a very positive development, to which the GAA may have contributed in some part.

4. CONCLUSIONS

The GAA is a milestone agreement in the development of international groundwater law. It constitutes an example of cooperation amongst four countries regarding the management of one of the largest transboundary aquifers in the world. In this paper I conclude that we are witnessing a cross fertilization between the UNILC Draft Articles and the GAA.

On the one hand, "one" of the reasons why the four Latin American countries were able to finally sign the GAA was the adoption of the UNILC Draft Articles, which is enshrined in the preamble of the Agreement. On the other hand, the GAA is likely to have an impact on the future of the UNILC Draft Articles, which will be discussed before the UN in late 2011. Despite the ongoing debate on the principle of state sovereignty as the cornerstone of the GAA, the latter constitutes important state practice and it provides interesting insights as to best practices regarding the regulation of specific areas of a transboundary aquifer system, which are more inclined to pollution and overexploitation. These elements will surely be taken into account by States before the UN when discussing the future of the UNILC Draft Articles.

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The Unece Protocol on Water and Health and the Right to Water

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ABSTRACT

The UNECE Protocol on Water and Health, adopted in London in 1999 is presented against the background of the solemn declaration adopted on 28 July 2010 by the UNGA on access to clean water and sanitation as a basic human right.
Accordingly, the Protocol is analysed especially in relation to Articles 11 and 12 of the 1966 UN Covenant on Economic, Social and Cultural Rights with special reference to the interpretation of those provisions given by the 2002 General Comment 15 of the Committee of the Covenant. Even if the Protocol stems from the water law process - which has been for long a far cry from the human rights diplomacy that produced the Covenant - a comparative analysis of the two instruments will show the complementarity and, in many respects, even the coincidence between them.
The paper illustrates how the Protocol requires State conduct meeting the minimum requirements of the core obligations stemming from Articles 11 and 12 of the Covenant, even if the term "human right" is to be found nowhere in the Protocol. This applies with special regard to the obligations a) "to ensure access to the minimum essential amount of water that is sufficient and safe for personal and domestic uses to prevent diseases"; b) "to take measures to prevent, treat and control diseases linked to water, in particular ensuring access to adequate sanitation"; c) on non-discrimination for disadvantaged groups.
The case is made that the Protocol, through its "duty oriented" approach to State conduct, is instrumental in the determination of the actual normative contents of the right of individuals to water and sanitation. In that respect, it shows how the *leit motiv* that underlies both instruments under consideration is to be found in the *due diligence* nature of their most characteristic provisions. This is considered to account for the progressive and goal oriented feature of their obligations enhancing the State legal accountability for water services, even under free-market regimes.
It will be noted how the Protocol introduces a new scope for inter-State cooperation with respect to traditional international water law and how this, together with the establishment of the Compliance Committee, will enhance – though at the regional level – the implementation of the basic human right to water.

Key words: water, sanitation, vital human needs, due diligence, privatization.

1. INTRODUCTION: REDUCING THE GAP BETWEEN INTERNATIONAL WATER LAW AND HUMAN RIGHTS LAW

International water law has developed for centuries as a set of general rules exclusively addressing the transboundary relations between co-riparian States focusing on the economic aspects of their competing claims over their shared waters. Only after the recent entry of the environmental dimension into the water law process basic human needs have received some recognition within that body of law.

The alarming degradation caused by mismanagement and overexploitation to many water related ecosystems of the world finally induced a growing number of water specialists to advocate the adoption of less economic-oriented criteria for the management of freshwater resources, focusing more on an "ecosystem approach" (Teclaff and Teclaff, 1987), and to increasingly take into account basic social factors.

The key catalyst of the gradual shift from an exclusively economy-focused branch of international law to one also, if not primarily, addressing environmental and vital social concerns has undoubtedly been the concept of sustainable development as applied to the use of international watercourses (Brunnée and Toope, 1994). This has resulted in the "settlement" of the long-standing conflict between the "equitable and reasonable utilization" and the "no-harm" doctrines with respect to which the concept of sustainability appears to be the lowest common denominator of both principles. This is corroborated by the way the general principles in point have been codified by both the UNECE 1992 Helsinki Water Convention and the UN 1997 New York Convention on international watercourses. Indeed, together with the principle of sustainable development, the priority of "vital human needs" over any other factors for the assessment of an equitable utilization has recently made its entry into international water law (Art. 10, para. 2), whereby a use of an international watercourse which causes significant harm to human health and safety would inherently amount to an inequitable and unreasonable use, hence, in breach, at one and the same time, of both the equitable utilization principle and the no-harm rule.

However, such developments in the context of international water law apply only to inter-State relations concerning transboundary watercourses and transboundary impact, irrespective of human rights concerns. In their turn, the developments pertaining to the right to water within the human rights body of law - which has culminated in the solemn declaration on 29 July 2010 by the UNGA on access to clean water and sanitation as a basic human right (Doc. A/64/L.63/Rev.1) – have been carried out totally irrespective of the developments in the international water law process. Nonetheless, international water law, by expanding its attention to environmental concerns so as to encompass those on human health, has recently produced an important instrument which may prove a concrete tool for the implementation of the human right to safe drinking water and sanitation: i.e., the UNECE 1999 London Protocol on Water and Health, entered into force in 2005 (http://www.UN/ECE.org/env/documents/2000/wat/mp.wat.2000.1.e.pdf).

2. COMPARING THE UNECE PROTOCOL TO THE EXISTING ENUNCIATIONS OF THE RIGHT TO WATER

One of the major positive law pillars of the human right to safe water and sanitation is to be found in Arts. 11 and 12 of the 1966 Covenant on Economic Social and Cultural Rights (ESCR). Accordingly, a comparative analysis of the Protocol with relevant human rights authoritative enunciations should prominently refer to the General Comment 15, adopted in 2002 by the Committee on economic, social and cultural rights (Doc. A/64/L.63/Rev.1).

As to the minimum requirements emphasized in the latter "to ensure access to the minimum essential amount of water that is *sufficient and safe* for personal and domestic uses to prevent diseases", and "to take measures to prevent, treat and control diseases linked to water, in particular ensuring access to adequate sanitation", Article 4, para. 2, of the Protocol provides the obligation to ensure "(a) [a]dequate supplies of wholesome drinking water which is free from any micro-organisms, parasites and substances which […] constitute a potential danger to human health […]; (b) [a]dequate sanitation of a standard which sufficiently protects human health and the environment". Most importantly, this provision requires, as a means for the implementation of the above, "the establishment, improvement and maintenance of collective systems".

The General Comment 15 places special attention to the obligation that access to water should be ensured "on a non-discriminatory basis, especially for disadvantaged and marginalized groups", as well as on the obligation (lett. (h) "to adopt relatively low-cost targeted water programmes to protect vulnerable and marginal groups". On this score, Article 6, para. 1, of the Protocol provides for the obligation for Parties to pursue: "(a) Access to drinking water for everyone" and "(b) Provision of sanitation for everyone", while Article 5 provides that "[s]pecial consideration should be given to the protection of people who are particularly vulnerable to water-related diseases", and that "[e]quitable access to water […] should be provided for all members of the population, especially those who suffer a disadvantage or social exclusion".

As to the means for achieving the above goals the General Comment requires States "to adopt and implement a national water strategy and plan of action addressing the whole population", requiring that such a plan of action include "right to water indicators and benchmarks" with periodical review and monitoring "on the basis of a participatory and transparent process". Such requirements are virtually paraphrased in Article 6 of the Protocol.

The detailed regulatory framework of the Protocol for setting targets for the fulfillment of the obligation to ensure access to safe water and sanitation is based on the key concept of "collective system", basically defined as a system for the supply of drinking water and the provision of sanitation, as well as treatment and disposal or reuse of industrial waste water. As to monitoring, which has been strongly required under the General Comment 15, the Protocol requires extensive obligations for Parties to establish and maintain arrangements at the national to that effect, provides a detailed regime on review and assessment to be carried out by State Parties individually, as well as collectively within the framework of the MOP (Art. 7). One can also recall the establishment of a compliance review committee, composed of independent members, which may be seized by submissions from Parties, referrals by the Secretariat, or communications from the public (Pitea, 2009). It should be emphasized that the admissibility requirements of communications from the public are far more flexible than in human rights judicial proceedings, insofar as a communication is admissible irrespective of whether the communicant has been a direct victim of the facts complained of in the communication. The Committee has the power to make recommendations and take measures, including addressing the Party concerned requesting it to prepare an action plan to achieve compliance, inviting it to submit progress reports on its efforts towards compliance, issuing cautions and making recommendations.

2.1. The due diligence nature of the State obligations corresponding to the "programmatic" right to water

Within the international body of human rights law, the so called "progressive", or "programmatic", nature of the right in point emerges from the well known general *chapeau* contained in Article 2, para. 1, of the Covenant, whereby each State party is "to take steps to the maximum of its available resource with a view to achieving progressively the full realization of the rights recognized in the […] Covenant by all appropriate means […]".

Much the same language is to be found in the UNECE Protocol. Article 4, setting out the general standards, provides that "1. The Parties shall take all appropriate measures to prevent, control and reduce water-related disease […and that] 2. The Parties shall, in particular, take all appropriate measures for the purpose of ensuring: (a) Adequate supplies of wholesome drinking water […]; (b) Adequate sanitation of a standard which sufficiently protects human health and the environment; […]". Similarly, Article 6 provides that "[i]n order to achieve the objective of this Protocol, the Parties *shall pursue the aims* of: (a) Access to drinking water for everyone; (b) Provision of sanitation for everyone […]"(emphasis added).

Against the above of language, one may feel tempted to make the case that, "States are under no obligation to give an immediate effect to [the] right [in question]" (Fitzmaurice, 2007). In legal jargon this would mean that the right of access to water under international law would not be of a self-executing nature. Namely, were a State party not to afford appropriately everyone on its territory the right of access to water, it would not be, as such, necessarily in breach of an international obligation. One might derive from this statement that an individual victim of such a conduct would not be entitled to bring a case before a domestic or international competent court. This argument should be qualified to the effect that it would hold true only to the extent that lack of access to an adequate amount of safe water would occur despite all appropriate action and efforts having been undertaken by the State in point in order to supply adequate quantity and quality of water .

That is to say that, in the present state of international law, the obligation for States correspondent to the human right to water is one of due diligence. This view is corroborated by the wording of the provisions in question, interpretative practice and legal literature (McCaffrey, 1992). When referring to due diligence obligations, as opposed to absolute obligations, one should not lose sight of the fact that they involve an articulated duty of care subject to being complied with, or breached. Hence, such obligations can be said to be immediately enforceable.

Besides, the margins of flexibility within the content of the due diligence obligations under discussion are becoming stricter and stricter through the merger of the developments within both international water law and human rights law. Already in its General Comment 3 of 1990, the Committee of the ESCR Covenant, while confirming the progressive nature of its provisions, contended that the Covenant "imposes various obligations that are of immediate effect" (Doc. E/1991/23, para 1). Among those, it singled out the undertaking in Article 2, para.1, 'to take steps' in order to stress that "while the full realization of the relevant rights may be achieved progressively, steps toward that goal must be taken within a reasonably short time after the Covenant's entry into force […]" (para. 2). Most importantly, the Committee underlined that "[…] the fact that realization over time, or in other words progressively, is foreseen under the Covenant should not be misinterpreted as depriving the obligation of meaningful content" (para. 9). Furthermore, the above comparative examination of the core requirements for the achievement of the right to water under both the Covenant and the Protocol account for the increasing specification of ever stricter due diligence standards in the field under consideration.

That of due diligence is not an oddly peculiar characteristic which applies to few human rights rules, but to an increasing *genre* of international obligations cutting across a wide range of sectors of international law, with special regard to environmental law (Barnidge, 2006).

It may be practically and legally highly difficult, when not impossible, for the victim of a breach of a due diligence obligation of prevention – be it a State, or an individual – to prove that all the appropriate measures required by such an obligation have not been taken. Consequently, there is a growing trend to recognize in this area of law an inversion of the burden of proof on to the State whose conduct is under consideration, which has to demonstrate that all such measures have been adopted within its jurisdiction (Condorelli, 1984; Pisillo Mazzeschi, 1991).

3. DEFINING THE CONTENTS OF THE RIGHT TO WATER

The ESCR Covenant is clearly a duty oriented instrument from which individual rights could inferred only by implication. Likewise, in the Protocol, even though the term "right" hardly appears in its provisions, the articulated elaboration of the legal duties for the States Parties appears provide important elements to the concrete assessment of the normative content of the right to water. Such a deductive approach to the identification of the content of the right to water is corroborated by the General Comment No. 15 with respect to the Covenant. It appropriately emphasized that "[w]hen the normative content of the right to water […] is applied to the obligation of States parties, a process is set in motion, which facilitates identification of violations of the right to water" (Para. 39).

On the basis of the above, the case can be made that the Protocol may enhance the justiciability of the right to water before domestic courts - at least before those of the States Parties - as well as before international competent human rights courts. In its turn, future national and international case-law elaborating on the point at issue will further promote the consolidation of the normative contents of the international right to water.

As already emphasized, the compliance review mechanism under the Protocol allows for individuals to communicate cases of non-compliance by Parties, without, though, the procedure ever resulting in a direct remedy, even less so compensation, for the communicant. However, such a procedure, in line with the wording of the General Comment "[would] facilitate […] identification of violations of the right to water". Accordingly, the future practice, or quasi-case-law, of the Committee will enhance the determination and development of the normative content of the right to water, while contributing to redress situations of non-compliance with such a right.

4. THE REGULATORY IMPLICATIONS OF THE "PUBLIC GOOD" NATURE OF WATER

The General Comment 15 enunciates that "[w]ater is a limited natural resource and a public good fundamental for life and health […]". This passage reintroduces the long debated issue of the compatibility between the "public good" connotation and the economic relevance of water, hence, that of the admissibility the privatization of water services (Williams, 2007).

From a purely international law standpoint, it appears that the answer to the issue - emerging from both international human rights law and international water law - is a neutral one. This derives from the very essence of the international law nature of the rules in point, namely, that of providing for obligations addressed to sovereign States. Indeed, States, as legal units, are ultimately responsible for meeting the due diligence standards required of by the relevant international obligations through the conduct of their organs, irrespective of whether water services are operated by state or private entities under their jurisdiction. In the former case, the State will be legally accountable directly for the conduct of the State entities being part and parcel of the national legal structure under international law (Draft Articles on Responsibility, 2001). In the latter case, the State will be legally accountable for the conduct of its organs in charge of ensuring that activities under its jurisdiction will not be in breach of international law. Under both circumstances, the State will be accountable as to whether its different organs live up to the international due diligence obligations of the State.

This contention is corroborated by the above described due diligence nature of the relevant instruments of both human rights law and international water law, with special regard to the Protocol on Water and Health. As to human rights law, the General Comment 15 explicitly addresses the circumstance in which water services may be operated by private entities emphasizing that States have the duty to "prevent them [the separate entities in charge of water supply and sanitation, whether public or private] from compromising equal, affordable, and physical access to sufficient, safe and acceptable water" (Para. 24). It also provides that "[t]o prevent such abuses an effective regulatory system must be established, in conformity with the Covenant and this General Comment, which includes independent monitoring, genuine public participation and imposition of penalties for non-compliance".

The basic rationale of the Protocol most relevant to the point in hand is to be found in the general enunciation, according to which, under Article 5 on "Principles and Approaches", "[w]ater has social, economic and environmental values and should therefore be managed so as to realize the most acceptable and sustainable combination of those values". While the social values rank first in that wording, before economic and environmental ones, the Protocol remains neutral as to whether such economic instruments should be public or private. The neutrality of the Protocol on the point at issue is stated further when, among the objects of public awareness to be promoted, it lists "[t]he rights and entitlements to water and corresponding obligations under private and public law of natural and legal persons and institutions, *whether in the public sector or the private sector* […]" (Article 9, para. 1, lett. b, emphasis added).

Furthermore, the relevance to the point at issue of the Protocol's conceptual legal framework in terms of due diligence is prominent through the general obligation for States parties to take "all appropriate measures" in order to achieve its goals. It enhances the States legal responsibility - their social and political accountability - whereby, with their public legal personality, States are ultimately responsible for all the activities carried out under their jurisdiction including by private operators.

Further to the above, the Protocol elaborates *ex abundante cautela* with unusual precision on the issue of attribution. To that end, it defines as "Public authority", not only " (a) Government at national, regional and other levels [and] (b) natural or legal persons performing public administrative functions under national law, including specific duties, activities or services in relation to the environment, public health, sanitation, water management or water supply"; but also "(c) any other natural or legal persons having public responsibilities or functions, or providing public services, under the control of a body or person falling within subparagraphs (a) or (b)" (Art. 2, para. 12).

It is evident how letters b) and c) refer to private operators running water services. By defining them as "Public authority" for the purposes of the Protocol, the latter reinforces, or, rather, doubles the means for attributing to the State the international responsibility for conduct at variance with the obligations set out therein on the point at issue. Namely, under the general principles of attribution of an internationally wrongful act, the State might be responsible for the breach of the due diligence obligation to control and prevent that private operators in the field of water services do not comply with the Protocol's requirements, on the one hand. On the other hand, under the just quoted provision, the Protocol sets out a specific regime whereby whenever a private operator performs a "public administrative function", as it would be the case with "sanitation, water management or water supply", its actions, or omissions, would be directly attributed to the State.

5. THE ADDED VALUE OF INTERNATIONAL CO-OPERATION

Inter-State cooperation is certainly an added value which international water law brings into the legal process for the enhancement of right to access to water and sanitation in a way unknown to traditional international human rights law. While the general principle of cooperation is obviously key to the international law of transboundary watercourses, it appears most significantly expanded under the Protocol in point, also with respect to the primarily domestic dimension of its key provisions, which is the prominent dimension human rights law.

Under Article 11, in the most innovative way the Protocol requires Parties to take coordinated action not only in terms of international cooperation in support of its objectives but also, upon request, in terms of implementing national and local plans. Article 12 requires Parties to cooperate and assist each other in relation to the development of targets and indicators, the establishment of coordinated surveillance and early-warning systems and the exchange of information. Moreover, Parties are to assist each other in responding to outbreaks and incidents of water-related diseases, by using, *inter alia*, prompt and clear notification mechanisms. Special obligations are also provided for Parties bordering the same transboundary waters (Article 14). Namely, they must exchange information, share knowledge and consult each other, endeavor to establish joint or coordinated water-management plans, surveillance and early-warning systems, formulate contingency plans for the purpose of responding to outbreaks and incidents of water-related disease. Further to the above forms of "horizontal cooperation", the 1st Meeting of the Parties of 2008, provided a kind of "vertical cooperation" establishing an Ad Hoc Project Facilitation Mechanism (AHPFM) to assist Parties in the implementation of the Protocol.

6. CONCLUSIONS

International water law, traditionally aimed at reconciling conflicting claims on transboundary watercourses, has evolved readjusting the relationship between the reasonable and equitable utilization principle and the no-harm rule by expressing both of them through the principle of due diligence. Such principles have become subservient to the sustainability of admissible uses of water and to the principle that uses aimed at the satisfaction of vital human needs prevail over any other use. Accordingly, a use of an international watercourse which causes significant harm to human health and safety would be at one at the same time inequitable and in breach of the no-harm rule.

The human rights dimension of access to water and sanitation, concerned primarily with the position of individuals *vis-à-vis* the domestic authorities of their Country of residence - may appear in principle to find little support from the inter-State dimension of traditional international water law. However, the UNECE Protocol on Water and Health has shown a significant leap forward of the international water law process in that direction.

Most importantly, it appears from the above analysis that the UNECE Protocol specifies and articulates the minimum core obligations that the General Comment 15 has inferred from Articles 11 and 12 of the Covenant in relation to the fundamental right to water. This corroborates the view that the increasingly stringent standards of due diligence under both international water law and the human right to water prove to be nourishing each other. Likewise, fruitful cross-fertilization may take place in the future through the development of both domestic and supranational case-law, on the one hand, and the practice of implementation of the Protocol, while the future "case-law" and facilitative functions of the Compliance Committee of the Protocol may further enhance and provide guidance to such synergic process.

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Transboundary Water Resources in Latin America: An opportunity for friendship and cooperation towards sustainability.

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ABSTRACT

South America is a very large continent with a great amount of water resources. These resources have an irregular distribution and the continent also shows arid regions in need of water for development. This territory has very important superficial basins, most of them shared by several countries. There is experience on treaties and other legal tools developed by the riparian countries. Nevertheless, some disagreements or conflictive situations rise from time to time, and the countries must perform new strategies to prevent this and develop better solutions. South America has large transboundary aquifers as well. Regarding this topic, in 2002, the inventory of these aquifers by means of the UNESCO/OAS Programme ISARM Americas has begun. Historically, it has been more usual that the more intense interests and efforts were dedicated to studying and understanding superficial basins, and therefore, fewer efforts were dedicated to groundwater. Unfortunately, many of both kinds of resources have been affected by pollution or excessive exploitation. Therefore it´s deterioration in both, quality and quantity, represents a major risk for future development. In the particular case of Argentina, in the early 80's, some researches defined the possibility of occurrence of the Guarani Aquifer System, shared by Brazil, Uruguay, Paraguay and Argentina. Between 2002 and 2009, as a result of the UNESCO/OEA Programme ISARM Americas, six other transboundary aquifers were preliminary defined and the research efforts continue. Most of them were defined by the experts of the countries involved, some others have to be studied in order to better definition of its geometry and boundaries. Recently, in August 2010, Argentina, Brazil, Paraguay and Uruguay have signed an agreement related to the sustainable management of the Guarani Aquifer System, which constitutes a very important progress for protecting this transboundary aquifer for water supply, for human uses and for the sustainability of the groundwater dependant ecosystems.

Keywords: transboundary aquifers, management, protection, cooperation.

1. INTRODUCTION-OBJECTIVES.

1.1. Methodological Framework

The identification of transboundary aquifer systems requires a multidisciplinary approach and the generation, processing and analysis of thematic data and information, such as geology, hydrogeology, geological structure, hydrogeochemisty, hydrodynamics, hydraulic parameters, climatic information, biodiversity, legal and socio-economical aspects, and so on. All of these factors should be interpreted and accepted by the sharing countries to agree on the geometry, boundaries and characteristics of the shared aquifer. (Puri *et al.*, 2001) (Figure 1).

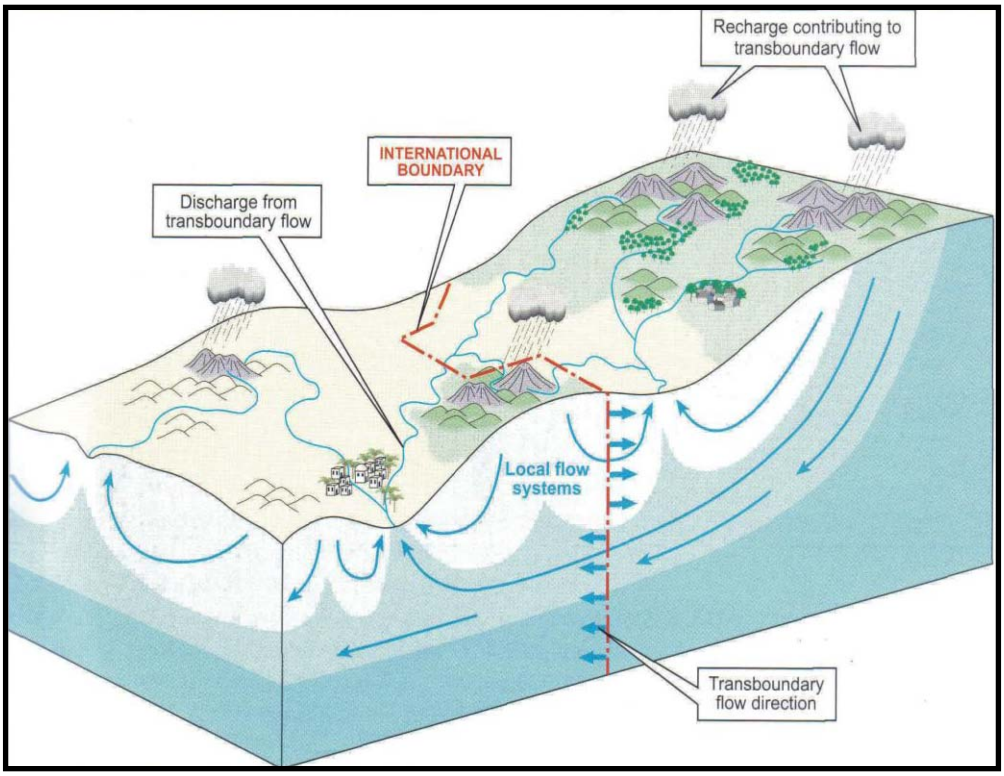

Figure 1. From Puri *et al.* (2001)

The appropriate methodological procedures and framework for this activity was offered by the UNESCO/OAS ISARM America Programme. The Programme is a local initiative launched by UNESCO/International Hydrological Programme (UNESCO-IHP) with the Organization of American States (OAS), which begun during the International Hydrogeologists Association (IAH) and Latin American Association of Groundwater for Development (ALHSUD) at the Mar del Plata Congress (Argentina, 2002). The main objectives of this Programme are: 1) reaching better scientific, environmental, legal and institutional knowledge on transboundary groundwater; 2) collecting information to create the Americas Transboundary Aquifers Inventory; 3) selecting prioritary study cases to implement pilot projects; 4) develop strategies for sustainable management in the region.

Up to now, the Results of ISARM Americas Programme are: a) the preliminary evaluation of transboundary aquifers systems in America, with 68 TBA recognized for the sharing countries, UNESCO (2007); b) legal and institutional framework in the management of the transboundary aquifer systems of the Americas, UNESCO (2008). The Programme has continued working about socio-economical issues related to the identified transboundary aquifer systems, and a proposal about management strategies.

2. ARGENTINA TRANSBOUNDARY GROUNDWATER SYSTEMS.

In the Argentine inventory, two important transboundary aquifer systems had been identified previously of the launching of ISARM America: the Guaraní Aquifer System (SAG) (Montaño *et al*., 1998); Silva Busso (1999) and the Yrendá Toba Tarijeño Aquifer System (SAYTT), Figure 2.

The other five aquifer systems are the result of the Programme mentioned above. Figure3.

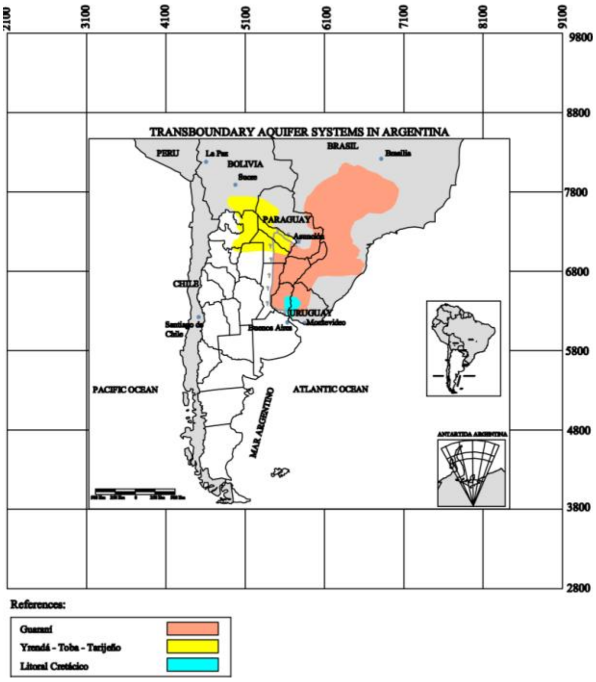

Figure 2.

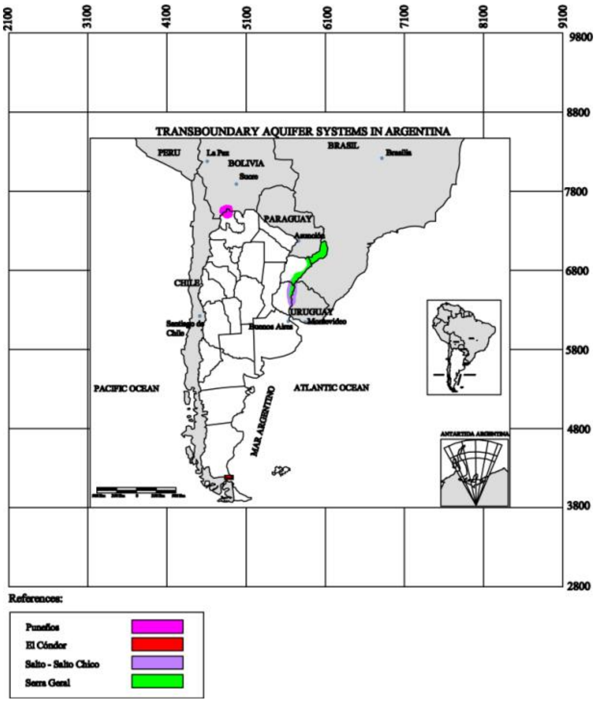

Figure 3.

The joint data collection carried out is an evidence of the acceptance of the participating countries to exchange available information on the shared groundwater resources, in order to develop a reliable conceptual model, design legal frameworks, and establish guidance on joint management and responsibility of these resources. The answers given by the different scientists or institutions consulted in this preliminary inventory are summarized below.

2.*1. Yrenda Toba Tarijeño Aquifer System (SAYTT)*

This aquifer system is shared by Argentina, Bolivia and Paraguay. The actual extention of the reservoir still has to be corroborated with the agreement of the three countries involved in order to establish the real extension of the aquifer system in their own territory. The collection, compilation and evaluation of the available information is considered to be a key issue for establishing, in a cooperative way, the reservoir geometry and its hydraulic behaviour. This scientific-hydrogeological approach helps for the equitable management of this shared resource.

2.2. Litoral Cretácico Aquifer System

This groundwater resource is shared by Argentina and Uruguay and is located underlying approximately the Uruguay River Basin. The region has humid climate with very important ecological systems. In this region more than 500,000 inhabitants are supplied by this aquifer. It is mainly used for irrigation, industry and cattle rising. This aquifer system is of great importance because it is situated under a region of a growing economic development. It is clearly important for both countries to address their efforts in promoting a unified and consistent knowledge of the aquifer system as the basis for its proper management and protection.

2.3. Salto - Salto Chico Aquifer System

It is located along the boundary between Argentina and Uruguay. It is also underlying the Uruguay River Basin, but it is above the Guaraní and Litoral Cretácico Aquifer Systems. In Argentina, this aquifer system is supplying 200 Mm3/year. This abstraction is mainly used for irrigation purposes. Moreover, this aquifer has a great regional impact because the economic development (rice crops) and the human supply depend on it. It is also recognized as a valuable and reliable fresh groundwater resource especially under the implied threat of the deterioration of its quality and quantity due to human activities.

2.4. Serra Geral Aquifer System

The Serra Geral Aquifer System occupies all the high lands, in the border area among Argentina, Brazil, Paraguay and Uruguay. In Brazil this aquifer is intensively exploited. In Uruguay this aquifer nowadays supplies an important population which uses it for drinking water. This system contributes to the La Plata River Basin with important amount of water that maintains the base flow of the surface water courses. In all the countries involved, there is a lack of information, particularly about the recharge process for controlling the exploitation. It is inferred a probable hydraulic connection with the Guaraní Aquifer System in its bordering area.

2.5. Puneños Aquifer System

The Puneños transboundary aquifer system is located in the Puna, a region located in the North-East of Argentina with the highest average elevation in this country and in the southwest Bolivian highlands surrounded by high plateaus and Andean cliffs (Fili and Tujchneider, 1990). The groundwater quality is good to very good, and it has an incipient exploitation. Located in one of the most arid areas of the world, the aquifer is of great regional importance as source of drinking water and for the dependent ecosystem. However it is subject in terms of the affectation because of the mining works. This is one of the main activities in the region.

2.6. Cóndor Aquifer System

This aquifer system is shared by Argentina and Chile and located at 62° South and 69° west, on the Magellan Strait which entirely separate Argentina mainland from the Isla Grande of Tierra del Fuego. Up to now, it is considered the most southern aquifer in the world. It is situated in an area of cool extreme climatic conditions, with little population but with important oil companies activity. Nowadays, these companies use the groundwater for secondary recovery. The aquifer system presents a fresh-salty water interface sensitive to the volume exploited. The aquifer system is of regional importance not only because it supports the oil activity, but rather also the local communities which use it for water livestock and human consumption.

2.7. Guaraní Aquifer System (SAG)

The SAG is one of the most important fresh groundwater reservoirs due to its estimated areal extent of approximately 1,200,000 km2 and volume (40,000 km3). It is shared by four South American countries: Argentina, Brazil, Paraguay and Uruguay, which use this resource for very different purposes at varying exploitation levels (Tujchneider *et al*., 2007). Since 2003 to 2009 a Project called: Environmental Protection and Sustainable Development of the Guaraní Aquifer System (WB – OAS – GEF) has been developed. The Project included the following components: 1) Expansion of the knowledge base; 2) Development of a joint management program; 3) Public and stakeholders participation; 4) Monitoring, evaluation and dissemination; 5)Development of management and mitigation measures in Hot Spots; 6) Assessment of the geothermal energy potentials. A very important experience was the public and stakeholders participation, with several meetings, conferences and technical courses held, and the elaboration of books and a lot of information material like videos, flyers, etc.

Nowadays one of the most relevant issues is the Agreement for management and protection of the SAG, signed by the four countries last 2nd August 2010.

3. FINAL CONSIDERATIONS.

Nowadays, most of the American countries participate in different projects on transboundary aquifers with border countries, to enhance knowledge and consider joint management procedures.

As a result of the work of the UN International Law Commission, the Law of Transboundary Aquifers was approved last December 2008, at the 63th Session of the UN General Assembly. The law contents 19 articles, with hydrogeological definitions and strong recommendations to the UN Member States about cooperation for groundwater management and protection.

Each country has different organizations involved in activities related with the elaboration, execution and control of the national hydrologic policies. Latin American countries have developed different political tools for multilateral understanding related to transboundary superficial water, groundwater is not very often mentioned. In a general, the basic situations that we can find are:

*focused in current traditional policies, with an evolution intimately conditioned by the government decisions of administrative order.

*focused on regulation and centralized policies, in which it is considered that the traditional legal and institutional mechanisms are enough to assure an appropriate management of the basins. The system is characterized by a binomial political / technical instance and by the nonexistence of the of users participation.

Now, a new scenario is being built:

* with focus in participation and negotiated policies, in which it is considered that the application stricto-sensu of the legislation in each country doesn't generate an institutional frame of planning.

So, the great and main challenge for all the South American countries will be the selection of appropriate models of institutional organization to manage and protect the transboundary water resources, independently of the diversity of the possible institutional models.

This involves a the great responsibility for the environmental sustainability and an equitable and efficient management that must be solved on the basis of system (natural and social) knowledge, the develop of legal instruments, capacity building strategies, control and protect policies to avoid conflicts, strengthen the institutions, raise awareness, improve the water governability, reduce poverty and achieve the Millennium Goals.

The Agreement on the Guarani Aquifer System, signed between Argentina, Brazil, Paraguay and Uruguay last august 2010, shows the entire world these countries commitment on this challenge.

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Transboundary Aquifer Institutions, Policies, and Governance: A Preliminary Inquiry

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ABSTRACT

The paper considers types and modes of institutions, policies, and governance that deal with transboundary aquifers. The work comes at the outset of a research effort that combines a case-study approach with an analysis of the status of international aquifers and prospects for global governance. The authors begin by posing and exploring a number of salient questions centering on determining prevailing modes of governing transboundary aquifers *multinationally*? Each nation has its own way of administering, managing, and governing water resources within its own territory. But to what extent have nations developed instruments—formal and informal—to address shared water resources cooperatively, fairly, and equitably, while minimizing conflict. What geographic, social, political, and economic characteristics and conditions are most conducive to achieving effective transboundary institutional arrangements? What are key criteria for effective governance (e.g., practicality, domestic political viability, mutual acceptability to all basin countries, transparency, cost-effectiveness, and conflict-preventive capacity)? The UN General Assembly, in December 2008, adopted a resolution aimed at eventually approving an international "Law of Transboundary Aquifers." Shared aquifers, because they include national territories and associated concerns over sovereignty and security, are likely to prove contentious. If such a treaty were to be agreed to, how effective would it be as a real transnational governance mechanism? How would its terms be monitored and enforced, and by whom? Finally, might it be possible to arrive at a more informal, less top-down, but more flexible form of global governance by harnessing the collective efforts of global water initiatives that have specific aquifer-management-related objectives?

Key words: Transboundary, aquifers, governance, institutions, policies

1. INTRODUCTION

1.1 Prefatory note

This paper is a prospective essay, describing research that began in late 2010. In it, the authors seek to raise a number of salient questions about the state of transnational aquifer management with the aim of uncovering unaddressed areas of inquiry relating to institutions, policies, and modes of governance. This paper, accordingly, should be read as a discussion piece, intended to promote further consideration of the sorts of questions posed below.

1.2 Background and rationale

Our planet possesses very limited volumes of freshwater. In many areas of the world, especially in arid and semiarid regions, the quantity of available freshwater is likely to diminish due to changes in climate, population growth, and economic development. Groundwater, the largest source of freshwater, is an increasingly important source for populations and for agriculture.[1]

[1] According to the U.S. Geological Survey, 99% of the world's available freshwater is stored in the ground. Surface water in rivers and lakes accounts for only 0.3% of total freshwater supplies, while fresh groundwater represents about 30%. The remaining freshwater is stored in glaciers and permanent snow and in soil moisture, and is not accessible for human use (Aureli and Ganoulis, 2009).

Much of the world's available groundwater lies in aquifers, many of which underlie politically constructed international boundaries. These transboundary aquifers are a prime example of common-pool resources whose effective management requires transnational cooperation.[2] In many instances, transboundary aquifers have been exploited unilaterally without any bilateral or multilateral institutional arrangements to promote cooperation. Yet until recently, there were few attempts to view the transboundary groundwater-management phenomenon globally. Instead, to the extent that transboundary aquifer management was studied at all, it was through the prism of unique, basin-specific forms of crossborder governance.

A decade ago the United Nations, via its International Hydrological Programme (IHP) housed at UNESCO, began addressing this issue by establishing a multiyear project on Internationally Shared Aquifer Resources Management (ISARM; IHP, 2001; Puri, 2001). While the ISARM project's long-term goals do include the promotion of international governance, especially through the adoption of an international treaty, much of its effort to date has been more fundamental: *To identify, inventory, characterize, and map the world's many aquifers that cross national borders* (Puri and Aureli, 2009). Nearly 300 such groundwater basins have been identified—nearly half of them in Europe, where information has been the easiest to obtain. In 2009, ISARM produced and published a comprehensive world map, "Transboundary Aquifers of the World" (Puri and Aureli, 2009), showing for the first time the full extent and distribution of such aquifers.

From information available to ISARM, Alice Aureli and Jacques Ganoulis, the authors of the project's most recent "Overview and Recent Developments" (2009), conclude that:

> *In the present situation national institutions dealing with groundwater are not sufficiently or effectively prepared to be able to undertake the joint management of transboundary groundwaters. Groundwater management units, when they exist, are often side-lined and nonvisible in surface-water dominated water administrations and groundwater is not explicitly addressed in national water legislations.*

To add to these observations, it can be said that national institutions—whose chief concerns are domestic—often lack the wherewithal even to deal with multinational institutions like ISARM, much less to comprehensively engage with multi-stakeholder, transboundary **management** institutions like river-basin authorities.

2. OBJECTIVES OF RESEARCH

The first objective of the present study is to explore the multinational institutional governance arrangements that exist in some of the world's important transboundary aquifers. The project will examine these arrangements—or their absence—in a sample of six such basins on different continents.[3] A key issue is whether and how these aquifers are being governed transnationally. Are there dedicated institutions such as organizations, accords, or other instruments that are specifically intended to deal with issues of concern to the states sharing the resource? These case studies will permit the development of a framework to determine which types and modes of transnational governance models appear to hold the most promise for successfully harmonizing domestic and transnational interests. While many observers

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[2] See, e.g., Blomquist, et al. (2004); Feitleson (2006); Milman and Scott (2010); and of course, the pioneering work on management of commons of 2009 Nobel Prize-winning scholar Elinor Ostrom.

[3] Likely case-study aquifer basins are San Pedro and Santa Cruz (North America); Guaraní (South America); Escaut, or Nestos-Mesta, or Prespa lakes (Europe); Inkomati or Limpopo (South Africa); and Mekong (Southeast Asia).

have overstated the potential for "water wars" posed by transboundary water disputes, in an environment of water scarcity it is essential to attempt to resolve resource disagreements peacefully. Thus, an important criterion for "success" in transboundary aquifer governance is conflict anticipation, avoidance, and mitigation.[4]

In addition, following on research by one of the authors on 'global water initiatives' and governance (Varady, et al., 2009; Varady and Iles-Shih, 2009; Varady, et al., 2008), the present research seeks to assess the prospects of collective global action for governing transboundary aquifers. Among the approaches currently under consideration by the world's nations are such water-law instruments as treaties and other multilateral protocols. But the authors are keenly interested as well in evidence of existing informal arrangements among aquifer-sharing states. Research over the past seven years has aimed to show that the collective impact of global water initiatives—most of which address issues related to surface waters—can be seen as a benign form of global water governance.[5] Can similar organizational efforts be harnessed to induce an informal mode of global governance of the planet's groundwater resources?

3. RESEARCH QUESTIONS

In an attempt to improve on-the-ground management of surface water resources, over the past several decades numerous observers have studied modes of water governance. Among the many paradigms developed during this period, Integrated Water Resources Management, or IWRM—which secured the endorsement of the Millennium Development Goals—has emerged as the dominant model. While IWRM has met with widespread acceptance, it has not satisfied all of its critics. Some of these call for more attention to context and to ethical considerations, while others question the resolve of governments to actually implement the elements of IWRM. But is there a globally-applicable analogue to IWRM, specifically tailored to the needs of aquifer-sharing states?

Before answering that question, it would be useful to know: What have been the prevailing modes of governing transboundary aquifers nationally, binationally, trinationally, and finally, *multinationally*? Of course each nation has modes of administering, managing, and governing the water resources on its own side of an international border. But to what extent have nations developed instruments—both formal and informal—to address shared water resources cooperatively, equitably, and effectively while minimizing conflict?[6] Going further, what geographic, social, political, and economic characteristics and conditions are most conducive to achieving effective transboundary institutional arrangements? (Feitelson, 2006; Dellapenna, 2001) What are the key criteria for effective governance (e.g., practicality, domestic political viability, mutual acceptability to all basin countries, transparency, cost-effectiveness, and conflict-preventive capacity)?

Because internationally-shared aquifers raise powerful questions related to international law, one set of potential answers has been offered by the United Nations (Stephan, 2010). In December 2008 the United Nations General Assembly passed a resolution aimed at eventually adopting a "Law of

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[4] UNESCO's IHP has been at the forefront of studying water-related conflict via its 'From Potential Conflict to Cooperation Potential' (PCCP) project, a nearly-ten-year-old effort). The PCCP project is closely linked to IHP's ISARM initiative. See also Delli Priscoli and Wolf (2009).

[5] Some publications resulting from this research are "Global Water Initiatives: What do the experts think? Report on a survey of leading figures in the 'World of Water'" (Varady and Iles-Shih, 2009); "Charting the emergence of global water initiatives in world water governance" (Varady, et al. 2009); and "Strengthening Global Water Initiatives" (Varady, et al. 2008).

[6] For an early discussion of this theme, see Nicol et al. (2001). Similar issues arise in the context of a concept known as 'hydrosolidarity'; see Gerlak, Varady, and Haverland (2009); and Gerlak, Varady, Petit, and Haverland (in review).

Transboundary Aquifers," roughly parallel to the United Nations Convention on the Non-navigational Uses of International Watercourses, which was adopted in 1997 (ILC, 2005). But it took 26 years for that convention to become international law. Transboundary aquifers, because they include actual national territories and associated concerns over sovereignty and security, are likely to prove more contentious.

Yet even if such a treaty—perhaps modeled on the "Bellagio Draft Treaty on International Groundwaters" developed in 1989[7]—were to be agreed to, many scholars and officials wonder how effectively it could function as a transnational governance mechanism. How would a treaty achieve necessary harmonization in a world with diverse legal and administrative systems? What is the likelihood that a convention that honors national sovereignty and is acceptable to the UN General Assembly as a whole would be strong enough to achieve its aims? And given that monitoring and enforcement would be constrained due to lack of resources, lack of will, and inevitable imbalances between 'strong' and 'weak' neighboring states, how could a treaty be uniformly and effectively implemented? Finally, how would a treaty overcome the reluctance of some countries to defer to international law? Such questions have plagued attempts to implement other international treaties and they are likely to delay the adoption of a groundwater treaty for many years.

The authors wonder whether—even as a treaty is developed and adopted—it might be possible to arrive at a more informal, less top-down, but more flexible form of global governance by harnessing the collective efforts of global water initiatives that have specific aquifer-management-related objectives. The elements of such a paradigm might resemble some of the ones outlined in the essays cited in Delli Priscoli and Wolf (2010). One especially promising insight is their observation that "any agreement or transboundary organizations must be built on constituencies from the bottom up but with buy-in at the highest levels. . . . Those organizations imposed from the top or bottom alone," they state, "will fail."

4. CONCLUDING REMARKS

In this essay, we have attempted to develop a research agenda for examining institutions, policies, and governance of transboundary aquifers. We have posed a number of questions regarding the difficulties of managing aquifers that cross international boundaries. With a rise of water demand globally, a decline in the amount of surface water available, aquifer overexploitation, and therefore, increased importance of aquifers, these questions come at a critical time. Because of the thorny nature of transboundary resource-management issues in general and the challenges to managing poorly-defined shared aquifers in particular, the world's nations have begun a dialogue aimed at addressing some of the most pressing issues.

Thus far, that dialogue has centered on legal-diplomatic approaches to transboundary aquifer governance. While definitive findings from our research will emerge as the work is completed, we believe international legal instruments—though perhaps a necessary first step to achieving progress—will need to be complemented by other, likely more informal strategies.

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[7] Hayton, R., and A. Utton, 1989. *Transboundary Groundwaters: The Bellagio Draft Treaty*. *Natural Resources Journal*. 29. 128 pp.

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MOVING TOWARD MANAGING THE GUARANI AQUIFER: THE BRAZILIAN CASE.

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ABSTRACT

Brazil shares eleven transboundary aquifers, among which the important Guarani Aquifer that has been the aim of international projects that broadened the debate on groundwater to beyond natural sciences and engineering. Of the four countries that share this Aquifer, Brazil is the one that has the most structured water-body management system. Nevertheless, groundwater public policy is still in an embryonic stage. The present study intends to contextualize the Brazilian regulatory landmarks and the ongoing strategies for the management of the Guarani Aquifer. The methodology employed was documental analysis. The international treaty among the countries that share the Guarani Aquifer and the way the Brazilian legal system regulates groundwater imposes barriers upon the construction of a shared and integrated groundwater-management system. Brazilian legislation determines that the ownership of the groundwater belongs to the federative states, regardless if such waters extend beyond their borders. The National water-body Policy brought important management instruments, but their implementation in the case of groundwater faces difficulties. Another problem is the artificial separation of groundwater and mineral water, which has been excluded from the water-body management system and is submitted to a completely different legal regime. The absence of a federal law that traces specific strategies for the theme and the freedom granted to the states to regulate the protection policies created a highly heterogeneous management system, with different implementation levels and the intermediation of the National Water Agency inferior to that applied to superficial waters. Initiatives gradually appear to insert groundwater in the water-body management system, but the Federal Government and the National Water Agency must have a more active role in the coordination of this process. A greater participation of these players could also contribute to stimulate an exchange of experiences between the South Cone countries and an attempt to harmonize their legal landmarks, especially in what pertains to the recharge areas.

Key words: environmental law, water management, groundwater, Guarani aquifer.

1. INTRODUTION

Groundwater management faces the challenge of protecting a hidden asset, which involves the two main resources of a political nature: water and soil. Such resources consolidate power relations by excellence. Water is a vital substance for life, ecosystems and production, whilst the soil is the territorial basis of production, being marked by the right to ownership and the right to sovereignty. The complexity of the theme increases as groundwater depends on science to reveal its characteristics and the risks it runs. Such characteristic hinders its political and social appeal, since its importance and the emergency of the impacts are not perceivable to laymen. If on one hand the lack of technical information hinders the creation of a policy for this resource, on the other, the lack of social understanding of the theme makes the practical legitimation of a possible aquifer legislation more difficult.

In the last few decades, a greater international concern with groundwater has been perceived. The increase in its use in several parts of the world calls attention to transboundary issues and the lack of experience in the management of aquifers. Within this context, several international centers appear dedicated to improve the knowledge on and management of groundwater. The inclusion of groundwater in the United Nations Convention on the Law of the Non-Navigational Uses of

International Watercourses (1997) and the efforts to consolidate the UN-ILC Draft Articles on Transboundary Aquifers (UN General Assembly resolution 63/124/2008) also stand out.

Latin America is a region wealthy in water, besides the superficial potential, 29 transboundary aquifers have been identified in the region (Stephan, 2009). Nonetheless, there is a lack of international agreement on the theme in the region. In the internal sphere, national groundwater policies are in an embryonic stage, due to the lack of technical knowledge or institutional and legal capacity.

Among the Latin-American aquifers, the Guarani Aquifer stands out, having been the target of several international projects that allowed for better knowledge of its geological dynamics and characteristics. This aquifer is located in the South American mid-west between 12º and 35º south latitude and 47º and 65º west longitude, in the Paraná Sedimentary Geological Basin. This is a transboundary aquifer occupying a 1.100.000-km^2 area spanning four countries: Paraguay, Uruguay, Argentina and Brazil. Its average thickness is of 250 m and the estimated water volume is of approximately 30,000 km^3 (Foster *et al.*, 2009).

Despite the signature of an international agreement between the countries, it does not intend to formulate a common landmark, since each country is free to manage the aquifer in accordance with their regulations. The biggest part of the aquifer is located in Brazilian soil, where it extends across eight states: Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, Mato Grosso do Sul, Minas Gerais, Mato Grosso and Goiás. As the main "Guarani owner", Brazil has great responsibility in its management; therefore, the present study intends to analyze Brazilian groundwater policy indicating its weaknesses and the main ongoing strategies for the management of the Guarani Aquifer.

1.1 Background of the Guarani Aquifer transboundary management

The most important international initiative developed in the region was the Project Guarani Aquifer–Sustainable Development & Environmental Protection Program of the Mercosur Nations of Argentina, Brazil, Paraguay & Uruguay and supported by GEF, generating a significant increase in the knowledge of this aquifer's characteristics, as well as removing the groundwater from anonymity. The main objective of this project was "to support Argentina, Brazil, Paraguay and Uruguay to elaborate and implement a shared institutional, legal and technical framework to preserve and manage the GAS for the current and future generations"(OAS, 2005). Nevertheless, the final conclusions of the project underestimated the transboundary management and impacts stating that the "most pressing and potential groundwater resource management and protection needs of the SAG fundamentally do not have an 'international transboundary' character" and that the "current transboundary groundwater issues are strictly limited in distribution and essentially local in character, and do not have major upstream-downstream implications". The project does acknowledge that transboundary management contributes to the exchange of experiences and knowledge, but attributes the responsibility for managing the aquifers to a local scale (Foster *et al.*, 2009).Analyzing groundwater age, the project also concluded that the central part of Guarani aquifer is not hydraulic connect with the watershed or the recharge areas (Foster *et al.*, 2009).

During the project, Mercosur also acknowledged the need to manifest its position on shared management. The first attempt was made when it instituted the Ad Hoc Guarani Aquifer High Level Group aiming at the formulation of an Agreement project among the Member States in regards to the Guarani Aquifer (Ruling GMC nº 25/04 e n° 48/04). One year later, the activities of the group were terminated without divulging any results.

The subject gained new strength at the Mercosur Parliament, which has pointed out the importance of instituting a common policy in the use of the Guarani Aquifer. For such, it proposed to the Common

Market Council the formation of a commission to study, analyze and compare each country's water-resource legislation aiming at recommending to the national governments modifications in their internal systems (October/2007) and a landmark Agreement on the cooperation for the sustainable management of the Guarani Aquifer system (2008). Moreover, it suggested the creation of a regional Research and Development Institute from groundwater and aquifer protection (INRA Mercosur - Mercosul/PM/SO/REC. 25/2009), besides the implementation of a transition project with the extinction of the Guarani Aquifer Project.

On August, 2010, Mercosur signed an agreement to the Guarani management. Unfortunately it does not follow the recommendations of UN-ILC Draft Articles on Transboundary Aquifers and reaffirmed the countries sovereign over Guarani Aquifer.

1.2 Methodology

This work is a juridical study of the Brazilian legislation related to groundwater protection and its qualitative analysis. The choice for this type of analysis is motivated by the importance of the law as an instrument capable of influencing water management. The research uses Mercosur documents, the Brazilian legislation, public administration documents, watershed plans, and the bibliography on water management. The main laws examined were: National Water Resources Policy (Federal law nº 9.433/97), National Water Resources Council resolutions (Resolutions nº 9/2000; 15/2001; 22/2002; 48/2005; 76/2007; 91/2008; 92/2008; 107/2010), and National Environment Council resolutions (resolutions n° 357/2005 and n° 396/2008).

2. GROUNDWATER MANAGEMENT IN BRAZIL AND ITS DILEMMAS

The National Water Policy (Federal Law 9.433/97) represented a great move in water management. This law introduced a new water management concept based on a decentralized, participative and integrated model that elected the watershed as its territorial base. In order to build a joint action of the Union, state members and municipalities, this law created the National Water Management System, known by the acronym SINGREH. This system counts on collegiate structures that minimize the centralized-government character of water management and allows for the participation of social and private players.

The SINGREH is composed in the Federal level by the Ministry of the Environment, represented by the Water Resource and Urban Environment Secretary (SRHU), the National Water Agency (ANA) and the National Water Resource Council (CNRH). At a State level, the SINGREH is formed by the state secretaries responsible for water management, the state water resource council and technical bodies. Moreover, the Union, state and municipality bodies related to water issues are part of the system. The base of the system is the watershed committee and water agencies. This water policy also foresaw a series of instruments to promote a better water administration, namely the watershed plans, the water quality monitoring framework, the water-resource information system, water pricing and water permits. All these innovations have a positive impact on groundwater management, but they face difficulties to address groundwater management peculiarities.

The absence of a specific federal law on groundwater, the state domain of the aquifers regardless of their geographic limits, and the municipal competency to manage the use and occupation of the soil generated a great lack of articulation and freedom between the three levels of power: the Union, States and Municipalities. Presently, the legal groundwater guardianship is performed almost exclusively by the states and with extremely different implementation levels, even when the same aquifer is shared.

The adoption of the watershed as a territorial basis to apply the National Water Resource Policy instruments is an important innovation, nevertheless it is based on the presumption that groundwater is hydraulically connected with superficial waters. Nevertheless, the main problem for the management of the waters is that this management unit created new territorialities that are not tied in with the classic administrative divisions: municipality, State and Union. This new way of managing water resources is interesting to supply an in-depth view of the water resources and yield a scale analysis to back up public water policies, but presents difficulties in transporting its decisions to the administrative divisions, which hold the power to implement the public policies, especially in the case of land management.

This difficulty can be seen in the application of the instruments foreseen by the water policy, especially in the case of water policy plans. Among other attributions, it is up to this instrument to propose usage and protection measures (Ruling CNRH 22/2002) and guide municipalities in the management of water resources. These plans establish a sort of territory zoning; nevertheless, this does not have binding legal effects for the municipalities or the other entities in the federation (Villar, 2008).

Watershed Plans seek a management format negotiated between the water users and acknowledge the competence of the municipalities in the soil usage management. The content of the watershed plans have a technical and political nature, but do not form a command and control instrument capable of imposing binding obligations upon municipalities or the other Federation entities in the use of the soil. Thus, the bodies from SINGREH have the duty of stimulating municipalities to adopt the measures established in the watershed plans, but acknowledge that the soil use management is a municipal attribution. SINGREH cannot impose or punish municipalities that do not comply with the content in the watershed plans in their territorial ordainment.

The water quality monitoring framework also aims at integrating territorial and water management. It determines the maximum polluting loads that can be launched according to the classification of the aquifers foreseen in CONAMA's Ruling nº 396/2008. In face of the technical difficulties, the lack of detailed information on the aquifers and the economic and social impacts generated by the regulation, no watershed committee was capable of applying this instrument, also because the committees concentrate their efforts on implementing superficial-water resource regulations.

To control the exploitation of groundwater, the permit and the charging for the use of water resources were foreseen. The permit is the instrument through which the Government attributes to the public or private interested party the right to exclusively use the water resource. This is not the transfer of water ownership, but the concession of usage rights, which may be paid or for free. The charge fits in the category of payment in consideration of the use of the water. Although the law allows charging for the extraction of groundwater, it is up to the committees to determine such amounts, which still has not been done to groundwater.

The number of permits has increased, but it is still far from supplying reliable groundwater exploitation standards in Brazil. One of the most severe problems concerning this procedure is the lack of a specific consolidated-analysis methodology for all state permits authorities. Moreover, it is necessary to determine the recharge volume, as well as define criteria that consider the relation of these waters with superficial waters. The interaction and articulation between the water use permit authorities and the National Mineral Production Department - DNPM must also be built to conciliate groundwater and mineral extraction.

Mineral waters and bottled waters are classified as mineral resources, being completely excluded from the water-resource management system. They are treated differently from groundwater, since they belong to the Union, are ruled by mineral-resource regulations and are under the wing of the National Mineral Production Department (DNPM). The SINGREH bodies do not have information on the number of wells or the amount of water exploited by the mineral-water sector that reports to the DNPM. To overcome the problem, the CNRH edited Ruling nº 76/2007 determining the integration of mineral- and bottled-water management, but how such integration will be done is ambiguous.

Another instrument facing problems to be put into effect is the National Water Resource Information System[1] (SNIRH). ANA is responsible for operating this system; nevertheless, most of the information on groundwater is in the Groundwater Information System (SIAGAS) coordinated by the Brazilian Geological Service (CPRM). Both systems operate in an autonomous and independent fashion, without proper communication. To minimize this problem it was edited the CNRH resolution nº 107/2010 which states that the groundwater monitoring network will be planned and coordinated by ANA, meanwhile the implantation and operation of the system will be made by CPRM. It must be pointed out that the information produced by the Guarani Aquifer Project is not available to the public yet. The low compliance of water users with the permits and the distinction between mineral waters and groundwater hinders the formation of the system.

2.1 Groundwater perspectives and Guarani Aquifer management

One of the main expectations with regards to groundwater is the change in ownership of the aquifers that extend beyond state or national boundaries. If the constitutional amendment project nº 43/2000 is approved, such aquifers would belong to the Union and no longer to the states. Despite counting on the support of federal institutions, this project faces strong resistance from the States and watershed committees. The States understand that such alteration would centralize the management of the aquifers in the Union and that they cannot have the same legal treatment as superficial waters.

In the present landscape, the Guarani Aquifer belongs to the eight states it spans. During the life of the Guarani Project, such states tried including groundwater in their legislation, although in most cases in a superficial manner. Nevertheless, some strategic actions to manage this aquifer can be highlighted, especially in the state of São Paulo, which is the main user of the aquifer and already counted on specific groundwater legislation.

The bodies from the São Paulo State Water Resource System performed a few corrective actions in over-exploited areas or those with water contamination through the creation of intervention areas. In the case of the Guarani Aquifer, the municipalities of Ribeirão Preto and São José do Rio Preto were characterized as intervention areas with restrictions to the use of groundwater. Moreover, the São Paulo state government launched the Aquifer Project[2], which aims at (1) identifying the critical areas, (2) creating prevention and control mechanisms and (3) defining water-use guidelines. Within this project, the Guarani Aquifer recharge area was the target of several studies that shaped the Environmental Development and Protection Plan. Such area, which extends through seven watersheds in the state of São Paulo, would be transformed into a spring-protection area. The bill is being drafted, but depends on the approval of the committee and the legislative power.

The payment for environmental services was not foreseen in the waters law, nevertheless, this instrument proves to be highly efficient for the protection of the resource. ANA created the Water Producer Program[3], which compensates farmers that preserve and recover the springs located in their properties. The tendency is for this instrument to be increasingly adopted in both the government initiatives and the negotiation of the public-service concession agreements. The state of São Paulo has already approved a resolution authorizing the payment for environmental services to the farmers. Moreover, the municipality of Botucatu (SP), located in the Guarani recharge area, obliged the company that won the concession bid for basic sanitation services to destine 1% of its net revenue to the payment of environmental services. The focus of the initiative was the superficial waters, but nothing keeps the instrument from being extended to aquifer recharge waters.

[1] This is an information collection, treatment, storage and recovery system on water resources and factors that intervene in their management.
[2] http://homologa.ambiente.sp.gov.br/aquiferos/15052009_cap_dos_agentes_publicos.asp
[3] http://www.ana.gov.br/produagua/

3. CONCLUSIONS

The absence of a federal law that traces specific strategies for the theme and the freedom granted to the states to regulate the protection policies created a highly heterogeneous management system, with different implementation levels and the intermediation of the National Water Agency inferior to that applied to superficial waters. The Guarani aquifer and its recharge areas are submitted to different protection standards within the country and there was a lack of initiatives to make this structure uniform. The present legal structure contains general presuppositions and legal loopholes. Groundwater management is also compromised by the different treatment to groundwater and mineral waters. Groundwater regulations start to become more complex and some initiatives gradually appear to insert groundwater in the water management system; however, they face limitations and are restricted to specific cases. The local scale plays an important role in water management, but there are organizational and power asymmetries between the municipalities and the watershed bodies. Also these actors often have different interests and do not necessarily share a common position in relation to groundwater problems. In fact, at the local scale there are significant problems that prevent the inclusion of groundwater in water management plans and activities, which suggests that the decentralization of water management should avoid leaving the local scale isolated. Considering this scenario, the Federal Government and the National Water Agency must have a more active role in the coordination of this process, even though groundwater belongs to the States. Besides the national benefits, a greater participation of these players could also contribute to stimulate an exchange of experiences between South Cone countries and an attempt to harmonize their legal landmarks, especially in what pertains to the recharge areas.

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TOPIC 4
Strengthening cooperation

RESEARCH WORK

Transboundary Aquifers: Analysis of Negotiation for the Use of Groundwater Sources in the Communities, TheTotora, The Huaraclla and Pomabamba District of Jesus, province and department of Cajamarca

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ABSTRACT

The work was carried out in three communities called the Totora Huaraclla Pomabamba and whose UTM coordinates are 9'200, 000 N, 784.000 E 9 'E 788.000 196.000 N, 9'200, 000 N, 788.000 E 9'196, 000 N and 784.000 E , altitude of 2.670 to 3.680 m.s.n.m.

This research was made in these communities because there are conflicts to use the water which is originated from a spring, named "Chim Chim, whose flow is 18 liters. / sec that pertaining to the Commonwealth called Pomabamba, from which supplies water for human consumption and irrigation through a main channel called La Huaraclla that it has 280 users and a secondary channel called Monte Alegre, with 22 irrigators, Totora is independent in the conflict.

The sub basin is formed by three physiographic positions: A **cone fluvio glacier** that corresponds to the Huaraclla, which is nearly flat position with sandy clay stony soil where the most part of the year without any drinking water and irrigation. The sloping area is Pomabamba, has crops to feed due to there is water almost the time. mostly 60% of the year of the total area and the mountain area is La Totora, where the landscape is permanently green color due to the rain, but lately the peasants burns the vegetation to expand their farm, so these areas has been becomed desert.

The research has been done in three stages: Preliminary stage cabinet to plan the study, field study to know the Geospace and identify conflicts between communities and the end of cabinet to analyze problems and develop the report.

There are conflicts in the basin because the water is not enough to supply 350 hectares with so little flow that after many legal processes more than 100 years and physical assault because there is not enough water, nevertheless these communities have reached the following agreement:

During the day Pomabamba community will use the water for human consumption and irrigation , and the evenings, saturdays and sundays will use the water Huaraclla community with the same purposes. The distribution of water makes a person who is denominated water´s judge, who is elected by universal election such agreement, will be respected by all the users. Totora is independent of this agreement, it is not part of the conflict..

The maintenance of the channels is done by users no state involvement, the absence of any of the users will be fined the price of a work day equivalent to 25 soles ($ 8.77 USD), the running costs will amount commissioners prior authorization of users.

Key words: GRH-Huaraclla

INTRODUCTION

The ecological, social, cultural and ethnic minority communities in Peru, are expressed in local forms of water management, so it is very difficult to describe the overall water management, since each community or people, have their own ways to manage this resource to reach an understanding between them so that gap in research communities have a very particular way of managing water to solve their needs.

The water has its three attributes that relate to the integrated management of water, are vital to life, rolling in practical terms, because water is a finite resource, since the use of one may preclude the use others, but it is also fleeting, because you can not evaluate their stock and flow, you cannot define its limits, this makes planning and monitoring their removal and exclusion from participation of users (Ven der Zaag, P. 2007)

Sphere Project, 2004:74, Steering Comittee for Humanitarian Response, reported that the water needs for domestic consumption vary according to climate, sanitation facilities, customs, people, religious and cultural practices, the food they cook, the clothes that they wash and wear .etc. water consumption usually increases as the place of supply is near.

Peru is no stranger to this type of premises, because throughout its history is one of the examples of highly elitist societies emerged in the development context for the use and availability of water, where there are people who do not have water and others have plenty of water.
In Peru the first actions that led to the development of a national strategy for water management was in 2003 when the Ministry of Agriculture through the INRENA requested FAO support to the preparation of the document entitled "Contributions to the strategy National Water Resources ". In this sense has been adopted and practiced these types of water management throughout history of Peru. During the nineteenth and mid twentieth century, water management was aimed at major projects. With the General Water Law in 1969 and even complementary current water management has evolved to give priority to projects in sub-sectoral approach, this evolution was accompanied with a large infrastructure and technological development.
Ore, Maria Teresa, 2005:19, argues that Peru is no stranger to this type of negotiation, because throughout its history is one of the examples of highly elitist societies emerged in the context of the development of irrigation and availability water between the people of greater and lesser economic power, social and political.

Hendriks, Jan, 2005, the economic value, cost of water and water tariff, says that water is a critical element that must be analyzed from multiple dimensions: social, cultural value, environmental value and economic value when due consideration of all these dimensions will cause management systems on water resources are socially acceptable, economically viable and environmentally sustainable: Therefore, these dimensions must be expressed in a country's water policies, as well as the structure , the actions and behavior of institutional frameworks
Cover all dimensions of water is very important because ignoring them produces a large gap between the economic value of water (or use system) earned yourself the perspective of a

user, and the economic value produced by the use of such water or system for society as a whole and may even shed a negative balance for the latter.

Although limited in this thematic text, only the economic dimension of water pricing, is that the real cost of water supply in the Andean countries have a much wider area of conceived until the water tariff or other sources of support. In the economic dimension should be considered for full funding:
Water costs at the end user.

The costs of operation and maintenance of collective systems for use.

The costs of amortization, depreciation and / or reinvestment of collective use.

The costs of preservation and development of water sources in major areas (watersheds, etc.).

The costs of institutional systems.

This integrity in the approximation of the cost of procurement, use and water management is not present in current policies regarding the collection and use of water tariffs in the Andean countries.

GWP, 2003, the IWRM approach promotes the coordinated development and management of water resources, land and other partners to optimize in an equitable socio-economic benefits arising without compromising the sustainability of vital ecosystems. This requires greater coordination in the development and management: Land and water, surface water and groundwater, river basins and adjacent coastal and marine environments, interests of upstream and river below.

OBJECTIVE

Identify ways of negotiating the use of water among the communities to provide timely acting the challenged water.

RESULTS

After more than one hundred years of conflict over water use, the result is that it has come to negotiate on the use of spring water Chim Chim, as follows:

The restoration of the intake, cleaning of canals and reservoirs are borne by users in general.

The maintenance of irrigation infrastructure is carried out by the villagers of Pomabamba and Huaraclla, but in case of absence of one of the users are rewarded with a day of work or a payment equivalent to $ 8 the day's work.

The fines for absences may be used to buy construction materials like cement, iron, nails, pipes, etc., But when there are surpluses can make expenditures for a party, where there will be food, beverages and folk dances.

The valuation of water in the Huaraclla, Totora Pomabamba and have important features of Andean culture, during the rainy season the water has social and environmental value in times of drought has economic value.

Payment of fees for water there, but if the fines payment for the maintenance of canals and the intake.
The users generally lack the financial capacity to fund major investments, such as lining of canals where there is leakage, build a water inlet through the direction of a professional, installing drip irrigation, training and research.

There is no water management by the state, nor have elbuen training for management and use of water. It works by customary arrangements.

There are no any support for strategic projects have environmental or agricultural and livestock technology.

Globally, water valuation lacks a vision of integrated management of water resources.

DISCUSSION

The promotion and strengthening governance of water management in the communities of the Huaraclla, Totora Pomabamba has a social process, has several components and requires a comprehensive approach and long term.

Users develop some maintenance activities and immediate use of irrigation infrastructure, but lack of a proposal and vision.

There are no major plans for water harvesting for increased flow, improved water use and capacity building, if any, are isolated and are not integrated. There is no leadership to make integration of the basin.
Water users, show little change in water management and governance, since they respond with practices that they are effective.

A higher bodies of water appears to have no interest promotion processes and improve water management in the country, although it was one of the keys to his choice of the current president, who offered water and sewer for all.

CONCLUSIONS

Governance of the Integrated Management of Water Resources has very significant gaps in the promotion and improvement of water use in the Andean communities.
Users respond to daily and traditional practices regarding water governance.
Water governance is accomplished through a board of users, without an integrated approach to water management, as they have no vision, principles, strategies, capacity building, financing or strategic research.
Water management in the communities studied, pluralism precedence policy that combines the formal system with local law, there is also the combination of multidimensional assessment with the predominance of economics, but there are also important features of assessment and social mystique but not environmental.

ACKNOWLEDGEMENTS

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PICTURES FROM THE STUDIED PLACE


Location of the Studied Area


The Totora Community


Small dam to catch water


Sandstone to infiltration of water


Rudimentary reservoir of water


Rudimentary channel for irrigation


Spring in the highest part


Spring in the highest part

The urgency of preventive mediation on water issues: the Bolsón del Hueco aquifer in El Paso (USA)/Ciudad Juárez (Mx).

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ABSTRACT

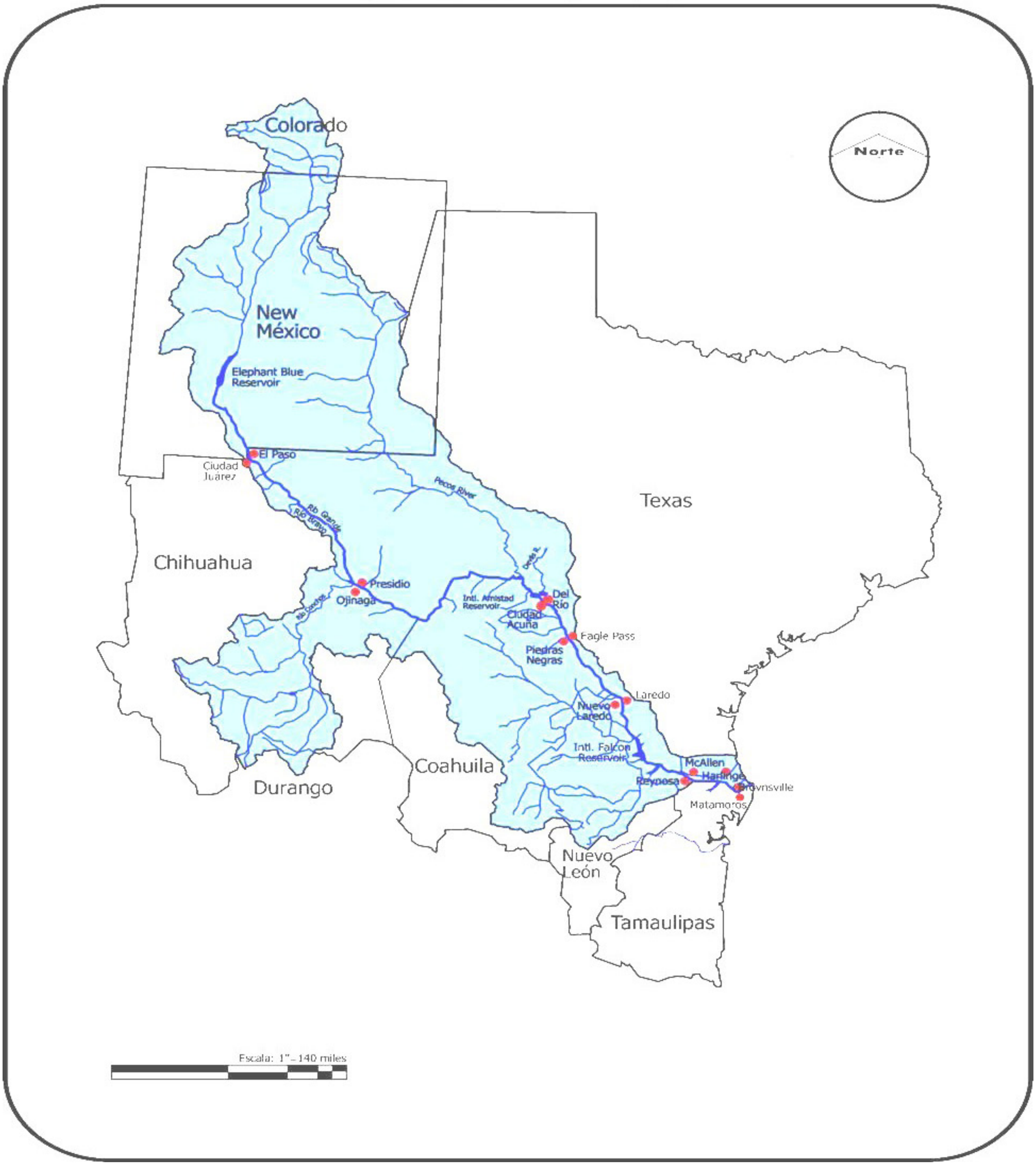
The Bolsón del Hueco aquifer forms part of the Rio Grande water system. It starts in the US, extending from New Mexico to the Texas border between El Paso and Ciudad Juárez in Chihuahua, Mexico, and ends 90 kilometers to the south,
Water from the aquifer is used for home use and for industrial purposes. Juárez depends completely on water from the aquifer, while only 50% of the water for the city of El Paso comes from it. Overuse of the aquifer, pollution of the water, and increased salinity are major problems connected to the fact that the Rio Grande, when it reaches Juarez, carries very little water on the Mexican side. Two dams, located in the north, only allow the water flow to meet the needs of farmers in New Mexico and Texas. Today, little water reaches Juárez, and the allotment of water to the Mexicans by the Americans is grossly inadequate. As a result, there are constant conflicts and risks of heightened tensions between the two countries.
Together the border cities Juárez and El Paso form a very large metropolitan area. In light of the increased population on the Mexican side, officials on both sides of the border have sought more cooperation in matters related to the quality and distribution of water. The Paso del Norte Water Task Force was created to promote cooperation on water issues with the International Boundary and Water Commission. Preventive mediation between the two cities should be based on the following goals: to promote an understanding on both sides of the border regarding the importance of water management in Ciudad Juárez and El Paso as one of the major issues of sustainability in the area; to work to ensure that less than 200 liters of water is consumed each day per inhabitant; to encourage dialogue and exchanges about water treatment; to increase sanitation; to optimize natural resources and their just distribution. Preventive mediation could, eventually, contribute to further economic development in this area, which is currently undermined by violence and insecurity, and could help to sustain cooperative efforts between the Americans and the Mexicans on themes other than narcotics trafficking.
Keywords: Ciudad Juárez-El Paso ; Global management of water; Education of the demand; Water treatment of waste and sanitation; Redistribution; Mediation; Etics.

1. INTRODUCTION: THE SITUATION

The Bolsón del Hueco aquifer forms part of the Rio Grande water system. It starts in the US, extending from New Mexico to the Texas border between El Paso and Ciudad Juárez in Chihuahua, Mexico, and ends 90 kilometers to the south, following the course of the Rio Grande. Its total length is approximately 10,800 km² (7,200 km² in New Mexico; 2,400 km² in Texas; and 1200 km² in Chihuahua). In the El Paso/Juárez area, it is between 8 and 13 kilometers wide and more than 60 meters deep. The sandy composition of the bed where the two cities meet across the Rio Grande normally allows the aquifer to function well; however, towards the south overuse has caused a reduction in both the quantity and quality of the water and an increased salinity.
The Bolsón del Hueco is the only reservoir of drinkable water of Ciudad Juárez, which shared by three states New Mexico, Texas and Chihuaha. Water from the aquifer is used for home use and for industrial purposes, for irrigation and municipal needs. Juarez depends completely on water from the aquifer, while only 50% of the water for the city of El Paso comes from it. Overuse of the aquifer, pollution of the water, and increased salinity are major problems connected to the fact that the Rio Grande, when it reaches Juarez, carries very little water on the Mexican side. Two dams, the Elephant Butte Dam and the Caballo Dam, located approximately 150 km and 200 km to the north of Juarez, only allow the water flow to meet the needs of farmers in New Mexico and Texas. The Caballo Dam, a flood control and storage dam begun in 1936 and completed in 1938, was built to provide flood protection for the projects downstream, as well as to store power generation waters for dry season irrigation.

To summarize the importance of the Hueco Bolsón is the following: Ciudad Juárez could run out of Hueco water in as few as 5 years. El Paso could run out of Hueco water in as few as 20 years.

Cuenca del Río Bravo



Today, due to severe river drought and the fact that the water supplied by the river is inadequate to meet the needs for water distribution on both sides of the river, as provided for by legal agreements between Mexico and the US, little water reaches Juárez.

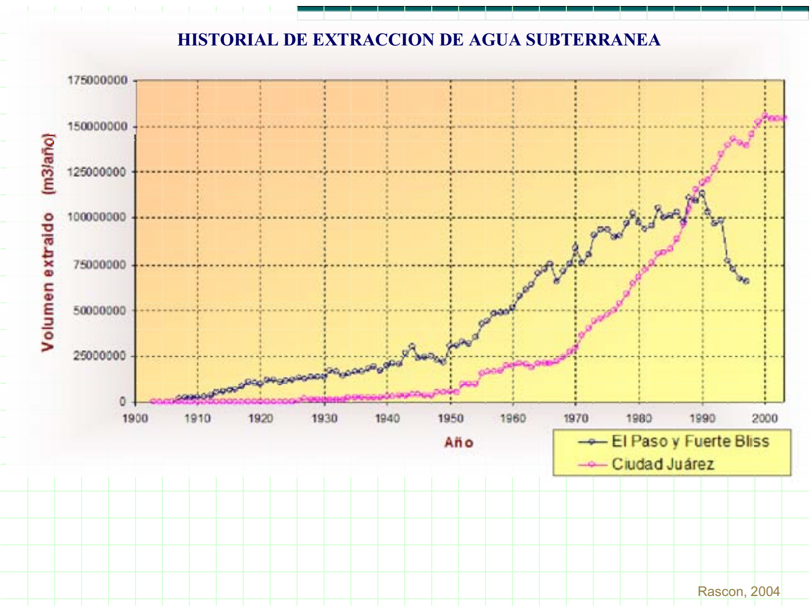
Only 60,000 acre-ft./yr. (19.55 billion galons) of Rio Grande water given to Juárez. All Rio Grande water given to Juárez is controlled by farmers. Rio Grande is 40% of el Paso's water supply. The are major supply of water for Juárez. El Paso currently working on was to treat and store water from the Rio Grande.

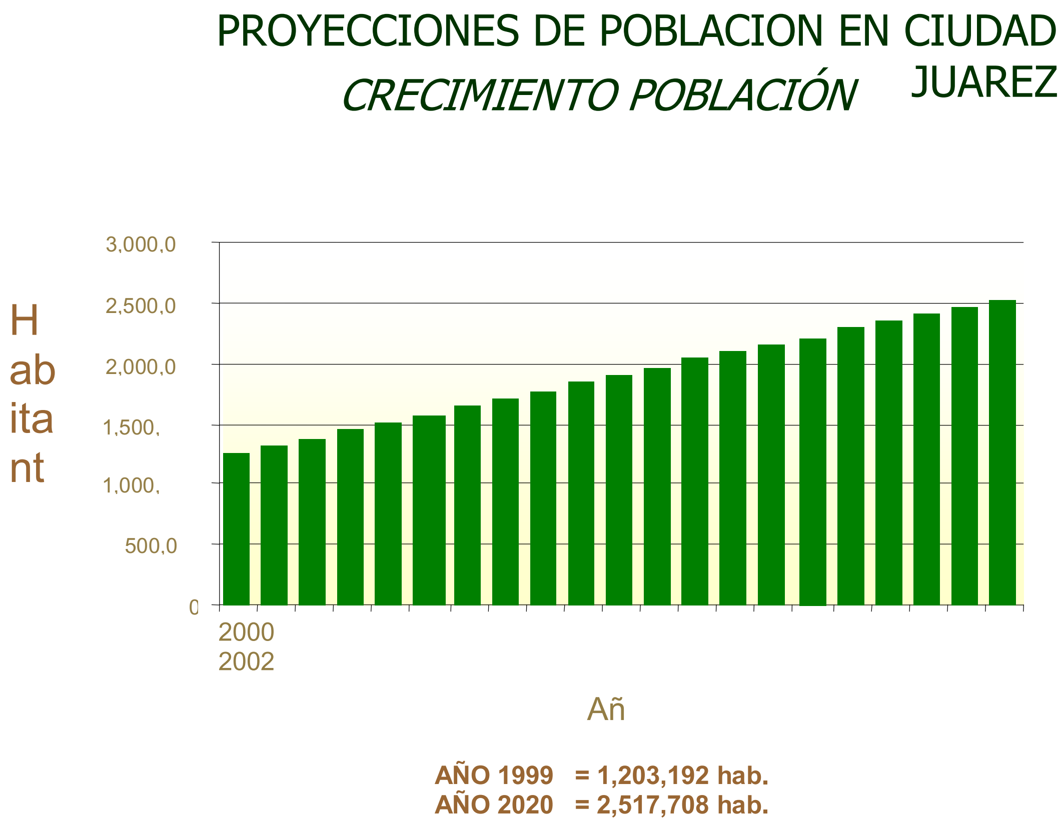
(Fot. Fernando Lozada, 2010)

Not only is the Rio Grande today an inadequate source of water due to droughts, but also the allotment of water to the Mexicans by the Americans is grossly inadequate. As a result, there are constant conflicts and risks of heightened tensions between the two countries.

2. OBJECTIVES: EFFICIENCY AND EQUITY

Together the border cities Juárez and El Paso form a very large metropolitan area. The Valley is experiencing explosive growth, and is home to many of the fastest growing cities in both the U.S. and Mexico. The total population of the Valley has doubled from 1.1 million to more than 2.2 million since 1970. And it's expected to double again by 2030. In light of the increased population on the Mexican side, officials on both sides of the border have sought more cooperation in matters related to the quality and distribution of water. The number of people in Juárez has doubled since NAFTA and increased industry.





(Rene Franco Bareno, 2005)

The Paso del Norte Water Task Force (Comisión del Agua del Paso del Norte), which unites water managers, water users, experts, and citizens, was created to promote cooperation on water issues that affect the future prosperity and long-term sustainability of the aquifer. Along with the International Boundary and Water Commission, the Paso del Norte Water Task Force is working to protect and conserve the transboundary aquifers.
Efficiency: Preventive mediation between the two cities should be based on the following goals: to promote an understanding on both sides of the border regarding the importance of water management in Ciudad Juárez and El Paso as one of the major issues of sustainability in the area; to work to ensure that less than 200 liters of water is consumed each day per inhabitant; to encourage dialogue and exchanges about water treatment; to increase sanitation; to optimize natural resources and their just distribution.
Equity: Preventive mediation on water issues could, eventually, contribute to further economic development in this area, which is currently undermined by violence and insecurity, and could help to sustain cooperative efforts between the Americans and the Mexicans on themes other than narcotics trafficking.

3. RESULTS OF WATER MANAGEMENT COOPERATION

Thanks to binational cooperation, Ciudad Juárez and El Paso are developing together many projects on Water Utilities:
-Project of the three states, New Mexico (Las Cruces), Texas (El Paso) and Chihuahua (Ciudad Juárez): to use the water of the Rio Grande/Rio Bravo to extend the life of the aquifer.
-Project to treat used water.
-Project with El Paso: to re-use treated water.

Junta Municipal de Aguas y Saneamiento, Ciudad Juárez

Future Water Treatment Facilities (Rene Franco Bareno, 2005)

Goals (Junta Municipal de Aguas y Saneamiento, 2008)

El Paso
Three types of water conservation: voluntary, forced, and incentive-based: for example, showerhead replacement program, low-flush toilets, water-efficient washing machines, refrigerated air conditioners over water coolers, etc. New water sources are available to El Paso including the Antelope Valley resource, which could be initiated first.

If both the population and water needs could be controlled, this control alone could sustain the El Paso/Juárez region and could become a reasonable solution to the water problem. For this reason Ciudad Juárez and El Paso are developing cooperative programs of communication to exchange scientific and technical expertise and to establish a individual and collective new water culture.

4. DISCUSSION

How to make the treated water drinkable? There are two options: 1) to build a water treatment facility in El Paso and to treat the water following the international treaty assigned to El Paso and the water assigned to Mexico; 2) to build a smaller water treatment facility in Ciudad Juárez only for Mexico.
In both cases, the autorisation of the CILA/IBWC* is required:
-to negociate the rules for water usage with the farmers;
-to locate the necessary financing.
*The Comisión Internacional de Límites y Aguas/International Boundary and Water Commission is the official organization for communication between the two countries on water issues along the border. In Mexico water management is a federal responsability, whereas in the United States it is primarily a state issue. The CILA/IBWC was the authority for settling conflicts arising over interpretations of agreements of the 1944 Water Treaty. The 1944 Water Treaty stipulates that the CILA/IBWC commissioners from each country must be engineers. The commission conducts mediation and makes recommendations by taking into account opinions from each side of the border, and by taking into account the positions of their respective capitals, and this is key for binational water management and planning.

5. CONCLUSIONS

Despite majors problems that persist in this region, the cooperative management of water, with responsabilities shared between the U.S. and Mexico (El Paso/Ciudad Juárez), is developing a new water culture that practices both efficiency and equity, and is certain to have positive implications for politics, economics, and ethics.

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2003: Drought, population growth, profit and politics are turning water into a very precious commodity in the Rio Grande river basin on the US-Mexico border. And tensions are increasing on both sides - between an impoverished part of Texas and a Mexican city already very dangerously low on water reserves - over who has water, and who is suspected of having it. The dispute stems from the fact that people are legally entitled to more water from the Rio Grande than is actually in the river itself. "The drought that we're looking at, for this area of Texas and New Mexico - and Mexico - is what we call a river drought," said David Crowder, the environment correspondent of the El Paso Times.
http://www.acfnewsource.org/science/rio_grande.html.

Managing Hidden Treasures Across Frontiers: The International Law of Transboundary Aquifers

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ABSTRACT

Although there is only one international agreement in the entire world squarely addressing the allocation and management of a transboundary aquifer (for the Genevese Aquifer shared between France and Switzerland), that distinction may soon be an historical oddity. In recent years, transboundary aquifers have received growing attention in numerous policy-making and negotiating circles. Cooperative agreements have been forged by the countries overlying the Guarani Aquifer in South America and the Nubian Sandstone Aquifer in northern Africa. Likewise, arrangements have been developed on local, sub-national levels, such as between the sister-cities of Ciudad Juarez, Mexico, and El Paso, USA, and between the US State of Washington and Canadian Provence of British Columbia. And in 2008, the UN International Law Commission presented the UN General Assembly with 19 draft articles in their effort to codify the international law of transboundary aquifers.

The law of transboundary aquifers is in an early stage of development. Nevertheless, there is a growing body of experience that indicates the emergence of accepted legal principles. This is evidenced by the increase in local and regional arrangements over transboundary ground water resources, as well as the growing attention that the subject is receiving in various fora. By reviewing these recent arrangements, as well as pronouncements of international organizations, this study identifies trends in the development of customary international law for transboundary aquifers. It also considers gaps and shortcomings in the emerging governance system and offers recommendations for the further development of the law.

Keywords: international water law, international groundwater law, transboundary aquifer, water dispute

1. INTRODUCTION

In recent years, transboundary aquifers have received increasing attention in policy and law-making efforts at all levels of civil society, in academic exercises, and in a number of significant negotiations. Rudimentary consultative and data-sharing agreements have been implemented on the Nubian Sandstone and Northwestern Sahara aquifers in North Africa, while more detailed management schemes were developed for the Genevese Aquifer situated along the French-Swiss border and the Guarani Aquifer in South America. A detailed cooperative arrangement was crafted for the Iullemeden Aquifer System in West Africa, while less detailed arrangements were entered into by sub-national political entities for the Hueco Bolson aquifer underlying the cities of El Paso and Juarez on the Mexico-U.S. border, and for the Abbotsford-Sumas Aquifer between the US State of Washington and Canadian Provence of British Columbia; a model aquifer treaty was developed by water law experts for the Mexico-U.S. border; and the UN International Law Commission (UNILC) formulated 19 draft articles on the law of transboundary aquifers. In addition, transboundary ground water resources feature prominently in the 1992 UN/ECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes, the 1997 UN Convention on the Non-navigational Uses of International Watercourses, the 2000 Revised Protocol on Shared Watercourses in the Southern African Development Community, and the International Law Association's 2004 Berlin Rules.

This expanding interest in transboundary aquifers is largely a reflection of the growing importance that ground water resources, especially those traversing international boundaries, are having in meeting nations' development goals and interests. It, however, is also a response to the realization that few concrete rules exist in international law to govern relations over these hidden treasures. As nations around the world begin to extract (or intensify their withdrawals of) ground water from aquifers traversing political boundaries, they are raising question related to their rights and obligations over these shared resources.

State practice and experience related to the utilization of transboundary ground water resources are now slowly developing, and nations and scholars are beginning to give more thought to the articulation of rules and regulations for the management of these critical resources. While the law of transboundary aquifers is in an early stage of development, it is already possible to ascertain trends that are relevant to this nascent body of law from the practices of states. This study reviews such practices, as well as relevant pronouncements by international organizations, as a means of identifying emerging rules governing shared ground water resources. It also assesses trends in these practices implicating the emergence of generally accepted international legal norms, identifies gaps and shortcomings in the emerging regulatory regime, and offers recommendations for the further development of the law.

2. THE IMPORTANCE OF TRANSBOUNDARY AQUIFERS

In places like the Middle East and the Mexico-U.S. border, transboundary aquifers often serve as the primary or sole source of fresh water for human and environmental sustenance. Libya, for example, which has no meaningful surface water resources, obtains the majority of its fresh water – some 6.5 million cubic meters of water daily – from the Nubian Sandstone Aquifer, which also underlies sections of Libya's neighbours (Chad, Egypt, and Sudan) (Watkins, 2006). Similarly, the city of Ciudad Juarez, Mexico, obtains nearly all of its fresh water from the underlying Hueco Bolson Aquifer while across the border, El Paso in the United States obtains around 30-40% of its water from the same source (ISARM, 2005).

Although the total number of aquifers traversing international political boundaries is still unknown, transboundary aquifers underlie the territory of nearly every non-island nation (Puri and Aureli, 2009). An ongoing study indicates that there are at least 273 transboundary aquifers globally (UNESCOPRESS, 2008), including more than 155 on the European continent, 38 in Africa, 68 in the Americas, and 12 in Asia (Stephan, 2006). In comparison, there are 263 watercourses crossing international boundaries (UNEP, 2002). Additionally, ground water today is the most extracted natural resource globally, providing more than half of humanity's freshwater for everyday uses such as drinking, cooking, and hygiene, as well as 20% of irrigated agriculture (Water for People, 2003). In Europe, 60-99% of drinking water comes from ground water (Almássy & Busás, 1999); in the United States, that figure is between one-half to 97% (Burchi, 1999). Accordingly, ground water resources and specifically transboundary aquifers are a crucially important source of fresh water globally and the sound management and regulation of these resources are critical for ensuring the sustainability of human communities and the environment.

3. EXAMPLES OF REGULATRY MECHANISMS FOR TRANSBOUNDARY AQUIFERS

The best known, and still the only treaty managing and allocating the waters of a transboundary aquifer, is the 1978 (revised in 2008) Franco-Swiss Agreement on the Protection, Utilization and Recharge of the Franco-Swiss Genevese Aquifer. This singular arrangement addresses ground water quality, quantity, abstraction, and recharge, largely through the creation of a joint Genevois Aquifer Management Commission. While the Commission has only consultative status, its recommendations and technical opinions carry considerable weight in the modification of existing and development of new water extraction works. The regime also recognizes Swiss artificial recharge obligations, allocates expenses between the countries for the Swiss recharge efforts, and places strict withdrawals limits on the French side (see Preamble, Arts. 2.3, 8, 11-14, and Annex). The particular significance of this arrangement is that it strikes a balance between state sovereignty and state responsibility in its management scheme, which is based almost exclusively on principles of transparency, good faith, and cooperation. Moreover, the agreement is unique in proffering a purely technical mechanism that is devoid of any provisions directly related to nations' sovereign rights to the aquifer or its waters.

Another fascinating arrangement, albeit one still undergoing development, is the 2009 Memorandum of Understanding relating to the creation of a Consultative Mechanism for the management of the Iullemeden Aquifer System (IAS MoU) entered into by Mail, Niger, and the Republic of Nigeria. While not a binding instrument, the details and language used in the IAS MoU reflects an intention by the parties to comply with the terms of the resulting agreement once it comes into force. The arrangement creates a Consultative Mechanism tasked with promoting cooperation over the management of the IAS and responsible for, *inter alia*, formulating opinons related to water management and utilization operations, coordinate IAS-related activities and harmonize procedures and policies, and develop action plans for implementing its recommendations (see Art. 5). In contrast to the purely consultative Genevois Aquifer Management Commission, the Consultative Mechanism has legal personality and authority to contract, acquire and dispose of property, seek and obtain loans, gifts, and technical assistance, and be a party in legal proceedings (see Art. 6). In addition, the IAS Memorandum explicitly relies on international water law and environmental law principles, including equitable and reasonable utilization, no harm, exchange of data and information, prior notification, environmental protection, public participation, precautionary approach, and polluter and user pays (see Arts. 13-17, 19-22, & 24). Nonetheless, like the Genevese Aquifer agreement, the IAS Memorandum focuses more on balancing state sovereignty and state responsibility while avoiding any reference to sovereignty in its formulation.

The memorandum of understanding entered into by the municipal water utilities of the City of Juárez in Mexico and the City of El Paso in Texas, United States (Juárez-El Paso MoU) is distinctive because it was entered into by sub-national political entities without the oversight of the respective federal governments. While legally unofficial and unenforceable, the purpose of the arrangement is to generate cooperation over the management and exploitation of the Hueco Bolson Aquifer, which as a result of population growth and development in the overlying region, has been overexploited raising concerns over the aquifer's viability as a source of fresh water for the area (Eckstein & Hardberger, 2008). The arrangement "seeks to identify the mechanisms between the parties to increase communications, cooperation, and implementation of transboundary projects of common interest." Moreover, in its "general objectives," the Juárez-El Paso MoU alludes to data and information sharing related to transboundary natural resources, and cooperation in the management, use and protection of natural resources that traverse an international boundary (see final paragraph of Recitals). Furthermore, it obligates the sister cities to develop and coordinate a compatible plan "to secure water supplies and extend the life of the Hueco Bolson" (see parag. 3(a)).

Possibly the most profound effort to develop a governance system for transboundary aquifers are the 19 draft articles prepared by the UNILC and contained in a 2008 UN General Assembly (UNGA Resolution). Largely modeled on the 1997 Watercourses Convention, the chief substantive state obligations are the well-known rules of equitable and reasonable utilization and no significant harm. Those principles, however, are tailored to the unique qualities that differentiate surface from ground water resources. For example, the list of factors for assessing what constitutes equitable and reasonable utilization includes "the natural characteristics of the aquifer or aquifer system," "the contribution to the formation and recharge of the aquifer or aquifer system," and "the role of the aquifer or aquifer system in the related ecosystem" (see Arts. 5(1)(c), (d), and (i)). Likewise, the no significant harm rule also obligates aquifer states not to cause significant harm through "activities other than utilization of a transboundary aquifer ... that have, or are likely to have, an impact upon that transboundary aquifer" (see Art. 6). This latter modification specifically relates to the distinct likelihood that non-aquifer activities undertaken above or around aquifers could detrimentally affected those aquifers, such as industrial and agricultural operations in the recharge zone, mining activities in the aquifer matrix, and construction, forestry, and other activities that might affect the normal recharge process (Eckstein, 2007). Other notions found in the Resolution include obligations to regularly exchange data and information, protect ecosystems, protect recharge and discharge zones, prevent pollution, monitor the aquifer, and provide prior notification of planned activities (see Arts. 8, 10, 11, 12, 13, and 15).

4. DEVELOPING INTERNATIOAL LAW FOR TRANSBOUNDARY AQUIFERS

The international law for managing and allocating transboundary ground water resources is still in a nascent state. Nevertheless, the increasing number of agreements, as well as the growing international interest in the subject, evidences evolutionary trends in customary international law. Customary international law refers to international law that is based on accepted practices of states rather than codified rules. It emerges from broad and consistent state conduct that is justified by a belief that such behaviour is both legally appropriate and mandated (Brownlie, 1998). While the extent of the practice relating to the management of transboundary aquifer is still somewhat limited, a review of arrangements, including those discussed above, nevertheless indicates a number of emerging trends in customary law applicable to transboundary aquifers.

Possibly the most palpable customary obligation to emerge from the evolving state practice is the procedural duty to regularly exchange data and information. Appearing in all of the arrangements discussed in this study, the duty is fundamental to the cooperation over and sound management and protection of transboundary aquifers. Without sharing such information, aquifer states will be unable to fully project and mitigate deleterious consequences that might result from the utilization of a particular transboundary aquifer (Eckstein 2007). Accordingly, the duty requires aquifer states to share collected information on the aquifer and its functioning on a continuing basis. While the precise type of data and information that to be shared is not always specified, it is obvious that they should relate to the character, use, and functioning of the aquifer. Draft Article 8 of the UNGA Resolution provides that it should include material of a "geological, hydrogeological, hydrological, meteorological and ecological nature and related to the hydrochemistry of the aquifers or aquifer systems, as well as related forecasts."

A corollary procedural obligation to this duty is the requirement to generate additional data and information through monitoring and related activities. Found in a majority of the arrangements discussed here, this obligation is indispensible to fulfilling the duty to exchange. The obligation also acknowledges the need to maintain vigilance in managing a transboundary aquifer and the need to continuously check on activities related to the aquifer's utilization and the possible impact they may have. While focusing on a transboundary watercourse, the International Court of Justice in its recent decision in the Case Concerning the Pulp Mills on the River Uruguay asserted that "once operations have started and, where necessary, throughout the life of the project, continuous monitoring of its effects on the environment shall be undertaken."

Another related procedural obligation found in a majority of the above-noted instruments is the duty of prior notification of planned activities. Where a planned project may adversely affect the territory of another aquifer state through the transboundary aquifer, the acting state must notify the potentially affected state. This obligation is designed the latter to evaluate the possible consequences and to seek an understanding or compromise with the acting state (Eckstein 2007). While the precise procedures vary among the instruments, the basic processes are well accepted in international water law. Under the UNGA Resolution, aquifer states would be obligated to provide "timely" notification "accompanied by available technical data and information ... to enable the notified state to evaluate the possible effects of the planned activities" (see Art. 15). In contrast, the IAS MoU proffers a more rigorous process that prohibits the notifying state from proceeding with the planned activity for a specific review period, authorizes the planned activity in the absence of a response to the notification, consultation and negotiations in good faith where the acting and notified states disagree about potential consequences, measures in the absence of prior notification, and an emergency exception (see Arts. 24-28).

Among the substantive obligations found in the arrangements discussed here, two well-known principles appear in a majority of instrument: equitable and reasonable utilization and no significant harm. Recognized broadly as the cornerstone principles of international watercourse law, these two principles appear to have been extended to transboundary aquifers. Under the first doctrine, aquifer states must ensure that their utilization of transboundary aquifers are both equitable, in terms of the benefits derived from the use of the aquifer, and reasonable. A non-exhaustive list of factors is typically provided in these instruments to aid in determining whether a particular use confirms to these criteria. Similarly, aquifer states are bound to ensure that their activities related to the shared ground water resources do not result in significant harm to other aquifer states. As occurs in the watercourses context, none of the transboundary aquifer arrangements elaborate on the implementation of these principles. Nonetheless, they represent the nascent state of the substantive law of transboundary aquifers.

Although the instruments discussed in this paper present other rules and procedures for transboundary aquifers, the lack of their consistent appearance across the instruments suggest that these additional principles do not yet represent a trend in the development of customary international law for transboundary aquifers. Nonetheless, the presence of these other rules and procedures – such as obligations to protect aquifer-dependent ecosystems, protect the recharge and discharge zones of aquifers, and prevent aquifer pollution – should not be discounted. Rather, their use and effectiveness as regulatory and management mechanisms should be reviewed and assessed periodically, as should their applicability for other transboundary aquifer agreements.

5. CONSIDERATIONS FOR THE CONTINUED DEVELOPMENT OF INTERNATIONAL LAW FOR TRANSBOUNDARY AQUIFERS

While surface and ground water resources share numerous similarities, ground water possesses a number of unique characteristics that must be considered when formulating regulatory tools for managing these resources. For example, ground water is typically more vulnerable than surface water to pollution and deterioration because water in aquifers generally flows at slower rates than in rivers and lakes, usually measured in distances of centimeters or meters per day (Hamblin and Christiansen, 2001). This slower flow rate greatly diminish the natural filtering capacities of aquifers and, thereby, their ability to reclaim and clean themselves. In addition, because of the geographic extent of most aquifers and the difficulties associated with monitoring underground formations, the artificial reclamation of a polluted aquifer can be prohibitively complex and expensive. The result is that once contaminated, an aquifer may be rendered unusable for years, decades or longer (Eckstein, 2007).

Accordingly, these unique aspects must be taken into account when formulating appropriate regulatory mechanisms for the sound management of transboundary aquifers. For example, special attention must be paid to the "functioning" of aquifers, which refers to how particular aquifers behave as aquifers. Aquifers typically store and transport water, dilute wastes and other contaminants, provide a habitat for aquatic biota, and serve as a source of fresh water and nutrients to aquifer-dependent ecosystems. Some aquifers even provide geothermal heat. Each of these characteristics comprises a function that is dependent on the particular aquifer's hydrostatic pressure, hydraulic conductivity, and mineralogical, biological, and chemical attributes, all of which may be interdependent with each other to the extent that the aquifer's continued operation depends on the continuation of one or more functions (Heath 2004). If any component related to an aquifer's natural behaviour is impaired or destroyed, it could seriously impair the viability and integrity of the aquifer as a whole. Accordingly, mechanisms must be developed to maintain and protect the functioning of transboundary aquifers.

Highly related to the functioning of aquifers, recharge and discharge zones of aquifers also require special attention since, with the exception of some non-recharging aquifers, these zone help regulate the flow and water quality of water moving into and out of the aquifer and, thereby, the functioning of the aquifer itself. Hence, the recharge and discharge process, as well as the geographical area in which they operate, must be maintained and protected. Mechanisms might include restrictions on activities in the two zones, such as industrial, agricultural, and municipal development projects that might affect the volume or quality of water percolating into and out of aquifers, regardless of whether or not those activities are related to the use of the aquifer itself.

Finally, a conceptual notion inherently tied to the transboundary characteristic of these aquifers pertains to the perception by some nations that they have unqualified sovereignty over the portion of an aquifer that lies within their jurisdiction. The belief, which harkens back to the long-discredited Harmon Doctrine, suggests that states are free to exploit resources within their jurisdiction without regard to the extraterritorial effects of such action. While a number of the instruments reviewed here appear to subscribe to this notion, the suggestion that water resources can be subject to a state's sovereignty is contrary to the community of interests approach governing transboundary surface waters. Moreover, the idea contravenes the basic tenets of international water law, including those of equitable and reasonable utilization and no significant harm, which clearly espouse a more limited conception of sovereign rights over transboundary waters (McCaffrey, 2009).

The above recommendations do not cover the gambit of issues and aquifer characteristics that require attention within an international legal context. Others issues that must be addressed include, *inter alia*: the threshold of harm necessary to trigger a violation of no significant harm; what aquifer aspects, in terms of functions and geographic scope, are covered by a regulatory or cooperative regime; harmonization of metadata and methodologies among aquifer riparians for generating information about shared aquifers; and exploitation of non-recharging aquifers. Nevertheless, this paper provides a starting point from which to further the conversation about the characteristics of transboundary aquifers that must be considered as well as the regulatory and legal mechanisms that might develop.

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Complex Projects Modelling as a Tool to Establish a Cooperation Framework within Transboundary Aquifers

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ABSTRACT

Transboundary aquifers are a relatively new subject. In the particular cases when the resource is confined and its flow is relatively slow, parties tend to wait for the emergence of a problem to start cooperating. Nevertheless, the geological and hydrogeological specificities of transboundary aquifers prove them to be a less contentious resource than surface water and a great factor of cooperation. Unfortunately, the lack of anticipation of risks and uncertainties and the underestimation of the importance of stakeholders' management often leads to conflicts.
This article considers the creation of cooperation through the development and implementation of projects (taken in their broad sense). It explains how, by modelling the development of cooperation projects, it is possible to anticipate the risks and uncertainties which can give rise to conflicts and get over them in order to ensure the success of both project and cooperation. A study of transboundary cooperation water projects in ten different basins is reported here, with a focus on the "Guarani Aquifer System Project" (SAG) between Argentina, Brazil, Paraguay and Uruguay that ended in 2009. This study is based on the scientific application of Development Modeling© techniques that help defining, evaluating and classifying degrees of complexity in the management of large international projects.
The study allowed identifying three main concepts explaining sources of conflicts within transboundary aquifers: Innovation, Instability and Uncertainty. First, *the degree of innovation of project processes:* transboundary aquifers cooperation projects being a novelty on which stakeholders usually never worked, thus lacking of references concerning the working process. Second, *the degree of instability of project environment:* to be sustainable, a cooperation project at a transboundary scale has to go through a political dimension which is subject to many changes coming from the environment. Third, *the degree of uncertainty of project decision making:* The combination of degrees of Innovation and Instability reveals project elements that cannot be forecast accurately by stakeholders and project management teams. This can heavily impact the cooperation negatively.
This article shows that preparation is necessary for the cooperation project to be sustainable. Complex projects' modelling is one way to consider the system as a whole and to avoid conflicts, whatever their source. Nowadays, the durability of transboundary aquifers resources does not only depend on technical, but also managerial knowledge and behaviour, and there is a lot to learn from existing best practices.

Key words: Systems modelling, conflict anticipation, complexity, uncertainty, stakeholders' management

CAUSES AND IMPACTS OF CONFLICTS ON TRANSBOUNDARY AQUIFERS (TBAs)

Groundwater, and particularly Transboundary Aquifers (TBAs), have been exploited for a long time through private, public or industrial wells. Some aquifers contain important quantities of fresh water and represent for the population a consequent water supply. However, it's only recently that this resource began to be evaluated as such. Uses and exploitation have started faster than the legal and institutional framework, as well as the knowledge upon this resource, could go.

Groundwater is mobile. It is not stopped by political borders and forms a "pure common pool" resource for a variety of users (Giordano, 2003). Locally, neighbouring property owners' pump into the same resource while internationally, countries have sequential control of the shared water (Matthews, 2005). Disputes over common shared resources originate from two main causes: quality or quantity. At both international and local level, the resource has to face the conflicting demands of the different users. A proper management practice must, on the one side, ensure the equitable allocation of the resource within a context of increasing pressure on water demand (Taylor *et al*, 2010) and on the other side, limit the spread of polluted water throughout the aquifer.

Apart from quality and quantity reasons, some conflicts around TBAs are caused by the nature of those aquifers itself. Aquifers have hydrological and geological specificities that influence the way they are, and should be, managed. The studies into TBAs led by the Internationally Shared Aquifer Resources Management programme (ISARM) show that most of the TBAs are diffusive in nature: part of their water follows a flux. Consequently, any intervention in the aquifer at one location by a user "A" may have environmental and/or economic externalities upon user "B" at another location. This specificity increases the conflict potential degree around aquifers. However, no sweeping generalization can be made upon TBAs: if usually, the appropriation of groundwater is relatively easy, cheap, secure and clean and the water system is diffusive, the example taken in this article, namely the Guarani Aquifer System (SAG) - shared by Argentina, Brazil, Paraguay and Uruguay - shows the exact opposite. Hydrological and geological studies led between 2003 and 2009 through the "Environmental Protection and Sustainable Integrated Management of the Guarani Aquifer" project (SAG Project) show that, unlike most other aquifers, the SAG is confined, non renewable and compartmented. TBAs are not well known to policy makers. Their hidden nature associated to the lack of International law governing shared aquifers invite misunderstandings which may lead to conflicts. (Jarvis *et al*, 2005, Puri and Aureli, 2005)

Conflicts around TBAs can have irreversible impacts upon both the resource and the projects started around it. To name few, the competition towards the resource and over exploitation can lead to the exceeding of the practical sustained yield; conflicts among stakeholders can get the project to abort or have a lesser performance in terms of delay, cost or quality; and, in the broader extent, the dispute can block the whole cooperation process, impede the exchange of data and eventually provoke repercussions on other sectors.

GROUND AND BENEFITS OF SOUND COOPERATION

Be it for a quality or quantity reason, conflicts on TBAs still often appear before any planning scenario can be enforced in the basin. Naturally, stakeholders around TBAs tend to wait for a conflict to emerge to start cooperating. Interviews of thirty-five stakeholders working in the SAG area allowed the identification of two main causes for this issue: first, the stakeholders involved on groundwater in the area don't know on which subject they should start to cooperate; second, they don't see the point in cooperating if there is no problem to face and they place the TBA on a secondary level on their agenda. Moreover, the systems' theory shows that human beings, when facing a complex system, will tend to chose the wrong solution because complex systems behaviours are counter intuitive (Sterman, 2001). Shall stakeholders be willing to cooperate before the emergence of a conflict; they would meet difficulties in framing their initiative. And that is why it is mandatory to anticipate the cooperation but not before modelling it. The cooperation process will be even easier to implement when the TBA is still at its initiatory phase: when no structure has been created, no working process exists yet and not too many elements have to be taken into account (social, uses, juridical...). One prefers building a project on a sound basis rather than an unsuitable one.

Another ground for cooperation comes in with the nature of aquifers. Globally, groundwater is less contentious than surface water. Firstly, aquifers never tend to become legitimate borders. Uses are physically restricted by existing borders. Secondly, in most aquifers or at least in most parts of them, the flux is quite low so environmental and economic externalities have a weaker conflict potential degree. Additional sources of water are less often a source of conflict than scarcity. For the SAG, the groundwater resource was a great factor of coordination and unity between the four countries.

Whatever the hydrological or geological nature of the aquifer, cooperation will always result in a better situation than conflict. This is proved scientifically by the games theory (Von Neumann and Morgenstern, 1944) and the totality principle of the systems theory (Von Bertalanffy, 1968) showing that "The interaction between the parts will prove in a more performing result than the properties that the parts own separately". Taking examples in the field draws the same conclusions concerning the reasons and benefits of cooperation:

- *Financial and economic*: countries will only start cooperation when they are convinced that the cost of cooperation is less than the cost of non-cooperation (Feitelson, 2003). Cooperation has a cost, but it also generates higher benefits than non cooperation (economies of scale,…)
- *Mapping*: Countries cannot know if the aquifer is transboundary as long as they haven't studied it.
- *Networking*: Cooperation strengthens linkages among stakeholders, particularly technicians.
- *Systemic view*: By bringing a wider knowledge of the resource, its hydrological specificities and functions (depth, outcrop area, surface, water table,…) and its stakeholders, cooperation allows having a systemic view of the TBA and ultimately establishing common managerial instruments.
- *Uses*: Particularly when uses are not spread yet, collaboration helps their anticipation. Espacially for deep aquifers, it is mandatory to think years ahead as most of the water is non-renewable.

The SAG is already a source of disagreement between geologists and hydrologists. The first consider that groundwater should be managed separately when the latter believe that surface and groundwater should follow a common integrated approach. Who is in charge of managing groundwater in each country? And what is groundwater for each country? Countries sharing a unique groundwater resource will most probably face the same issues. Cooperation will help them in finding common answers.

DEFINITION OF COMPLEXITY AND SCENARIOS FOR ITS MANAGEMENT

Once proven the necessity of cooperating around TBAs, one shall consider a management strategy for this cooperation. Now, cooperating on TBAs is not easy because TBAs are complex systems, therefore requiring a specific managerial approach. A project is a combination of various functional sub-systems (political, technical, legal, social...). All these systems can be classified in two different fundamental categories: "complicated" systems or "complex systems" (Le Moigne, 1977)There is complexity as soon as there is a high degree of uncertainty for the people involved in the project (managers, decision-makers, scientists…). Uncertainty is the result of two factors: instability and innovation (Daniel, 2010). Following the field of complexity management, hydrocomplexity arises from the "2I + U" (Instability, Innovation and Uncertainty) equation:

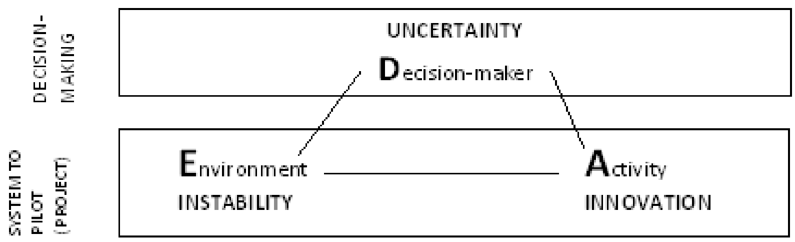

Fig.1 EAD triptych

There is INSTABILITY when the initial conditions of the project, its ENVIRONMENT, are totally or partially new. The degree of instability concerns the means, stakeholders, inputs and resources at the beginning of the project. TBAs involve a large number of stakeholders (well owners, industrial users, geologists,...) with different objectives and suffer from a lack of data. Finally, underground water is a new natural resource for most of the project stakeholders who had never worked on it before. All of these parameters add on the degree of instability of the project environment.

There is INNOVATION when the ACTIVITY carried out to achieve the project results, i.e. the transformation process, the tasks and methods, are totally or partially new. To take the example of the SAG Project, each of the four countries initially possessed its own technique to design a hydrological map of its portion of the aquifer. In order to create a common "mapabase", they had to adopt a common process that was novel for them. In the same way, the project team had to hire oil wells drilling companies instead of water wells drilling because the latter didn't have the ability to drill that deep. For the hired companies, dealing with water was an innovating process.

UNCERTAINTY results from the two previous parameters. As indicated in its name, uncertainty gathers elements that cannot be forecasted by stakeholders and project management teams because these project elements are revealed by the ENVIRONMENT and the ACTIVITY during the project life cycle. Depending on the degree of uncertainty of the project decision making (certainty, uncertainty, risk, unknown), the manager will have to adapt its decision making mode.

Hence, managers of groundwater resources, in order to know the degree of complexity of the concerned system and adopt appropriate strategies, can calculate the degree of instability of the project environment as well as the degree of innovation of the project processes, both resulting in the degree of uncertainty of the project decision making. The definition of "project" used in this article is the one developed by the Project Management Institute: "a project is a temporary endeavour undertaken to create a unique product, service or result" (PMI, 2004). We take here the word "project" in its broad sense, possibly taking the form of an infrastructure, a research, a treaty, an exchange of information, a network, in conclusion, any initiative that the stakeholders could take to cooperate around the TBA. Any form of cooperation must therefore go through a project.

The complexity of TBA's projects make them become highly potentially contentious. Most of the traditional approaches consider a successful cooperation as the absence of conflicts, hence waiting for the conflict to emerge to try and solve it. Chronologically, it places the use of those mediation, negotiation and resolution techniques during the project cycle, after the emergence of the dispute. The complex project modelling approach that will be presented now is one way to consider the system as a whole and a tool to anticipate and prevent conflicts before they appear. Complex project modelling can help in anticipating and driving the changes rather than undergoing them.

THE COMPLEX PROJECT MODELING APPROACH

Taken the fact that TBAs are complex systems, they will automatically follow the paradigm developed by Herbert A. SIMON (1989), according to which complexity exists but is difficult to manage. When facing it, human beings have to clarify it and represent it through an arborescence. Modelling is a way to depict the project. Particularly when considering complex projects for TBAs, it allows clarifying the project by drawing a clear representation of it. The objective of modelling is to name clearly the outputs that must be realized by the end of the project. The SAG project was confronted to the issue that any complex project can face: the whole process was much delayed at first because the Terms of References didn't explain clearly what each stakeholder's mission was. Hence the people involved in the project got confused about what they had to do. The outputs of the project shouldn't be hidden in excel pages of the framework, but rather exposed in bright light.

As a transboundary resource, TBAs are often managed by a team partly composed of politicians. This traditional approach to complex project management of TBAs attempts to mask oppositions in order to find a consensus as quickly as possible gained through ignorance. There is no real object to the discussion but rooms to manoeuvre and power created by uncertainty (Crozier and Friedberg, 1977). This approach is embodied when taking the example of transboundary surface water like the Nile River: the ten riparian countries are now trying to sign a treaty to share the water and one of the options considered to find an agreement is not to mention an exact quantity of water but rather let the contentious article 14.B. vague "Nile Basin States, agree, in a spirit of cooperation, to work together to ensure that all states achieve and sustain water security and not to significantly affect the water security of any other Nile Basin State". This political approach is commonly used nowadays in the field of international laws. It's a political paradigm in the sense that it aims at maintaining the power through hierarchy and top-down decision making.

On the opposite, the Complex Project Management Approach starts by enabling negotiation and makes room for potential conflicts to appear before the beginning of the project. It works through systems and networks and allows all stakeholders to be involved thanks to transversal decision making. This paradigm is based on facts rather than ideas and has for objective to go straight to results, performance indicators, costs and outputs in order to highlight concrete facts. On the opposite of the first approach that we call here "administrative management mode", this latest is called "pragmatic modelling mode".

Nowadays, most of the projects around underground and surface water, and more broadly dealing with development, follow the political approach. We think that we should let behind this paradigm to turn towards a more field oriented project management mode. Field interviews show that most of the stakeholders involved in such kind of project feel limited by the heavy weight of politics that let few margins to initiatives. Most of the time, politics take the gold seat at the project management table. Unlike the traditional approach, the pragmatic modelling mode places politics only as one portion of the whole system, along with others such as: social, cultural, financial, technical, media, academic... Each has results to achieve and all are interlinked: if one of the aspects is falling apart, the whole system will. In most of the projects led only by politics, the projects' outputs are governed by the funding: as soon as the latter stops, the sustainability of the project is threatened. To start the move towards a more systemic way of thinking, it's necessary to start managing projects with more realism, pragmatism and negotiation.

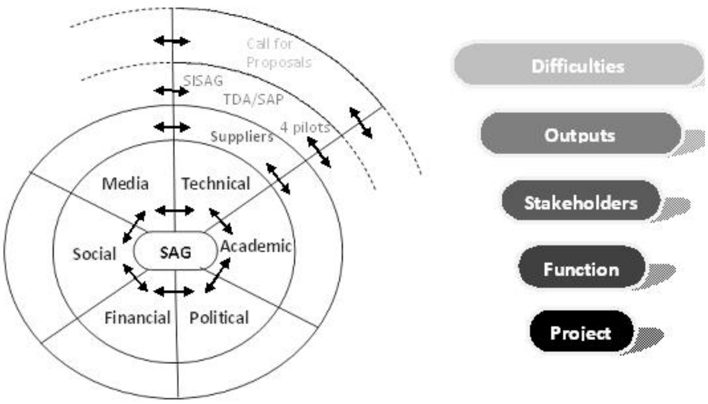

Fig.2 Project Systemic Wheel

Fig.2 shows an example of a more systemic representation of the SAG project. It illustrates the technical domain of the project, for which consortiums were asked to collect the hydrogeological data in the field to create an Information System (SISAG), and ultimately a Transboundary Diagnostic Analysis (TDA). Three main difficulties happened in the technical field: 1/ the Project Implementation Plan (PIP) suffered a 6-months delay that was passed on to all project outputs, including the technical ones; 2/ Because of negotiation issues with the only one company that answered to the first call for proposal, the company that answered to the second call for proposal was hired first but necessitated the outputs of the first one to work; 3/ Resulting of the two first difficulties, there was no time left for the implementation of the technical outputs that were made but never subsequently used by the stakeholders.

All these elements are then placed in the roadmap following the time frame:

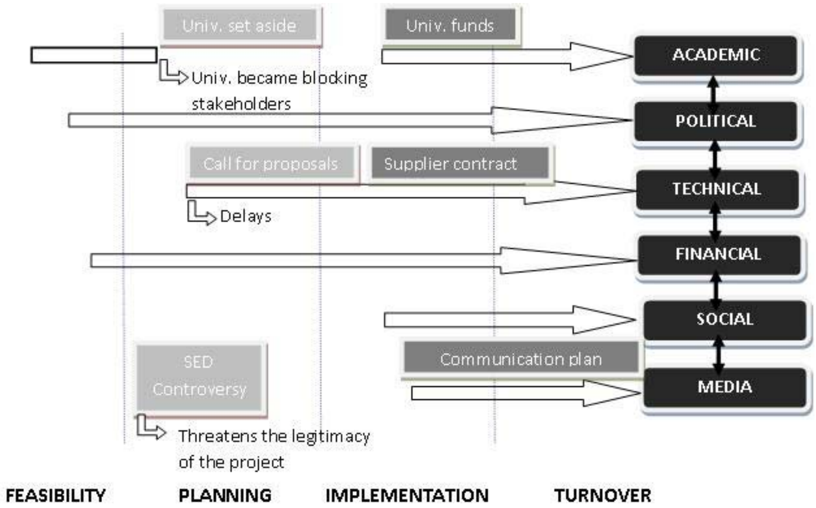

Fig.3 Roadmap

All elements need to be managed simultaneously and have to be integrated from the beginning until the end not to unbalance the whole project. If some aspects are prioritized upon others, it might affect the equilibrium of the system. *Figure 3* shows a simplified roadmap for the Guarani project. The technical issues mentioned above can be found in the technical line. Had a census of the potential companies that answered to the criteria of the call for proposal be made earlier, there wouldn’t have been such delays in the realisation of the technical outputs. This issue threatened the whole project as it nearly stopped when the conflict cropped up. Finally the company contract terms were renegotiated, yet preventing the total achievement of the objectives of the technical part of the project.

Concerning the academic domain, the issue is similar. Universities were involved during the feasibility phase of the SAG but then put aside when the planning phase began. Realizing that they were pushed out of the way, some scientists began to challenge all the academic outputs of the project, trying to get the project to lose its credibility. The fourth phase includes again the academic aspects thanks to a fund provided to universities for specific researches. The interruption of the academic timeline provoked troubles that could have been avoided, had universities been included throughout the four phases. Finally, the media domain went through a harsh difficulty when international journalists launched a controversy, partly through a documentary called “*Sed, invasión gota a gota*”, saying that the aim of the project was for the Americans to appropriate the groundwater of the Guarani Aquifer. As the communication manager was planned to be hired only halfway during the life of the project, the project manager had to face the controversy. Had communication started earlier, the diffusion of erroneous information about the project would have been avoided.

This representation clearly shows that the domains that were underestimated at some point of time favoured the appearance of difficulties and conflicts. Modelling the project’ system allows decision-makers to have a clear representation of all domains and stakeholders and anticipate conflicts.

CONCLUSIONS AND RECOMMENDATIONS FOR THE MANAGEMENT OF TBAS

Complex project modelling is a way to depict uncertainty and guide decision-makers in the management of transboundary groundwater resources. Complexity cannot be represented objectively but it can be simplified to facilitate its comprehension and governance by the stakeholders involved in the project. Some recommendations can be drawn from this methodology and the field study made on the Guarani Aquifer. Many transboundary projects include project management as a component of the project. Instead, piloting the project is a role incumbent upon the project team that needs to be made during the preparation phase of the project, not its realisation. It’s important to anticipate and take time to formalize the structure of the project before its launching. Complex project modelling is a tool that assists decision makers in planning their activities by forecasting potential conflict. Nevertheless, public consultations are a key of success to ensure that none will subsequently block the realization of the project. Without cooperation, even the project with the best framework and the best experts cannot reach its goal. So far, project management is often seen by managers as a reporting duty towards bilateral donors. On the contrary, it should help them guiding the project and make sure that no parameter or stakeholder has been underestimated. This way will ultimately tend to a pragmatic modelling and multidisciplinary approach. Needs have now been identified concerning TBAs: need for legislation, need for transboundary institutions, need for data; those needs can be modelled and clarified to ensure the durability of both transboundary aquifers' resources and projects' results.

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Peak Water meets Peak Oil: Moving Towards Unitization of Transboundary Aquifers

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ABSTRACT

Economists and legal scholars in property rights suggest integrating the concept of "unitization", as employed in the development in oil and gas reservoirs, to the problem of excessive access and related drawdown to aquifers. Intensive exploitation of petroleum "reservoirs" has led to premature depletion and, in some cases, irreversible damage to the storage characteristics of oil and gas reservoirs. Unitization, as employed in the oil and gas industry, is defined by government-mandated single ownership and management of a reservoir or "field".

Unitization of groundwater is a pro-market approach that could be used to implementing the Law of Transboundary Aquifers. Unitizing some situations associated with transboundary aquifers could be used as one means to mitigate the inefficiency of a possession or use-based system of groundwater along with the inefficiencies associated with joint access to groundwater. Under a groundwater scenario, a single "unit operator" could extract from and develop the aquifer system with other parties tapping the aquifer system sharing in the net returns as shareholders.

Beyond the traditional focus of groundwater allocations from aquifers storing water, unitization can address many other situations and benefits associated with aquifers. The core principles, or "4P" framework, behind unitization of transboundary aquifers includes (1) Promote groundwater exploration and development in underutilized areas, for example, in "megawatersheds" that are being promoted as a new exploration paradigm, (2) Preserve the storativity of aquifers by promoting local control of groundwater development, (3) Private investment in the "post-modern hydrologic balance" including Aquifer Storage and Recovery (ASR), managed recharge (similar to secondary and tertiary recovery operations used in the oil and gas industry), nonrenewable groundwater which does not fit well within the paradigm of Integrated Water Resources Management, as well as other opportunities such as remediating contaminated groundwater, ecosystem services, and the spirituality of water, and (4) Prevent disputes instead of conflict resolution by "blurring the boundaries" thus creating a new community of users with a superordinate identity who agree to how to "share" of groundwater and the associated benefits.

Unitization may serve as one approach to eliminating the "race to the pump" ultimately directing extraction toward maximization of the economic value of the aquifer system, rather than trying to meet the unreachable star of maintaining the "sustainable" or "sovereign" water rights held by individual parties and jurisdictions within a megawatershed, transboundary aquifer, or in nonrenewable groundwater situations. A few case studies where unitization concepts are being applied to groundwater will be presented.

Key words: Institutional advances, unitization, dispute prevention, economics

1. INTRODUCTION

"Water is the oil of the 21st century".
Dow Chemical Chairman Andrew Liveris, World Economic Forum, February, 2008

The 2008 World Economic Forum in Davos, Switzerland brought to the fore the issue of water scarcity and its relationship to future economic wealth and political security. Contrary to the adage that oil and water don't mix, oil and water truly do mix when it comes to the global economy considering the "energy–groundwater nexus" or providing power to the groundwater–intensive agriculture industry (World Bank, 2010).

Building upon the doomsday proclamations about "peak oil" in the popular press and environmental texts, the concept of "peak water" is gaining momentum. The concept of peak oil was first introduced by geologist M. King Hubbert who predicted in 1956 and again in 1968 that oil production from the United States would peak in 1970. Although his predictions were dismissed at the time, US oil production in fact peaked in 1970. (Hubbert, 1969; Hall and Day, 2009). Heinberg (2007) examined other arrays of "peaks" by looking at the bigger picture of the production of global liquid hydrocarbons peaking in 2010, as well as the peaking use of freshwater resources, in his book "*Peak Everything*".

Falkenmark (2009) describes "peak water" as a "…new and apt name for the present and looming threat of amplified water scarcity of both blue and green water sources occurring around the world". Gleick and Palaniappan (2010) indicate that water has characteristics of both renewable and nonrenewable resources and provide a detailed assessment and definition of three concepts of "peak water": peak renewable water, peak nonrenewable water, and peak ecological water. Peak nonrenewable water is groundwater stored in aquifers. Consideration that groundwater is the world's most extracted raw material with withdrawal rates approaching 800 to 1,000 km^3 per year through millions of water wells gives some credence to the concerns over peak water (Shah, 2009). Reference to "nonrenewable groundwater" is controversial, but it usually refers to situations where present-day replenishment is limited but aquifer storage is large, many times "decoupled" from the hydrologic cycle (Foster and Loucks, 2006). The concept is not new; the seminal work of C.V. Theis (1940) determined that "All water discharged by wells is balanced by a loss of water somewhere…This loss is always to some extent and in many cases largely from storage in the aquifer…Some ground water is always mined".

But peak water is not limited to just mining nonrenewable groundwater. Narasimhan (2009) indicates that the definition includes aquifers where the storage characteristics have been permanently changed due to pumping. This phenomena is limited to confined aquifers "…when the geological material is subjected to unprecedented declines in water pressure (tens of meters of water level decline), it will behave in a 'non-elastic' fashion. Under such non-elastic deformation, a certain amount of porosity (groundwater storage) will be permanently lost (lost storage) when groundwater is extracted at rates causing large declines in water pressure". A national summary of neotectonic subsidence by Holzer (1991) found that neglecting reservoir compressibility in calculating hydrocarbon reserves in rock reservoirs lead to estimates that were potentially too large by a factor of two. Jarvis *et al.* (2002) observed a 50 percent reduction in productivity from a water well targeting a fractured-rock aquifer within just a few years after it was completed; this rock aquifer served as a nearby oil reservoir in Utah. Narasimhan (2007) reports permanent loss of about 80 percent of storage space due to non-elastic deformation in three of the large groundwater artesian basins in the US.

2. OBJECTIVES

When one considers any "peak" resource situation, economics comes into play (Hall and Day, 2009). For example, Vaux (2007) indicates "Where extractive behavior entails independent action on the part of competitors who seek to maximize their individual net benefits, the aquifer will be managed in a suboptimal and often nonsustainable fashion. In instances where groundwater is not recharged, any extraction is inherently nonsustainable. In these circumstances, the economic theory of the mine applies and the level of extraction should be that which maximizes net benefits over time. The economics of nonrenewable groundwater are identical to the economics of extraction of any nonrenewable resources such as coal, oil and diamonds".

These hydrologic, storage, and economic relationships between aquifers and oil reservoirs have direct bearing on the implementation of the Law of Transboundary Aquifers. Careful consideration of Article 2 detailing the use of terms indicates "utilization of transboundary aquifers or aquifer system includes extraction of water, heat and minerals, and storage and disposal of any substance". Clearly, the emphasis extends beyond the equitable and reasonable sharing of water to acknowledging that the available storage is also a shared resource as described by Puri and Struckmeir (2010). This is the foundation of the concept of "unitization" of oil fields that was developed to protect the "corresponding rights" or "sovereignty" of all pore space owners in the unit and to not waste valuable pore space. While some readers may consider the concept of unitization another name for common pool resource management, this paper will compare and contrast the two concepts as they relate to groundwater and aquifer resources. This discussion is followed by a framework arguing for the consideration of unitization in the portfolio of options for implementing the Law of Transboundary Aquifers.

3. THE COMMONS VERSUS UNITIZATION

3.1 Groundwater and the Commons

Groundwater is a resource that is found everywhere. The commons refers to resources, facilities, or property institutions with some aspect of joint ownership and access. Common pool resources are valued resources that are available to use by more than one person and subject to degradation due to overuse. Groundwater systems are an example of a "pure" common pool resource because of the costly exclusion and subtractability attributes.

An exhaustive analysis of common pool resource theory as applied to groundwater resources is beyond the scope of this paper. The topic has garnered international interest for decades. Groundwater was one of the common pool resources profiled by the seminal work of Ostrom (1990 among many others. On the basis of over two decades of research on the commons, Ostrom (1990) developed the following eight design principles for the management of common pool resources: (1) Clearly define boundaries for the user pool and the resource domain; (2) Appropriation rules should be developed for local conditions and provisional rules be developed for resource maintenance; (3) Collective choice arrangements should be developed by the resource users; (4) Monitoring programs should be developed for the resource; (5) Graduated sanctions should be developed for "violators" of the rules; (6) Conflict management schemes should be developed; (7) Rights of organized environmental regimes should be respected by external authorities; and (8) Nested enterprises are used to administer the management of the common pool resource. Blomquist (1992) provided a case study of implementing the design principles for the management of groundwater in southern California.

Shah (2009) promotes the importance of "aquifer communities" as a means to "taming the anarchy" of groundwater development by the over 20 million wells in India. India epitomizes a "peak water" situation as the largest groundwater user in the world. Groundwater resources are being depleted at an alarming rate with 29 percent of groundwater blocks are semi-critical, critical, or overexploited, and the situation is deteriorating rapidly. And by 2025 an estimated 60 percent of groundwater blocks will be in a critical condition (World Bank, 2010).

The World Bank (2010) completed The Andhra Pradesh Drought Adaptation Initiative (APDAI), a pilot project that implemented the design principles of common pool resource management in India. Before the APDAI project, only the richer farmers had access to groundwater because they could afford to dig deep wells. The poor farmers had to depend on the unreliable monsoon rains to irrigate their crops. But according to Narenda (2010), "…convincing the richer farmers to share the water from their wells was not easy. However they agreed to do so because many of them too had fields that were far from their wells. If a pipeline was laid, these fields would also gain access to water". The project's success can be summarized by some of the rules for community management of common pool resources.

3.2 Aquifers and Unitization

The subject of unitization is too broad to be covered in a single paper as multi-volume law treatises are dedicated to the subject. The reader is referred to Libecap and Wiggins (1985) and Libecap and Smith (2001) for excellent summaries of unitization theory as applied in the US oil industry. Unitization is defined the joint operation of an oil or gas reservoir by all the owners of rights in the separate tracts overlying the reservoir or reservoirs (Weaver and Asmus, 2005). "Pooling" is sometimes referred to as unitization. While oil exploration and production are usually regarded as private property, the production of oil and gas has always been treated as affecting the public interest because has beneficial use to both the private and public welfare and is an important revenue stream for the many states and countries (Knowlton, 1939).

Without unitized operation of the reservoir, the common law "race to the pumps" results in competitive drilling and production with consequent economic waste, physical damage to the pool and reservoir, with each owner drilling more and pumping faster than their neighbor. The concept was designed to permit reservoir engineers to plan operation of an oil "pool" in order to conserve petroleum resources. To dispel the myth that unitization is part of the theory on common pool resources, it is important to note the early history of unitization is centered almost entirely around a pioneer in the US oil industry, Henry L. Doherty, who apparently coined the term and promoted the concept in the early 1890s (Knowlton, 1939). While the institution of unitization started in the US, it is spreading to other parts of the world such as Australia, United Kingdom, and Brazil (Weaver and Asmus, 2005).

Units are generally are classified as to purpose and are acknowledged as the best method of producing oil and gas efficiently and fairly. On the basis of over 100 years of application, Knowlton (1939) and Weaver and Asmus (2005) conclude that the purposes and advantages of unitization include the following attributes: (1) Develops and operate as a unit; (2) Uses pressure maintenance on the reservoir; (3) Provides foundation to carry out a secondary-recovery program; (4) Avoids the economic waste of unnecessary well drilling and construction of related facilities that would otherwise occur under the competitive rule of capture; (5) Allows sharing of development infrastructure, thus lowering the costs of production through economies of scale and operating efficiencies; (6) Maximizes the ultimate recovery of petroleum from a field according to the best technical or engineering information, whether during primary production operations or enhanced recovery operations; (7) Gives all owners of rights in the common reservoir a fair share of the production; and (8) Minimizes surface use of the land and surface damages by avoiding unnecessary wells and infrastructure.

There are a broad spectrum of oil units recognized by legal scholars and depending where the units are used, but they are of four general types as summarized by Kumar (2007): (1) *Voluntary Units* – Agreements among interested parties which can be undertaken for exploration or conservation; (2) *Compulsory or Conservation Units* – A high level of knowledge of physical characteristics of the "pool" is required for conservation; (3) *Geographic Units* – Typically applied where poor well control precludes defining boundaries of productivity, or in areas of complex geology; and (4) *Geologic Units* – Typically applied based on geology, productive area, lease position, precedent in a field, producing horizon or trend, or economics.

In the case of groundwater, Libecap (2005) suggests that "…government-mandated unitization of groundwater…is a solution to excessive access and drawdown…[where] a single "unit operator" extracts from and develops the reservoir. All other parties share in the net returns as share holders".

Knowlton (1939) recognized three principal fronts upon which the problem of unitization could be attacked in the early stages of oil unitization in the US. By comparison to groundwater, the least difficult units to form will be the ones addressing the problem of underutilization of groundwater as described by Giordano (2009) or deeper, undeveloped aquifer systems such as the "megawatersheds" described by Bisson and Lehr (2004). In these cases it should not be difficult to develop the means of establishing and dividing equities and benefits.

Conversely, the difficult task is met when an attempt is made to unitize an area undergoing intensive exploitation. At this stage there is only a limited amount of information available to all parties due to information asymmetry; however, Knowlton (1939) long ago recognized that agreements can be reached "…by the broadmindedness and generous approach to the problem by those who are conscious that the benefits received from unit operations will far offset any loss which might be suffered by their failure to receive their accurate equitable share".

No case studies exist regarding unitization of aquifer systems, but the principles of unitization are being applied in a few settings. In 2010, farmers and ranchers in the Escalante Valley of southern Utah located in the southwestern US were facing water level declines over 30 meters that occurred in the past 50 years. Lost aquifer storage was revealed through neotectonic subsidence – earth fissures tens of meters in length and up to two meters in depth. While the State of Utah introduced a plan to reduce groundwater use by 90 percent, the water users found the plan unacceptable and "pooled" their water rights to share in reductions in water use by voluntarily forming a unit – the Escalante Valley Water Users Association. The State of Utah passed legislation transferring the management of groundwater to the district that covers two counties (Hansen, 2010).

Shimada (*forthcoming*) provides an interesting case study balancing the spiritual value of water with private property rights using the concepts of unitization in Kumamoto, Japan. The city water is 100% supported by groundwater. Under Japanese law, groundwater resources belong to the landowners. Drilling data in the Kumamoto area permitted mapping with a high degree of certainty a region lacking a confining layer separating the unconfined and confined aquifers. The absence of a confining layer in this area permitted rainwater and irrigation water to recharge directly into the principal aquifer system. The groundwater recharged in this area flowed to springs filling Lake Ezu in Suizenji Park a spiritual shrine; the spring flows have diminished 20 percent in the past decade. The recharge area is overlain by rice paddy fields that lie outside the jurisdictional boundaries of Kumamoto. Kumamoto pays the local farmers who voluntarily fill their abandoned paddies within the identified "unit" to recharge of the aquifer.

4. DISCUSSION AND CONCLUSIONS

While the design principles for common pool resource management work well for the modern geohydrologic balance, unitization provides a more holistic approach to the post-modern geohydrologic balance because the post-modern view of groundwater resources acknowledges not only the pumped groundwater, but also storage of the aquifer system as outlined by Ragone (2007). Examples of "privatizing" groundwater include the unintentional poisoning of groundwater by agricultural and industrial wastes that are manifold in nearly every country; unitization of contaminated groundwater may provide new opportunities to remediate and market the previously unusable water and storage. Likewise, unitization may promote increased private investment in manufactured water (e.g., Aquifer Storage and Recovery) much like the enhanced recovery methods used in the oil industry. Indeed, the concept can be extended to the new strategies to combat climate change by storing carbon in aquifers. For example, the State of Wyoming passed HB 80, which became law on July 1, 2009, and provides for carbon sequestration units.

Social psychologist Mark van Vugt (2009) identified four conditions for the successful management of shared resources: information, identity, institutions, and incentives. Clearly, transboundary aquifer situations can create competition and conflict between communities and institutions that do not promote the welfare of groundwater resources. Van Vugt (2009) suggests that it is important to think of ways to "blur" the boundaries by promoting that "we are all in this together" to prevent disputes and promote efficient management of shared resources. Knowlton (1939) promoted this philosophy when recommending that unitization agreements be entered into "…with an open mind. Although we may feel, when the deal is consummated, that we have not received the share in the unit which the value of our properties warranted, we also know that because we have been willing to cooperate we are now the owner of an interest in a unit which will pay far more ultimate profit than our individual holdings would have netted".

The core principles, or "4P" framework, behind unitization of transboundary aquifers includes (1) Promote groundwater exploration and development in underutilized areas, (2) Preserve the storativity of aquifers, (3) Private investment in the "post-modern hydrologic balance", and (4) Prevent disputes by "blurring the boundaries" thus creating a new community of shareholders. Unitization can serve as one tool in implementing of the Law of Transboundary Aquifers by not only acknowledging equitable and reasonable use of groundwater, but also recognizing the sovereignty of the each aquifer State by valuing the pore space.

"We have conquered Mother Nature; now we have only to conquer human nature".
D.R. Knowlton, Phillips Petroleum Co., Address to the American Petroleum Institute, 1939

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The Use of Water Allocation Models in Managing Trans-boundary Water Resources:
A Case from Palestine

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ABSTRACT

In many regions of the world, water is scarce. This scarcity of water resources usually causes conflicts. These conflicts in case of trans-boundary water resources are often between political entities or states. Different states put forward conflicting arguments as to their water rights to a certain trans-boundary source. These conflicting arguments are usually based on different conflicting principles. If arguments are between states of different political and military abilities, Caesar's Law often replaces the principles of International Law. A good example of the above is the conflict over the trans-boundary water resources between Israel and Palestine. In such case, the use of water allocation models, especially by Palestinians, can proof the inequitable distribution imposed by the Israelis in addition to the gain that parties can get through cooperative management of trans-boundary sources. Such gains can be estimated through the use of water allocation models. An example of such models is the WAS tool. The Water Allocation System (WAS) is a tool developed by a group of scientists from Massachusetts Institute of Technology (MIT) along with the involvement of a group of scientists from Palestine, Israel and Jordan. The model presents a different way in looking at water disputes. That way is based on economic principles in its broad perspective. The WAS model tries to maximize net benefits for each region from the different water using sectors based on the requested water demands, available water resources, water infrastructure, the existence of treatment plants and desalination units, water conveyance, policy considerations, and penalties imposed. The model shows how efficiently the different states can efficiently implement the water related policies. This paper presents the results of different future scenarios in terms of shadow values, water allocation quantities, social benefits and others. These scenarios are developed taking into consideration two driving forces; economy and political stability. Results show that present water allocation between Palestinians and Israelis is not based on equitable foundation and indeed is unjust. WAS presents a more equitable and economic based allocation of water between Palestinians and Israelis. In addition, the paper demonstrates the prospective benefits from cooperation between different riparian of the trans-boundary water resources.

Key words: Palestine, Water allocation, Management, WAS, Trans-boundary

1. INTRODUCTION

Water has unique features that make it difficult to regulate using laws designed mainly for land. Water is mobile, its supply varies by year and season as well as location, and it can be used simultaneously by many users. There are several types of conflict likely to arise: absolute shortages, shortages in a particular time or place; diversions of water that reduce the flow available to others; pollutants or other changes (such as temperature or turbidity) that render water unfit for others' use; and the need to maintain "in-stream flows" of water to protect the natural ecosystems.

Water law involves controversy in some parts of the world where a growing population faces increasing competition over a limited natural supply. Disputes over rivers, lakes and groundwater usually cross national borders. Although water law is still regulated mainly by individual countries, there are international sets of proposed rules such as the Helsinki Rules on the Uses of the Waters of International Rivers and the Hague Declaration on Water Security in the 21st Century.

Long-term issues in water law include the possible effects of global warming on rainfall patterns and evaporation; the availability and cost of desalination technology; the control of pollution, and the growth of aquaculture. History proves that international law cannot be implemented successfully between different states when these states have different political and military abilities. For that, using models that can incorporate long term issues is seen necessary. An example of such models is the Water Allocation Model (WAS) and its implementation on the Palestinian- Israeli case is the main theme of this paper.

2. INTERNATIONAL WATER LAW

Modern international law has considered the environment and water in numerous sources. The international community eventually recognized a human right to water explicitly (UN, 2002). Although these rights are likely binding international law, the human rights to water and to participation in environmental decisions do not impose any substantive responsibilities upon individual countries. Instead, one must consider other documents to define the scope of the right. The academic literature almost entirely depends upon codified customary international water law to define the range of these rights in regions lacking binding water treaties. The two main sets of principles that are seen applicable to the Palestinian- Israeli case are:

The Helsinki Rules (1966)

The International Law Association (ILA), a law-related nongovernmental organization, drafted the Helsinki Rules, "the first comprehensive expression of equitable utilization and international river (drainage) basin principles." Article V of the Rules notes that "the weight to be given to each factor is to be determined by its importance in comparison with that of other relevant factors." These addendums force each basin state to argue over what weight each factor should be given (Elmusa, 2004). Thus, the Rules do little more than provide structure for future riparian negotiations (Stephen, 1992).

The Convention on the Law of the Non-Navigational Uses of International Watercourses (1997)

Aware of the Helsinki Rules' shortcomings, the United Nations soon took its own steps to codify international water law through the International Law Commission (ILC) (Jonathan, 1995). Much like the Helsinki Rules and the ILC Draft Articles, the Convention drew heavily upon equitable utilization. Moreover, the convention included consideration of "optimal utilization, which can improve the condition of any watercourse, including perhaps the Jordan River, by forcing riparians "to achieve the optimal use of the watercourse as if no State boundaries existed." This optimal use could be determined through the implementation of greater joint, technical analyses of the condition of disputed watersheds. This discussion shows that for the law to be implemented, allocation models like the WAS model is needed to provide answers to many questions that might arise during negotiations on weights, optimal utilization and others.

3. DESCRIPTION OF THE WATER ALLOCATION SYSTEM (WAS)

The water Allocation System is based on the view that water is an economic good, although it is one with special qualities (Amir and Fisher, 1999). This view implies that:

- Water has a cost (composed of at least the production – and distribution cost)
- Users produce benefits from using the water. If the availability of water is limited, only the most beneficial activities will be realized. As a consequence, the demand for water will be reduced if the price increases
- The economic optimum water distribution is the one that produces maximum benefits for the users of water
- However, water in certain uses (i.e. agricultural or environmental protection uses) can have value that exceeds its private value to water users. Theses social values must be respected

Environmental issues were handled in several ways. First, water extraction is restricted to annual renewable amounts; second, an effluent charge can be imposed on households and industry; finally, the use of recycled water in agriculture can be restricted.

The WAS model generates the water distribution for the rejoin that produces the optimal benefits to the model user. It computes the value of an additional quantity of water and the shadow value at a particular location. The distribution of water over the areas is such that the total benefits from water related activities are maximal. The model can be used wide and may also aid in setting water disputes (Jayyousi, 2001).

The model has been applied to the Israeli, Jordanian and Palestinian water systems under the Institute for Social and Economic Policy in the Middle East (ISEPME) project. Each of the three countries was subdivided into districts, which are treated as homogeneous units. Each district has access to specific data on water related activities.

The model assumes that water consumption is influenced by the price of water in the form of a constant price elasticity demand curve. The formula for the demand curve is (Amir, 1999):

$$Q= a P^b$$

where P is the price paid for the water, Q is the quantity of water consumed, a is a scale parameter and b is the demand price elasticity. The coefficients a and b may represent sectors or districts. Values of these coefficients were obtained from available data.

4. STUDY AREA EXISTING WATER SOURCES

The study area (The West Bank and Gaza Strip, Palestine) was divided into a number of districts according to the Palestinian administrative division. Within each district, water demand curves were defined for each household use, industrial use, and agricultural use. The annual renewable amount of water from each source was taken into account. The option of wastewater recycling was considered and the possibility of inter district conveyance was taken into account. This procedure was followed using actual data for the year 2007 from the Palestinian Water Authority (PWA) and projections for the future year 2020. Data on the Israeli side for the regional simulation runs of the WAS model were obtained from the Hydrologic Survey of Israel (HSI) reports. The table below (Table 1) summarizes the renewable shared water sources adapted for the simulations presented in this paper.

Table (1). Renewable Water Sources and Overall Water Consumption (mcm/year)

Water Resources	Annual Recharge	Israeli Consumption	Settlements' Consumption	Palestinian Consumption	Total Water Consumption
Mountain Western Basin	362	344	10	22	376
Mountain NE Basin	145	105	8	35	148
Mountain Eastern Basin	172	40	50	69	159
Coastal Aquifer	305	260	0	140	400
Jordan River	890 (available after the use by other riparians)	890	0	0	450

(Adapted from the water supply report of PWA and HSI report, 2007)

5. SIMULATION RUNS AND RESULTS

Alternative scenarios for the year 2020 were considered. For the year 2020 many parameters are uncertain outside the water sector. Perhaps the most important of these for our purpose is the projected population. This is especially true for the Palestinian population, a politically sensitive matter. Hence, we examine the effect of quite a large increase in Palestinian population. We begin, however by using the population projection provided by the Palestinian Center Bureau of Statistics (PCBS, 2007). Ten different simulation runs were performed. A certain parameter or a group of parameters was changed for the different simulation runs and the effect on the different output parameters was assessed. These different runs with their main output results are presented in Table 2.

Table 2. Description of the Performed Runs and their Main Outcomes

Run ID	Run Description	Main Outcome
1	Existing conditions where lack of cooperation and the deficiency in infrastructure and inequity in the allocation of water	The results signal a crisis situation all over the West Bank and Gaza Strip. The shadow values of water in some Palestinian districts are alarmingly high
2	Allow reallocation of additional water to Palestine but with no additional infrastructure	The gain in total surplus is $525 million per year with $420 million to Palestine and $105 million per year to Israel
3	Do not allow reallocation, no cooperation but with removal of fixed price policy	As compared to run 1, the Palestinian situation is improved by $22 million per year. The shadow value of water increase but only by a cent or two per cubic meter
4	Allow reallocation of additional water to Palestine, allow cooperation, remove fixed price policy but with no additional infrastructure (Similar to run 3 but with additional reallocation of water and cooperation)	The gain is much higher than in run 3 with $419 million per year with most of it going to Palestine. Based on this run, Palestinians take 68 mcm/year from the Jordan River and also receive a substantial amount from the mountain aquifer
5	Allow reallocation of additional water to Palestine, allow cooperation, add recycled wastewater infrastructure	The total surplus in Palestine is increased by $161 million over run 4 where no infrastructure is added. The run shows that additional development in infrastructure is a must especially in the northern part of the West Bank
6	Allow reallocation of additional water to Palestine, allow cooperation, additional conveyance lines are added	The total surplus in Palestine in increased by $ 155 Million over run 4 where no infrastructure is added. The run shows major international movements of water due to allowing cooperation
7	As run 6 but with additional increase in population by 1.75 million persons	Shadow values rise but no obvious crisis is observed due to additional population. Per capita domestic water consumption decreased from 74 to 63 cubic meter but still well above actual current levels

Run ID	Run Description	Main Outcome
8	As run 6 but with additional increase in population by 3.5 million persons	Like the previous run, shadow values rise but no obvious crisis is observed due to additional population. Per capita domestic water consumption decreased to 59 cubic meter but still well above actual current levels
9	As run 6 but with drought conditions by reducing all available natural resources by 30%	The total surplus is reduced by $87 million compared to run 6. The per capita domestic consumption falls to 67 cubic meter per year from 74 in run 6. Shadow values rise making desalination a likely option in Gaza Strip
10	As run 6 but with no additional reallocation and no cooperation	Total surplus, relative to run 6, declined by $242 million per year. These are the gains from reallocation and cooperation in the presence of substantial Palestinian infrastructure

6. CONCLUSIONS

Water as an economic commodity has at least two implications for the design of a lasting water arrangement that is to form part of a peaceful agreement among neighbors. The first of these has to do with negotiations over the ownership of water quantities. The second, and more important implication has to do with the form and the basis that a water agreement should take. Based on the reviewed literature, it is noted that for international law to be implemented between countries, there is a need for allocation models to provide answers to many questions regarding optimal use, weights and others especially models that can incorporate long term issues. The main conclusions obtained with the current version of the WAS model for the Palestinians can be summarized as follows:

1. Additional quantities of water should be allocated to the Palestinians from the renewable water resources in the area (the Mountain Aquifer System and the Jordan River System). Based on the above simulations, these quantities ranges from 250-300 mcm/year
2. Cooperation is a "win-win" policy that can be worth $100-$200 million dollars per year by 2020. Model results show that both parties would always gain from cooperation. The exact gains from cooperation naturally depend on the assumed allocation of ownership rights
3. Desalination on the Mediterranean coast will not be needed during normal years. With cooperation in water and the construction of infrastructure (recycling plants and conveyance systems, largely for the Palestinians), there will only be a need for additional sources of water in 2020 in years of considerable drought
4. The need for desalination will crucially depend on the status of cooperation in water. Without such cooperation and with the 2007 ownership allocations, the Palestinians will find desalination at Gaza an attractive option by 2020
5. The construction of recycling plants in the West Bank and particularly in Gaza will be highly beneficial regardless of water ownership or cooperation
6. Finally, the usefulness of using allocation models does not end at the international border and such modeling effort can also be used in the resolution of water disputes. That use is seen to reduce property rights in water to monetary values. Moreover, the availability of seawater desalination means that the monetary value of disputed water property rights will generally not be very large. If this is realized, negotiations over water should be facilitated

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Transboundary Aquifers: Challenges and New Directions
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Setting Stage of Cooperation Between Bangladesh and India for Transboundary Aquifers

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ABSTRACT

Keywords: Ganges, Brahmaputra, Maghna, Farakka, Bay of Bengal, arsenic, shared aquifer.

Bangladesh, a landmass of 147,500 sq. km is sandwiched inside the neighboring country of India. Three big river systems, all originating outside her boarder, dominate the human life, economy, environment and eco-system of Bangladesh.

(i) The Ganges river system having its origin in the foot of the Himalyas has a length of 2510 km, (2185 km in India and 325 km in Bangladesh). (ii) The Brahmaputra river system is 2840 km long with only 410 km in Bangladesh. (iii) The Meghna river system with a total length of 946 km, travels 669 km within Indian territory. These river-systems have altogether 1.72 million sq. km catchment area of which only about 8% is within Bangladesh. Apart from these 3 river-systems, another 51 rivers enter into Bangladesh from India. In the monsoon, all the rivers having origin in India force about 1250 billion cubic meter water annually over the territory of Bangladesh to drain into the Bay of Bengal. This amount of fresh water is mainly generated by monsoon precipitation (about 80% of the total amount) in four months from June to September of the year. On the other hand, Bangladesh faces acute shortage of surface water in the dry season from November to April period when rabi and staple food boro paddy (HYV) are produced with irrigation water. Previously, prior to 1975, Bangladesh had enough water in the rivers in the dry season too that was generated on melting of glacier in the Himalayas, and partly from groundwater at shallow depth released mostly in the Indian territory. But gone are those days! India commissioned a barrage on the Ganges at Farakka in 1975 and started diverting surface water towards Kolkata port in the dry season which otherwise would reach the lower riparian Bangladesh. In fact, such withdrawal of river water by India forced Bangladesh to engage in irrigation practice with groundwater sinking shallow tube wells. At the same time, about 95% population of the country could have access to groundwater as potable water through shallow tube wells. This has become a practice within India bordering Bangladesh. But a serious setback struck in the 1990s when scientists detected large scale contamination of groundwater with arsenic element.

This situation led to severe health problems in Bangladesh and also in regions of India bordering Bangladesh; and of late scientists reported that crops caught up arsenic contamination. Now Bangladesh and India are going for abstraction of groundwater from deep aquifer for irrigation and drinking. In the past for about last three decades, there was insignificant cooperation between India and Bangladesh on sharing of common rivers' water. For this reason sufferings of the Bangladesh citizens were more compared with Indians. Similar situation will develop for people of both the countries in the future in areas of shared aquifers.

This paper will highlight some aspects of conflict of interest, the possible impact of the conflicts, and possible means of cooperation between Bangladesh and India for negotiation and resolution of the shared aquifer.

1.0 INTRODUCTION

While debates about the management of trans-boundary river basins have been taking place for many years between upper and lower riparian countries, there are also internationally shared, or trans-boundary groundwater resources hidden below ground surface, in all parts of the world. Some trans-boundary aquifers contain huge fresh water resources, enough to provide safe and good quality drinking water for the needs of all humanity for many years. But these trans-boundary aquifer systems cannot be stated in the same way as that of the internationally shared river basins, The environmental issues that affect trans-boundary aquifers are wide ranging and can be viewed both from local and global perspectives. If the conventional definition of sustainable development, i.e. "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" can be applied to aquifers within a nation, then there is no reason why the same cannot be applied to trans-boundary aquifers.

Groundwater, though not visible as surface water, is ubiquitous in the global landmass and is contained in the pore spaces of rock formations (aquifers). Aquifer systems, due to their partial isolation from the surface impacts, on the whole, contain excellent quality water. In many countries these systems have been fully evaluated and extensively used to meet municipal and other demands. Such resources represent a substantial hidden global capital that still needs prudent management.

2.0 TRANSBOUNDARY AQUIFERS

However, the hidden nature of trans-boundary groundwater and lack of legal frameworks indulges to misunderstandings by many policy makers. Not surprisingly, therefore, trans-boundary aquifer management is still in its infancy, since its evaluation is difficult; suffering from a lack of institutional will and finance to collect the necessary information. Although there are fairly reliable estimates of the resources of rivers shared by two or more countries, no such estimates exist for trans-boundary aquifers.

The key features of trans-boundary aquifers include a natural subsurface path of groundwater flow, intersected by an international boundary, such that water transfers from one side of the boundary to the other. In many cases the aquifer might receive the majority of its recharge on one side, and the majority of its discharge would occur on the other side. The subsurface flow system at the international boundary itself can be defined to include regional, as well as the local movement of water.

Very few international geographical boundaries follow natural physical features, and water resources can cross them unhindered. For good management and fair share of these resources by riparian countries, scientists estimate the resources that cross these boundaries should warrant urgent attention. In hydro-geological terms, these crossing resources can only be estimated through good observations and measurements of selected hydraulic parameters, analogous to the estimation process of other trans-boundary resources; such as fisheries and wildlife, each requiring statistically sound observations.

Even where international boundaries may follow such features as rivers, the aquifers underlying them may not reflect the true transfer of groundwater flows from one side to the other. In any legal agreements to be drawn up for the equitable share of trans-boundary underground water resources, the initial stage must be the correct identification of flow and movement of water followed by its quantification. In reality, socio-economic pressures may have either already initiated withdrawal of water, or have such a priority that legal agreements cannot keep pace. Institutional weaknesses and political pressures may fail to address all the relevant issues potentially leading to severe environmental impacts and unsustainable development.

3.0 FACTORS AFFECTING AQUIFER BEHAVIOUR

Many factors may affect the behavior and the development potential of aquifers, which may include:

- hydraulic parameters;
- rainfall and recharge zones;
- confined and unconfined areas;
- natural discharge zones;
- present and planned groundwater development zones;
- water quality, potential risks of its deterioration; and
- vulnerability to polluting agents.

In trans-boundary aquifers, one or more of these factors may receive a different weighting on either side of a boundary. There are several examples of trans-boundary aquifers where recharge is received on one side while the natural discharges (and sometime better yields) take place across the border. Water abstraction from an aquifer transforms and re-organizes the groundwater flow in proportion to the piezometric adjustments induced.

This has a number of practical consequences, which are explained below.

Modification of the groundwater flow pattern

Groundwater flow passing an international boundary cannot be measured directly. It is estimated from parameters and calculated through mathematical models. Abstraction on one side of the border may alter the flow through the border.

- ✓ The underground outflow of the deep aquifer is a source of recharge for the coastal aquifer;
- ✓ Additional development from the deep aquifer may reduce the outflow to the coastal aquifer;
- ✓ Sitting and pattern of production from wells in trans-boundary aquifers can be planned to ensure equitable share of the resources.

Modification of the piezometric surface

Groundwater abstraction from wells results in modifications of piezometric heads in the form of a concentric cone of depression. Cones of depression may spread beyond international borders.

Deterioration of the water quality

Water quality deterioration may take place as a result of development of a well in an aquifer. Poorer quality water from the coastal area or inland saline water-bodies can be mobilized as a result of groundwater abstraction. The impacts could be transmitted from unilateral actions in one of the countries sharing the trans-boundary resources. Vulnerability of aquifer is higher when groundwater moves through formations where large interconnected fractures or cavities are present and encourage rapid flow.

Determining the sustainability of a trans-boundary aquifer with any degree of confidence can only be conducted in a resource planning context having detailed information and understanding. Ultimately, though, resource development policy involves tradeoffs. Most aquifer systems have ecosystems, landscape elements, or pre-existing water users that are dependent on current discharge or recharge patterns. Further development may require trading off these dependencies in favor of new plans or policies. If dependencies are not well understood or considered, management changes may have major unanticipated impacts.

4.0 CONFLICTS OF TRANSBOUNDARY AQUIFERS

Examples of ecosystems that depend partly or totally on groundwater are numerous. There is often no inherent conflict between preservation of these ecosystems and withdrawals from trans-boundary aquifers for socio-economic development. Since an aquifer system is essentially located below the ground, biodiversity issues generally relate to the regions where aquifers discharge through rivers, lakes or swamps. Such water bodies frequently have specific characteristics, related to the physical and hydro-chemical features of the aquifer that create special ecosystems.

The impact of climate change on trans-boundary aquifers of the world is yet to be fully evaluated in the same way as it has been done for agriculture and land use. In some regions, climate change will result in increasing recharge and in other regions reducing resources and increasing groundwater salinity. The consequences of either of these impacts on abstraction, maintenance of wetlands, and discharge to water bodies could be very serious, especially where well developed infrastructure has been established. Global sea level changes may impact marine saline intrusion – the hydraulic reference point change could mean that many aquifers may extend inland intrusions, thus affecting groundwater quality.

The earlier discussion about aquifers with and without contemporary recharge is relevant to climate change. The approaches that have been developed for managing non- recharging aquifers may need to be revised in the context of climate change. Conversely, aquifers currently being recharged, may suffer ‘surcharges’ due to increased recharge. This could have an impact on existing infrastructures, such as, a building with deep foundations. Swamps, wetlands and lakes that are supported by aquifer recharge may extend in area, possibly flooding surrounding infrastructures, such as roads and highways, etc. These impacts could be gradual and problems may not be noticeable until damages are physically detected.

5.0 ETHICAL PRINCIPLE OF TRANSBOUNDARY AQUIFER

An UNESCO Working Group on the ethics of freshwater use reported its activities in June 2000 (Llamas et al., 2000). A major output of the Working Group was a declaration of ethical principles for water management. Although this declaration concerns all waters, it can be made specific to trans-boundary ground waters as well. The key underlying statement is drawn from the universal Declaration of Human Rights and it states that “Every human being has the right to life sustaining resources, including water for drinking, food, industry and well- being.” Access to safe drinking water and sanitation, as well as water for economic development is essential for alleviating poverty and sustaining peace and stability.

In the application of these principles to trans-boundary aquifers, it is clear that water resources that pass through one country are to be utilized and developed ethically – that should not be knowingly abused such that human beings, be they in the country of the development or outside of it, may suffer. Ethical principles should be adopted when trans-boundary ground water resources are devoted to multiple uses, in the situation of natural and humanitarian disasters, such as drought, irrigation, and agriculture, industrial and municipal uses. The links between water and ecology need to be directly maintained.

6.0 BANGLADESH-INDIA TRANSBOUNDARY AQUIFER

Bangladesh is bordered by the Republic of India on three sides: the west, the north and the east (on her south is the Bay of Bengal). There exist some regional aquifer systems in both India and Bangladesh territory. Layers of these aquifer systems have the lateral extension crossing the border from either side and that also have evidence of trans-boundary flow. Such trans-boundary flow is more manifested in North-Western part of Bangladesh.

A brief description of Indo-Bangladesh trans-boundary aquifer systems is presented below.

- In Bangladesh, Major lithological units of the aquifer systems are unconsolidated 'Recent' to 'Sub-Recent' Piedmont Alluvial sediments deposited by rivers draining from the foothills of the Himalayas. Only south-eastern part of this region is occupied by older, somewhat compact, 'Barind' tract of Pleistocene age. Within the depth limits of water well drilling, the lithological change is always found lateral. Tectonic activity in the region may develop in such boundaries. The relict status of the western 'Teesta Fan' in Bangladesh bordering India, reflects tectonic uplift, and a southward tilting of the apical fan segment, which developed southward longitudinal hydrologic divide between Tangon and Karatoya rivers system in the country. In addition, multiple faulting and tilting of the blocks affect the control of movement and distribution of groundwater resources in this region. One of such smaller but prominent lineaments is quite interesting although it lacks any major tectonic significance. The river Punarbhaba in Bangladesh is a small south flowing stream that joins River Dhepa near Dinajpur (a district) town. It is conspicuous even on satellite images because of its straight reach and unusual bend near Kamar Digho, Birgonj that contrast with the pattern of other streams in the area and also with its upstream – downstream alignment as well as river bank sediments of both sides. This unusual river bend occurred due to faulting; and restricts southerly flows of groundwater along the fault-line traversing south (of village Barsha of Birganj Upazilla), where groundwater remains at or near the surface even during the dry season.

7.0 COOPERATION BETWEEN BANGLADESH AND INDIA

In Bangladesh, Groundwater elevation contours ranges from (+) 27 mPWD in the south to (+) 70 mPWD in the north. The general trend of groundwater flow is from north to south of the region. A regional flow is observed from central-southcentral region to west-southwest direction and groundwater flows away from the region towards Indian Territory (through Baliadangi and Haripur Upazila) from Bangladesh. The region's groundwater has also flow direction towards the inland major rivers from their vicinity. The average surface slope of the area is 0.45m/km from north to south; and from the groundwater elevation contour map it was seen that the gradient of groundwater level is steep in northern area, where the average value is 0.65m/km. In the southern part of the region, average gradient is 0.34m/km indicates comparatively slow movement of groundwater in the area. This is small area, where some investigations were carried out by the Institute of Water Modelling, a Trust Body under the Ministry of Water Resources of Bangladesh. From this very small study it is evident that withdrawal of ground water, or contamination or abuse of ground water from the aquifer, which is of course a shared one, will have a repercussion on the other side of the border. For ethical principle, and also for the mutual benefit of citizens of the both the countries, it is quite desirable that a mutual understanding and cooperation in respect of sharing the trans-boundary aquifer will be very much beneficial to both the countries.

Towards this end, development of a common monitoring and information management systems for facilitate cooperation in protecting regional aquifer and optimum utilization of groundwater resources in long-term integrated water resources management among these two sharing countries is a must. The output from such collaboration will come from the combined efforts of the key and non-key experts and the beneficiaries.

RECOMMENDATION:

The possible outputs of an initiative in respect of trans-boundary aquifer between Bangladesh and India may be achieved in the following manner:

- Review on the baseline situation based on the data available;
- Joint monitoring programmes designed and agreed by both the countries:
- Report on the joint monitoring be carried out in the selected locations;
- Assistance provided to the national water monitoring establishments of both countries where appropriate to help to address the key concerns;
- Common GIS database platform be established to facilitate information management and data exchange between the countries;
- Initially a draft Regional Aquifer Management Plan (RAMP), including tentative programme of measures, may be prepared for the selected pilot areas in each country;
- Proposals can be developed for the future international projects to help address priority IWRM problems in India and Bangladesh.

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Mitigation and Prevention of Conflicts on Border Aquifers between Colombia and Venezuela: Far from the Rhetoric, Closer to the Reality.

UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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ABSTRACT

Political and social conflicts about water resources in today's world should be eliminated. Realistically however, we can only reduce and/or deter such conflicts; it is imperative to do so. The majority of aquifers located in border areas between Colombia and Venezuela are not seriously considered as means towards eliminating or mitigating future conflicts about groundwater supply in both countries. It is necessary to have a better understanding of these aquifers if those governments would like to implement positive public policies protecting this precious natural resource. The absence of adequate knowledge concerning groundwater resources, and the lack of common public policies in those regions from both countries, are two problematic concerns. This situation can generate border conflicts in diverse areas such as science, economy, military, international policy, and social relations for Colombia and Venezuela.

The main objective is an evaluation in order to mitigate a conflict. It is based on personal field work on groundwater supply and geological exploration in different regions of Colombia, next to the border, where the groundwater usage has increased; also, academic knowledge and experience on public policy with emphasis in prevention and mitigation of disasters will be used to support the risk assessment. In addition, a literature review from official documentation will be included.

According to the levels of industry, agriculture and services in these regions, the use of groundwater supply was not a political priority in the past. Nevertheless, a rise in the coal industry has been steady for the last thirty years. The research paper will demonstrate that both governments have a political stake in studying and protecting their border's aquifers and compiling hydro-geological data. In addition, it is necessary to elaborate and share public policies for groundwater supply, implementing a special international agreement. For more efficiency, it is necessary to follow and control these policies on a deep emphasis on education through the creation of higher level educational institutions emphasizing groundwater themes. Finally, the paper provides recommendations such as the use of mitigation and prevention tools, strategies of management, and obviously, ways for stopping surface contamination.

Key words: Mitigation; Risk Assessment; Risk Management, Vulnerability; Political Conflict; Policy; Hydro-geology.

The interest of United Nations UN/ONU for groundwater supply, especially in the transboundary aquifers around the planet, has been conducting thought for the UNESCO for several years in the XXI century. The Internationally Shared Aquifer Resources Management (ISARM) Program is focused on trying to do very serious analysis about border aquifers in order to mitigate, to reduce, or to eliminate conflicts between nations and their governments (2000s). This institutional preoccupation pretend to create more motivation for scientists, technicians, lawyers, and other professionals related with sciences, environmental protection, engineering, mining, and more. In addition, some public, private and non-profit organizations around the world are interested in this topic working as part of some scientific investigations. The majority of aquifers located in border areas between Colombia and Venezuela are not seriously considered in order to eliminate or mitigate future conflicts about groundwater supply in both countries. It is necessary to have a better understanding of these aquifers if those governments would like to implement positive public policies protecting this precious natural resource. The absence of adequate knowledge concerning groundwater resources, and the lack of common public policies in those regions from both countries are two problematic concerns. This situation could be a generator of border conflicts in diverse areas such as science, economy, armed forces, international policy and social relations for Colombia and Venezuela. We must remember the history of the political conflict between Colombia and Venezuela regarding the ownership of the oil reservoirs in the Venezuela Golf. The research is based on personal field work on groundwater supply and geological exploration in different regions of Colombia, next to the border, such as Arauca, Casanare, Cesar, Guajira, and Santander, where the groundwater usage has been increasing. In addition, a literature review from official documentation in the two countries and some papers will be included

According to the low levels of development in industry, agriculture and services in these regions, the use of groundwater supply was not a political priority in the past. Nevertheless, an increment in the extraction of coal has been steady for the last thirty years. For example, the Guajira area in Colombia has the largest overland mine in the world. The coal extraction has been developing mining processes which can affect the groundwater conditions such as the water's quality level, its contamination, the lack of regulation of use and the drastic decrease in the water table and piezometric levels. At the North part of the border between Colombia and Venezuela, there are two Departments – Cesar and Guajira- in Colombia bordering the Zulia State in Venezuela. Both countries have had a conflict for territorial delimitation in the Guajira and Zulia sectors since the middle of the XX century, which is not finished yet. Since 1970s, the area has had recent mining extraction especially coal. In addition, the middle part of the border in the Catatumbo basin, both countries and the American States Organization ASO/OEA signed an agreement in order to protect hydrological resources. In contrast, the South-East border like Departments -Arauca and Vichada- in Colombia and Apure and Amazonas States in Venezuela have been extracting oil for more years without conflict but with a doubt regarding which nation is the owner. Moreover, these areas have no control over shared groundwater.

On the other hand, as a geologist with 25 years of experience in groundwater supply in Colombia, I knew about some conflicts for local and regional aquifers. I studied several aquifers in Colombia trying to show the community and authorities some benefits of groundwater supply. Another preoccupation is the general interest over the particular interest. Apparently, the border between Colombia and its neighborhoods is an 'intangible' where nothing happens. Colombia and Venezuela have been confronting much kind of conflicts since 1830 when "The Great Colombia" (*La Gran Colombia*) was dissolved. The conflict by groundwater transboundary aquifers does not still exist between governments but it is a potential hazard. However, due to a recent general interest in the last 30 years of the international organizations such as ASO/OEA in 1982, an agreement was signed with Colombia and Venezuela to protect hydrologic resources in a specific area; it is possible that it no works with effectiveness. Also UNESCO developed a program in 2000s, in order to learn more about hydro-geological information. In addition, it is important to analyze, compare and contrast some concepts from Scientists and Investigators in America and Europe about risk, conflict, mitigation, prevention, and more. Many mathematics formulas were created in trying to explain an uncertain situation, which will create a hostile atmosphere.

A territorial system simply raises the interactions that take place in a space. If you know the ordinance of a territory, you can prepare management plans seeking to reduce conflicts and obtain balances from one or more of the social, economic, environmental, political, emotional aspects in a neighborhood, community, region, nation or continent. If we do not know how the territory is organized, we will have many conflicts. My concept about problem is the difference between an actual situation and a situation hoped for. For instance, I need to know how the transboundary shared aquifers between Colombia and Venezuela are. The global interest of UN/ONU and ASO/OEA represents the benefit that improving quality of life can have on the scientific communities, governments, decision makers, academic activities, and populations in many countries. For example, to combat poverty was one mandate from a group of countries called G-6 (today G-8) in Helsinki 1974. One way to combat poverty is to explore and utilize groundwater for diverse uses. Especially, in shared transboundary aquifers, which provide the opportunity to create and develop in shared interactions. However, some shared transboundary aquifers, will create conflicts (Medina, 2008).

It is important to analyze the necessity of some simple public policies and cooperation between actors in a potential conflict in order to improve the quality of life of people in those two countries. In addition, it is a priority to analyze why governmental agencies cannot enforce the laws and regulations regarding groundwater. In Colombia, the National Water Plans is trying to push all regions towards privatization of this precious natural resource through the Departmental Water Plans. It is illogical to give the administration of shared aquifers to a private company ignoring the mutual spatial possessions of other nations. International agencies such as UN/ONU, ASO/OEA, UNESCO, FAO, Andean Community, Andean Parliament, among others, need to help Colombia and Venezuela in the imminent potential conflict over groundwater in share aquifers.

Is it necessary to visualize real interests in regional and locals governments for an industrial future?

Governments of Colombia and Venezuela has had some industrial interest in the areas of their common border such as Norte de Santander (Colombia) and Estado de Táchira (Venezuela) in the denominated Catatumbo basin, since second part of the XX century, more specifically since 1969 when the countries' Presidents talked about the possibility of protecting hydrographic basins. These regions had accrue enough human interaction, transportation, natural resources, local and regional markets, financial institutions, and business through the border. However, the possibility to increase the agricultural and livestock industry or other industrial productions in the immediate future is low by today. The main cause is the lack of dialogue between these governments during the last decade. It is certain that both the Presidents of Colombia and Venezuela and their Chancellors have congregations every year, but those reunions are more about etiquette than substance.

According to Medina (2008) in Maganda (2008), the surface and groundwater shared resources are "invisible" to the common people in South America. Water could become a potential source of conflict or, in contrast, improve cooperation and regional integration. This statement is not entirely accurate because since 1981, I found organizations with an advanced methodology in order to protect groundwater. For example, in the South West part of Colombia a region named Valle del Cauca region, the common people and politicians at that time had the same level of information that academics and scientists had. It is certain that people can use groundwater for regional development. Fortunately, at this region, the Corporación Autónoma Regional del Valle del Cauca (CVC), had control over all aquifers regarding levels and extensions. Its data include the hydro-geological and hydraulic conditions of the aquifers. In Colombia and Venezuela most people know that they drink water and soda from aquifers drilled in the multinational bottling industry. According to Medina de Pérez (2006 y 2008), a Plan for the Conservation and Comprehensive Utilization of Water Resources of Catatumbo River Basin, signed in 1982 by Colombia, Venezuela, and the General Secretary of the Organization of American States OAS/OEA, unfortunately so far, it has not been executed, so this requires greater commitment from the two countries. It means that both governments do not have interest in industrial development in the near future. Maybe the current employees do not know the agreement. The efficiency of employees has decreased since the last century in many countries. It is amazing that they only know where the computer is; it is a sad but recurring behavior. In addition, it is necessary to recognize groundwater sources and their conditions because both countries have received information using Public Policy of Government (each four years). Actually, the two governments are acting without Public Policy of the State (20 or more years). As a result, a deficiency in knowledge of their shared aquifers can cover up some expectative of them as social, industrial, economic, and political ties. On the other hand, at the border at the Guajira and Cesar Departments (Colombia) in front of Zulia State (Venezuela), we can find an incipient interest in industries around mining coal. There are potential industrial and human developments. However, there is not enough information about the Perijá ridge for more mineral extractions or about groundwater.

In addition, the most extensive area is Arauca and Vichada Departments (Col) in front of Apure State (Venezuela) which complements Vichada Departments (Col) in front of Amazonas State (Venezuela) along Arauca and Orinoco basins. Most scientists and experts argue that a good knowledge about groundwater and shared aquifers will help any region increasing its future industry. The Bloom's taxonomy helps us to understand the way how the cognitive processes act. Usually, areas with high density of population have more scientific information. Is it discrimination or non-preoccupation from governments that causes this lack of information? Governments need to acquire more geological, geomorphologic, topographic, geophysical, hydrological, geochemical, statistics and more scientific information. In addition, sociological information is needed in order to complete their cognitive pyramid. In the future, we will have the necessity to understand how the share transboundary aquifers are interacting, and how they should act for benefits in both countries. The analysis of positive or negative effects is urgent. Next, a potential evaluation of the amount goes to increase our satisfaction. Finally, the creation of a shared plan to manage each trasnboundary aquifers will be the main goal.

On the other hand, Colombia and Venezuela's citizens have racial diversity, plural ethnicity, and show multicultural presence inside both countries; As a result, the discrimination is profuse. Nevertheless, similar to the majority Western's continent, the individualism and the sanctity of private properties are important cultural values in Venezuela. In contrast, Colombia's government usually does not have the same lucidity over its property and sometimes gives away its territory (i. e. Panama territory, Coquivacoa or Venezuela Gulf), to others. Therefore, it is important to adjust to Mileti's theory, which stated an approach to hazards in order to get the governments attention. The two Presidents of those countries must work on important aspects such as adopting a global systems perspective as ISARM objective, accepting responsibility for hazards and disasters; anticipating ambiguity and change; rejecting short-term thinking; accounting for social forces, and finally, embrace sustainable development principles.

Are the protection laws and regulations of water usage adequate in the borders of Colombia and Venezuela?

No, they are not. The protection's rules of water there are not adequate for shared transboundary aquifers. Actually, in both countries we can find legislations for superficial water and groundwater. The rules for shared groundwater are not clearly expressed. Local, regional, and national regulations are current in both countries, but apparently, they are working separately.

The Political Constitution of 1991 in Colombia changed the concept of the subsoil's owner. Before it, the Constitution of 1886 expressed clearly that the State was the owner of all natural resources in the subsurface. Now, it is not expressed. For instance the vagueness provides to any citizen the "potential right" to be the owner. However, it is possible to sign a business agreement with the government. Some rules for groundwater use such as "Código de Recursos Naturales de Colombia" (1974) had not real application because this new Constitution changed and introduced innovative but unproductive public agencies. Some communities ignored them because of their self convenience. Some people believe that the groundwater sources are public. Some people agree that groundwater aquifers will be private without the problem of getting an official authorization or contract. For example, Tunja city is located on a syncline; it has extended flanks. During 1990 to 1993, I directed a program there. Immediately, the construction was ended, a private company from Spain got control of the urban aqueduct through an official wrong transaction because Colombia did not have a Water Law. In contrast, the Political Constitution of 1999 and the Law for Water of 2007 in Venezuela, are protecting groundwater as the governmental property and its sovereign.

Today, we can find several methodologies for social and economic disasters as well. All of them are rhetoric more than effective. We need efficiency; for example, mitigating economic disasters, through the use of Business Continuity Plan, which is used by less than 40% of the big companies (Hiles, 2004). It is known that some authors like Miletti (1999), Beck (1999 & 2006),and Paulus (2004) show us interesting concepts on "risks" based on sociological and psychological issues more than natural issues. They agree that "risk" has a literary definition in all dictionaries, but the scientific definition of this concept is uncertain. In the same manner, some psychologists, like Professor Norman Groner (oral communication at John Jay's class 2007) mentioned that during a negative event many people do not suffer shock.

On the other hand, following Mileti (1999), we can find the root of the problems in order to prepare plans of mitigation and prevention. I agree with Mileti in his theory regarding the three main influences: first, working on the border zone between Colombia and Venezuela, such as the Earth's physical continuous changes; also, changes in the demographic composition and distribution along the border; and finally the third influence is the built environment is growing density and making the potential losses. We need to adapt some of Mileti's mitigation tools such as land use, engineering and building codes, new technology, and emergency preparedness. Mileti's theory suggested that a sustainable approach to hazard mitigation will require extraordinary actions such as building local networks, competence and consensus, establishing a holistic framework, building bi-national databases, providing Comprehensive education and training, measuring progress, and sharing knowledge internationally.

Did the conflict about Venezuela Gulf productivity to lead the vulnerability of the Colombian or Venezuelan governments?

The conflict about Gulf of Coquivacoa or Venezuela has been unproductive for Colombia's government. In contrast, it has been positive for Venezuela's government and population. The conflict by Venezuela's Gulf never ended; however, Colombia moved out of its naval border patrol in 1987. Colombia has missed the opportunity to use the water and others sources inside the gulf for twenty-three years. Obviously, Colombia has been missing the opportunity to get natural resources from there. The conflict was approximately between 1957 and 1987 when the last event occurred, but the conflict is current and remains silent. Those governments based on intuition more than reasonable analysis used emotional, political, and cultural aspects in order to solve that social and economic crisis. However, Venezuela's government has been using benefits from the oil more than Colombia. Why? In Colombia has been using the concept of Irving Janis "Groupthink" as a Presidential management system for many years. The worst symptoms of groupthink are an illusion of invulnerability, collective construction of rationalizations that permit group members to ignore warnings or other forms of negative feedback, unquestioning belief in the morality of the in-group, strong negative, stereotyped views about the leaders of enemy groups, shared illusions of unanimity of opinion, and more (Shafritz & Russell E. W. p. 249). Finally, according to Allison and Zelikow (2001) who make decision models, there are changes of the models in the last twenty years. Both countries have had Governmental Political Models for two centuries. They have been showing autocratic tendencies. For the transboundary share aquifers those countries will use the Model for International make decisions. According to (Mameli at John Jay class in 2006) the Rational Actor Model has core concepts which are: a) Goals and Objectives (interest and values of the agent are translated into "payoff" or "utility" or "preference" function. b) Alternatives (decision tree). c) Consequences (to each alternative is attached a set of consequences), and d) Rational preference.

CONCLUSIONS AND RECOMMENDATIONS

It is important to mention that the Colombian government has not had a Water Law while Venezuelan government has had one since 2007. Venezuela's government has interest in protecting this natural resource while Colombia's government pretends to privatize water through a regional initiative denominated as the Departmental Plan of Waters. It is the most incredible and pessimistic decision from the Colombian government ignoring the existence of shared superficial and groundwater deposits in their borders. Colombian and Venezuelan governments did not follow their hydrological agreement about Catatumbo basin signed in 1982 with AOS/OEA as a third part. Also, both countries abandoned their issue on the gulf of the Coquivacoa or Venezuela. Sometimes, the Colombian government likes to give away its territory and sovereignty. For example, in the XX Century, it gave the Itsmo of Panama, Gulf of the Coquivacoa, and the Peruvian border, among others.

As recommendations, Presidents of Colombia and Venezuela must make decisions regarding shared transboundary aquifers based not on the individual beliefs or Individual Attitude theory. The general interest is more important than the particular interest. They will act based on collective beliefs, values, attitudes, behaviors, customs, traditions, rites, ceremonies, and more. The President of both countries must maintain a positive attitude in order to improve the quality of life in areas close to the border. The suggestion is that they need to act based on governmental processes using the Rational Actor Model. Also, both governments must plan activities for mitigation of a potential conflict for share transboundary aquifers, such as: a) promoting international interest integrating third or fourth parts on their agreements; b) promoting international cooperation writing active agreements; c) searching international grants from UN/ONU, ASO/OEA, Andean Parliament, and others; d) accepting International rules for shared transboundary aquifers over national norms, and e) Systematization of the information on the shared aquifers, complementing data for its internationalization. Management Strategies via a bi-national agency can help conflict resolution. Private organizations like in the oil industry can be evicted because both countries will be affected.

In addition, both governments must plan activities of mitigations and prevention, such as: a) elaborating hydro geological studies scale 1:50,000 and 1:25,000 close the border, b) Creating a University specialized basically in geology, hydrogeology, chemistry, statistics, diplomacy, international groundwater law, and environmental sciences, c) implementing public policies for management share aquifers, and d) creating a permanent Bi-national commissions with sources to deter conflicts regarding groundwater. The project will offer products from the Geographical Information System and some modern software, such as: Maps (i. e. Geology, Hydrogeology, Geotechnical, Hydrology of basins shared, and Disasters prevention.) In addition, some products such as a) Quantification of the groundwater resources b) Promotion of the groundwater use c) Strategies for management all groundwater sources d) Potential development, and e) an inventory in a Map of the current and potential conflict. The resources to mitigate the potential conflict are basically budget appropriations from different entities, such as direct appropriations of Congresses of each country and from OEA/ASO, ONU/UN, ISARM, and other countries clients of the university. It is necessary that both governments have one or more international agencies in order to work on goals as soon as possible in the relationship to share aquifers and their use.

In addition, it is necessary to consider Conflict Mitigation and Prevention compromises, such as not privatizing the underground resource; encouraging the parties to implement bi-national commitments; encouraging the community about the importance of groundwater resources through community education, school and university; organizing and implementing a University of Water in border areas; establishing branches in the Guajira Cesar/Zulia, Norte de Santander/Táchira and Arauca/Apure regions; increasing their development; allowing the oversight of international organizations on the progress of activities. This body would be overseer of all aspects of groundwater. This body would be in close contact with organizations like Potential Conflict to Co-operation Potential PCCP; International Shared Aquifer Resource Management Programme ISARM; International Hydrological Programme IHP; Andean Parliament, Energy and Mines Commission, creating a subcommittee where groundwater.

Finally, it is necessary to develop Public Policies, such as a) creating a bi-national institution of higher education through the both congresses in the two countries; this institution would focus on promoting, strengthening and address the links between the governmental institutions of the two countries that are governing the investigation of natural resources. Institutions like *Ingeominas* in Colombia and *Ingeomin* in Venezuela should control it. Other institutions that would be furthered national authorities are responsible for the environment, water, and other related activities in Colombia and Venezuela; b) developing public policy to protect groundwater resources. Each country should develop a public policy for the protection of underground drinking water reserves. A simple internal regulation of each country is not accepted in a medium of conflict. Public policy will allow you to obtain resources; c) establishing a joint monitoring system. The agency should be no military-type interests; the only serious concern political and economic aspects, for the welfare of underground water resources, so as for the welfare of the residents of border areas Colombia and Venezuela as well. It could be used as a model and could be to extend the functions of these bodies in other areas bordering the two countries with other countries, d) reviewing of Departmental Water Plan with tendency to privatization of transboundary share aquifers in Colombia. Also, e) implementing a regional water plans in Venezuela for transboundary share aquifers, and f) eliminating contamination of transboundary river basins, especially upper valleys.

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Transboundary Aquifers: Challenges and New Directions:
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Transboundary Groundwaters: Experiences of Conflict Management and Regional Cooperation in East Africa

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ABSTRACT

Tanzania shares its borders with eight countries namely; Kenya and Uganda to the north, the Democratic Republic of Congo (DRC), Rwanda and Burundi to the west and northwest respectively and Zambia, Malawi and Mozambique to the south. Transboundary groundwater commonly implies a body of groundwater intersected by a political border with the attendant potential threat of dispute over a shared resource. A preconceived concern is that a Transboundary groundwater resource that is not managed in a cooperative and holistic way by one state may be over-exploited to the detriment of another state. Transboundary groundwater as a discourse has become prominent in recent years, and is increasingly linked to Transboundary surface water resources. Transboundary water resource management seeks to avoid disputes that might arise from uncontrolled development of such resources. The approaches that promote prudent assessment and management of Transboundary surface waters also inform the management of Transboundary groundwater. Conflict is a form of competitive behaviour between people or groups. It occurs when two or more people compete over perceived or actual incompatible goals or limited resources. The general lack of technical cooperation, data sharing, training and research between the riparian states on hydrogeology hampers a mutual understanding of Transboundary groundwater resources. There are however initiatives in the Southern Africa Development Community (SADC) under the water mapping project. Similarly Tanzania is signatory to various Treaties and protocols that address water issues both surface and underground. Countries should cooperate on basis of sovereign equality, territorial integrity, and mutual benefits. This calls for bilateral and multilateral financial institutions to reinforce their long term support to countries and regional organisations in the development of groundwater for their national economic development, including providing the necessary funds for resource exploration, evaluation and sound data collection to fill in data gaps leading to knowledge based sound management practices. In the political arena, support by African Ministers' Council on Water (AMCOW), African Union (AU) and their constituent bodies are needed. This paper addresses potential conflicts and cooperation potential as well as conflict management strategies that will result in peaceful transformation.

Key words: Conflict Management, Knowledge Base, Transboundary groundwater, Regional Cooperation

1. INTRODUCTION

Tanzania is endowed with relatively abundant freshwater sources; rivers, springs, lakes, wetlands, and aquifers. Water has become of strategic importance to the economies of the SADC region, forming an input to various sectors, such as agriculture, industry, mining and power generation. In addition, water resources have the potential to be developed in such a way as to contribute to the achievement of food security and poverty eradication objectives. Transboundary problems often contain the seeds for both conflict and cooperation at the same time. Such problems can be perceived as threatening the well-being, security and even the sovereignty of a nation, stimulating hostile and conflict responses. Yet, they may be resolvable through cooperative interdependent action among the states that share the problem. Negotiation used early and preventatively can generate a consensus for integrative solutions. A preconceived concern is that a transboundary groundwater resource that is not managed in a cooperative and holistic way by one state may be over-exploited to the detriment of another state. Alternatively, pollutants might migrate across the border to contaminate a neighbour's aquifer (Puri 2001). Transboundary aquifer system is an aquifer or aquifer system, parts of which are situated in different States. Transboundary aquifers receive limited coverage in international law. Furthermore, the provisions are tailored for a surface water body and do not cover the specific hydro geological characteristics of aquifers (Figure 1).

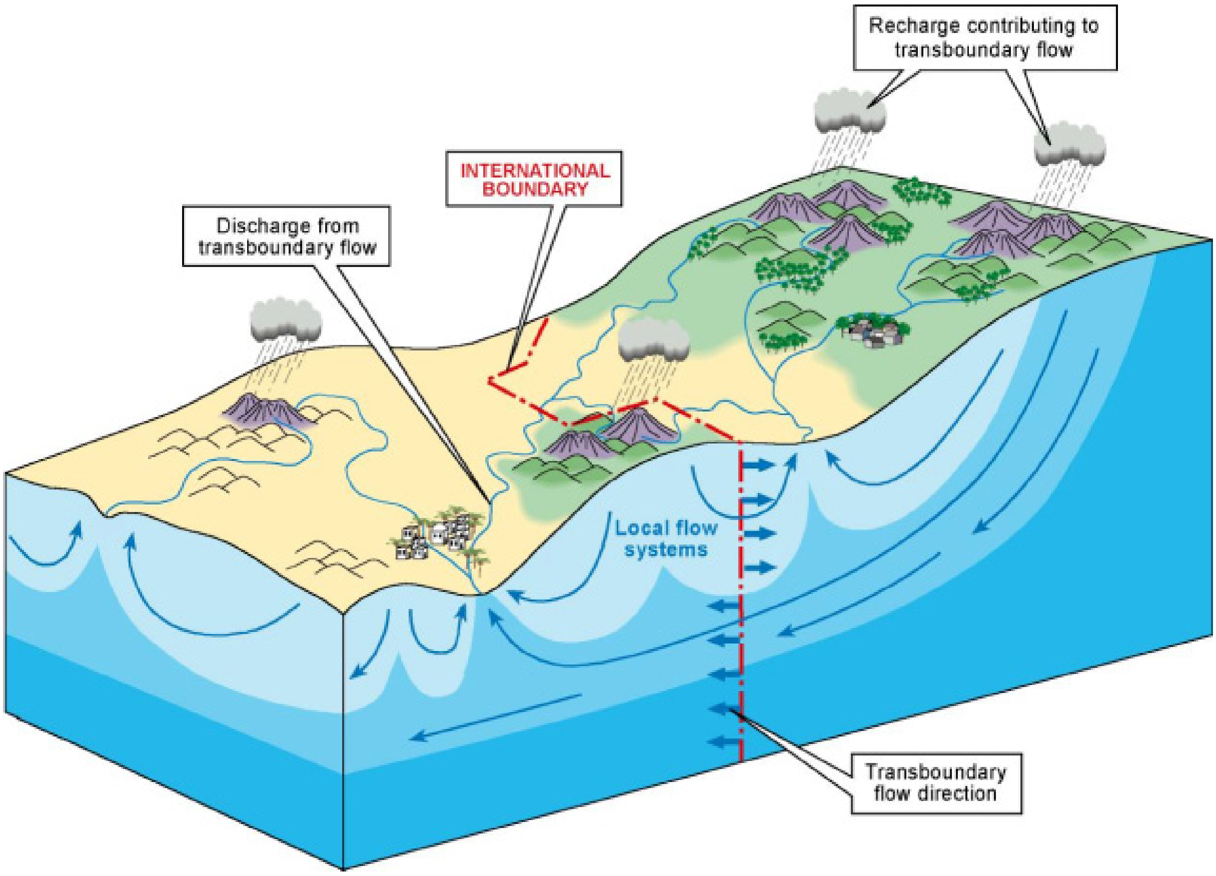

Figure1. 3-d illustration on of a Transboundary aquifer
PURI et al. 2001, modified, UNESCO ISARM Framework Document

2. TRANSBOUNDARY AQUIFERS IN EAST AFRICA

The geology of Tanzania comprise of, the Precambrian basement complex, Karoo supergroup, Post Karoo sedimentary formations and volcanic and alluvium deposits. Groundwater occurrence in basement complex rocks is largely limited to secondary features such as weathered zones, joints, fractures, faults etc. The transboundary aquifer type in the basement complex is metasediments aquifers that are dominant in west of Tanzania. This type of aquifer is crossing the border to Burundi, Rwanda and partially Northern DRC. Sandstones and conglomerates of Karoo are characterized by groundwater occurrence associated with primary porosity and inter granular flow, which may locally enhanced by secondary porosity created by fracturing. This type of aquifer crosses the border in the southern part of Tanzania to Mozambique. In the coastal sedimentary formations that attain a thickness of more than 200 m, has an aquifer lithology of limestone, sandstones, sand, marls, etc. This type of aquifer crosses to the north with Kenya and to the south with Mozambique. The greatest aquifer potential in Tanzania lies within the volcanic pyroclastic and volcano alluvium deposits found in the slopes of Mount Kilimanjaro. This type of aquifer extends as further as to the Kenyan territory. Last but not least the alluvial deposits that are confined in the deltas have also international significant. The country's boundary deltas of Kagera and Ruvuma that borders Tanzania with Uganda and Mozambique respectively can be included in the subject of Transboundary aquifers.

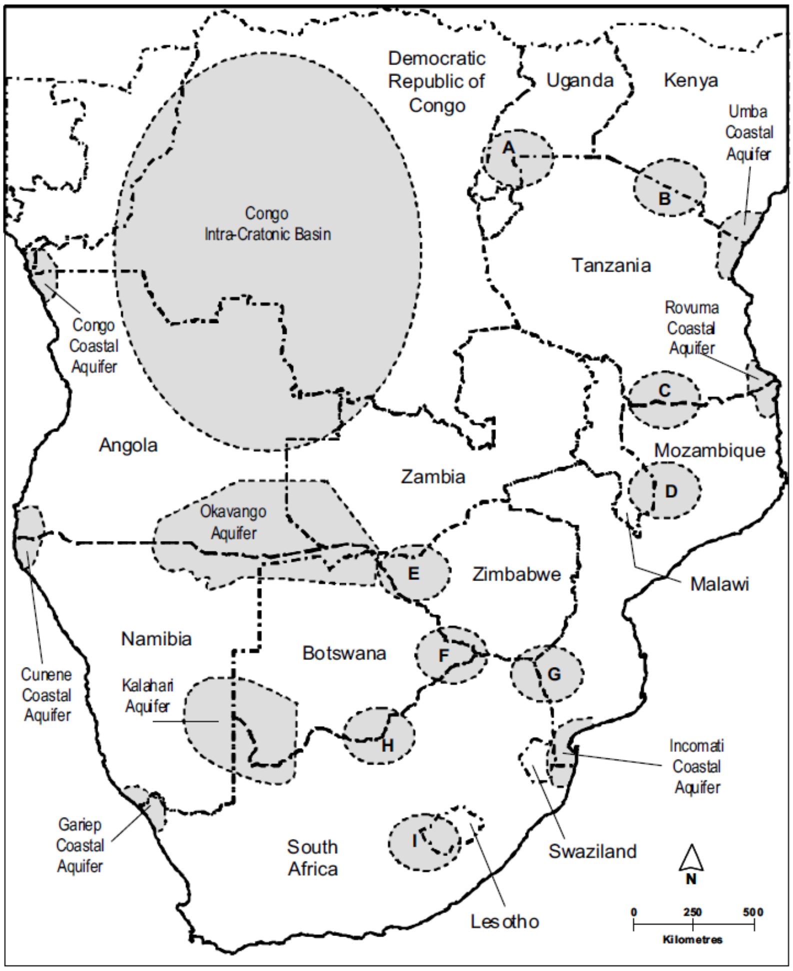

Figure 2: International (shared) aquifer systems: Map drawn from data in UNESCO-ISARM, 2004

Table 1.Transboundary aquifers in Eastern Africa as identified by ISARM

	Aquifer Name	Countries
A	Kagera Aquifer	Tanzania, Uganda
B	Kilimanjaro Aquifer	Tanzania, Kenya
C	Karoo Sandstone Basin	Mozambique, Tanzania
	Rift Aquifers	Kenya, Tanzania, Uganda
	Coastal Sedimentary Basin I	Kenya, Tanzania
	Coastal Sedimentary Basin II	Mozambique, Tanzania

2.1. TRANSBOUNDARY CONFLICT MANAGEMENT

Transboundary aquifer problems often contain the seeds for both conflict and cooperation at the same time. Such problems can be perceived as threatening the well-being, security and even the sovereignty of a nation, stimulating hostile and conflictual responses. Yet, they may be resolvable through cooperative interdependent action among the states that share the problem. Negotiation used early and preventatively can generate a consensus for integrative solutions.

2.2. TRANSBOUNDARY WATER COOPERATION

The main aim of transboundary water cooperation, apart from crisis and conflict prevention, is poverty reduction and resource protection. To reduce poverty, transboundary water cooperation is aimed at making more efficient and productive use of the shared water resources in a given basin. This also means designing water management in such a way that it is economically and socially sustainable, reducing the risks and costs of water use for the population, and improving the access of poor people to water resources with a view to resource protection, transboundary water cooperation is concerned with the sustainable protection of water resources and their surrounding ecosystems, including the protection of biodiversity and ecological integrity, as well as the viability of ecosystems. With regard to crisis and conflict prevention, transboundary water cooperation is aimed at reducing the structural causes of conflicts concerning distribution and use, preventing crises effectively and promoting mechanisms for peaceful conflict settlement. As a rule, however, water is only one of several crisis factors, with contrary territorial, economic and security policy interests frequently playing a central background role in disputes over water. Transboundary water cooperation also offers opportunities for further reaching collaboration amongst riparian states. In favourable settings, joint management of water resources can have beneficial impacts in the regional context beyond the confines of the river, lake or groundwater systems. It can encourage greater economic cooperation amongst the riparian states, a development which has already become evident in many transboundary watersheds There are examples of cooperation initiatives such as the Greater Pangani "Cross-border Dialogue" which aims to develop an integrated management plan and forum / dialogue for Lake Jipe, Lake Chala and Umba River, Facilitated by Coast Development Authority (Kenya) and Pangani Basin Water office (Tanzania) with support of InWent/GTZ. Also the East African Community Treaty provides for the establishment of cross-border natural resource management mechanisms under Protocol on Environment and Natural Resources Management. There are records of transboundary cooperation on water issues: Lake Victoria Basin Commission, Nile Basin Initiative, establishment of transboundary water use association for Mara River Basin.

3. CHALLENGES FACING TRANSBOUNDARY GROUND WATER MANAGEMENT

Shared water resources among countries require an effective governance framework at local, national and international levels, with sufficient implementation capacity required at all levels. The policy principle for water resources management for the East Africa region recognizes water as an instrument for peace, cooperation and Regional integration. Similarly, the UN resolution on Transboundary aquifers stipulates that Aquifer States shall utilize transboundary aquifers or aquifer systems according to the principle of equitable and reasonable utilization.

a) Limited Data availability: There is available data on surface water resources in the region; however there is limited information for groundwater resources. The government structures overseeing groundwater development face non compliance of groundwater guidelines and the submittal of hydro geological data from entities participating in its development, mapping and projects conducted are lost or no longer available within the government entity. Monitoring networks and data are limited as data collection is not consistent or continued once the initial development has occurred.

b) Lack of Human Resource: Trained technical experts in groundwater are not readily available in sufficient numbers in the entire region. There are few trained individuals at professional and technical level or remain severely under resourced.

c) Legal and Regulatory Limitations: Enactment of Laws in most member countries have been drawn up with regulation of surface water sources in mind, thus groundwater is generally not prominently featured in legislation.

d) Policy Harmonization: Policies between member states regarding groundwater are not always in agreement; thus there is a need for the harmonization of water strategies and policies between riparian states to facilitate the management of groundwater at a transboundary level for the sustainable economic development the Region.

e) Poor Prioritization of Shared Aquifers: There is little understanding of the transboundary nature of aquifers amongst managers and communities dependent on the aquifers. The international impact of groundwater abstraction/degradation has been in the past neglected against a focus on national water resources planning, because there was no evidence of potential competition across the border.

f) Institutional Limitations: The lines of Responsibility for management of water resources are often fragmented between different authorities and at different levels. In addition at the operational level there are large differences between government policies/regulations/practices and those that actually exist on the ground. This usually being the case as capacity and resources are not available at the local government level to conduct the obligations as mandated by the government.

4. CONCLUSION

Since 2002 the processes and achievements attained in region by SADC such as the SADC Protocol on Shared Water Courses, the SADC Water Policy, the SADC Water Strategy and the SADC Groundwater Management Programme currently ongoing provide a framework for Member States to manage water resources in a more holistic manner. Within this framework, individual Member States and River Basin Organizations' groundwater management performance continues to be hampered by the many challenges mentioned earlier slowing overall progress towards more sustainable use and management of groundwater resources. The challenges combined have major region-wide impacts which impede progress towards social and economic development and harmonization in SADC.

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Management of Transnational Groundwater Resources East of European Union – Challenges and Opportunities

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ABSTRACT

The climate changes affect the life of more and more numbers of people. This fact is clearly visible in water-related issues, where water is crucial medium for human life and living quality. Until recently, water management issues have been limited to a single area of the country. Now, statistics show that 60 million of EU citizens live at less than 25 km from the borders. That is why transnational cooperation is a key issue in the implementation process of Water Framework and Groundwater directives and to minimise the disparities in the status in national water management.

The paper present the main aspects concerning water management cooperation in the Bug river basin, comprising significant areas of Ukraine and Poland, which has been recognized by the international community as the area under the serious ecological stress. It is worth emphasizing that this river basin is also an eastern border of European Union.

The Science for Peace and Security NATO pilot study project "Sustainable Use and protection of Groundwater Resources - Transboundary Water Management - Belarus, Poland, Ukraine" and other scientific activities aimed at identifying and solving environmental problems in Bug river basin. The main principle of SPS NATO project is to prepare an expert platform for discussion about rational groundwater management and the efficient way of protection of transnational resources in Central and East Europe. The first steps to identify the main problems have been done, but there are many challenges to be undertaken. Among others there are the legal aspects of environmental activities cooperation in riparian countries to be solved, as well as preparing united methodology for research and measurement carried out in transnational area need assignment.

Developing of groundwater research and water management issues will be a great opportunity for the region to strengthen the environmental protection activities as well as understanding of those issues in local society. On the other hand solving transnational water related problems of eastern EU neighbours require understand and assistance of worldwide community to implement common standards there.

Key words: transboundary area, water management, Bug river basin, groundwater monitoring

1. INTRODUCTION

Groundwater resources play a tremendous role in Poland and increasing trend of its use by households is observed form 80s in last century. Groundwater resources will be of increasing significance for the domestic economy in the future because surface waters - the main water source used by humans over ages - become progressively more contaminated. Now in Poland 70% of water use is based on groundwater. Generally over the last 35 years the per capita quantity of globally available freshwater has decreased by about 30% and now amounts to 7,300 m^3/year.

Water is crucial medium for human life and living quality. Water has profound importance for biodiversity and protection of water resources and is a prerequisite for environmental sustainability. On the other hand it is highly relevant for regional economics as well.

The history of interest in water management issues on transboundary scale is a relatively new phenomenon, which kept growing during the last few decades. These issues include globalization, the development of civil society and an increasing competition among economy sectors for limited natural resources. In a transboundary context water management is much more complex and multifaceted than water management within a single country.

For a long time the knowledge of water resources protection has been wide spread, but the activities in that field were not complex enough because of lack of specific law instruments. Now when the Water Framework Directive (2000/60/EC) was introduce in 2000, water has been defined as a not commercial product like any other, but rather a heritage which must be protected, defended and treated as such. Complementary statements concerning groundwater protection against contamination as well as its status deterioration were established in the Groundwater Directive (2006/118/EC). Transnational cooperation is a key issue in the implementation process of those directives and to minimise the disparities in the status in national water management.

When Poland signed the accession treaty with the European Union in 2004, it was automatically obliged to comply with tasks specified in the existing European directives and now water management in Poland is based on European policy (Water Act). But Poland is also east border country of UE and divide Bug and San river basins between Ukraine and Belarus. Both neighbors use different definitions and terms applicable to the issues of water protection and management.

2. INTEGRATED GROUNDWATER MANAGEMENT IN BUG RIVER BASIN

The history of cooperation on border waters has a long track, but it was mainly focused on surface waters. The cooperation on groundwater had rather bottom-up form, non-institutionalized initiatives developed due to hydrogeologists' meetings. In 2006 the new Science for Peace and Security NATO Pilot Study project "Sustainable Use and protection of Groundwater Resources - Transboundary Water Management - Belarus, Poland, Ukraine" has been launch (Nałęcz, 2010).

Figure 1 Bug River Basin area

Integrated water management becomes a particularly complex challenge when two or more countries share a river and its drainage basin. The same situation we encounter on the territory of Bug river basin where three riparian countries Belarus, Poland and Ukraine manage water system (Fig. 1). The major challenge of the management of transboundary waters is that the waters must be manage in the contest of anarchy where is no single government to take control. There are different quality and quantity methods of research in every riparian country. Till now there have been some international projects aimed to cover that issue. Although most of the projects mainly emphasize the surface water management with little care of groundwater.

What distinguishes today's water management and makes the traditional, nationally focused solution less effective is the transnational and global character of many trends. That's why main principle of SPS NATO project is to prepare an expert platform for discussion about rational groundwater management and the efficient way of protection of transnational resources in Central and East Europe.

Project activities focused in the Bug river basin which is a border area between Belarus, Poland and Ukraine as well as eastern border of European Union. First of all it was very important to strengthen out the knowledge about water management systems in riparian countries. Very helpful in this case there were experience of other projects (Dobrovolski, at el., 2008; Zań, Goś, 2010) which have been done in that area. Gathering not only hydrogelogical experts, but introducing all participants of water management system will be a great advantage in accomplishing the objectives of the project. Presenting of different systems of water management and discussion enable understanding specific local problems and are the great goal for building up common transboundary water strategy.

The subsequent crucial element connected with transboundary issues is identification of the natural environment in the neighbouring countries. So a lot of activities were expended for presenting hydrogelogical and geological structures along the border as well as environment related issues.

The monitoring system is essential in a process of analyzing factors influencing water medium. The importance of building united transnational groundwater monitoring system was emphasised while project discussion. The coordinated measures should include other means aimed at achieving a good ecological status of waters and their reasonable management in order to protect groundwater resources and the environment.

Based on the measurements done by Polish-Ukrainian team comparison of probes taking methodology as well as chemical analyzes clearly indicate that considerable effort should be performed to establish united research systems (Nałęcz, 2010). There are two main levels which should be taken into consideration. Firstly field tests measurements equipment ought to be modified and united. On the other hand the chemical laboratories in riparian countries should be equipped into high-tech machines. Only this will allow to fulfil international standards of water measurements.

3. CHALLENGES AND OPPORTUNITIES

As far as environmental issues are taken into consideration natural processes do not stop at borders. Transnational water management is the great challenge not only for riparian courtiers, but also for European or even global community. There is strong demand for starting coordinated activates in eastern Europe in the scope of water management. According to the NATO project, among many others, the major challenges could be enumerated:

- Identification of differences among groundwater policies of EU and eastern neighbours countries;
- Development of research concerning groundwater transboundary flow;
- Creating the transnational area monitoring system base on united methodology;
- Providing united, high quality on-site measurement tools as well as chemical analyzes equipment for the national surveys responsible for groundwater measurements;
- Establish international body responsible for integrated water management system in Bug river basin (procedures, reports, measurements);
- Creating common, available for all interested parties the geoinformation system for archiving, managing and presenting transboundary environmental information for decision makers as well as for scientists.

Water occurring in areas separated by conventional administrative boundaries can also be a reason of conflicts with a very different medium. One of the objectives of joint management of water resources in the transnational areas, inter alia, is to prevent such problems through the implementation of common solutions. That is why cooperation between riparian countries which divide river basin allow to understand common problems and create reasonable solution for all interested parties. Starting projects dealing with water management one should remember taking into account not only surface water, but also groundwater. There is no doubt that joint research are a challenge on a scientific, social and economic level, but on the other hand, addressing such activities provide opportunities to cope with the negative impact of climate change occurring in the environment, disrupting the natural water cycle. Pursuing the idea of sustainable development locally within each country should be remembered also for the establishment of linkages across borders. The cooperation of scientists from various neighboring countries supported by external experts will on the basis of homogeneous data from water monitoring prepare homogeneous, regional studies showing trends in the environment.

Cooperation on transnational areas is not only limited to the countries participating of NATO project. Lessons learnt during the NATO project show a great need to expand for the whole area of East Europe and focus on developing Integrated Water Management System in that transnational area. That idea should cover the whole of Eastern Europe, with the support of international programs (NATO, UNIDO, Eastern Partnership). There are many challenges in the Bug river basin related to water management, but on the other hand working on them in international expert groups is the opportunities to find united solutions. Management of transnational water is challenge itself because of amount of different issues, which should be taken into account. When the whole water system is considered including rainwater and groundwater the task is even more complicated. The first step to be done in Bug river basin in the close future is to unify the water law issues. Of course, the methodology resulting from scientific papers is fundamental element contributing to the achievement of objectives. However, equally important are international legal agreements between countries of the region constituting the legal basis for expert groups cooperation. EU experience in the field of cooperation on transboundary waters (The International Water Commissions) using also the local knowledge of the partner countries should in future lead to present fit for purpose solution. The efforts should be directed to institutional capacity building for one international body for water management tasks supervision in that area by the use of Integrated Water Management System. Establishment of professional body as well as creation of the basement for the system is the next step for riparian countries to control their water issues.

The unification of water issues in Bug river basin will also help to identify and in the next steps to solve many environmental problems which affect not only to the water dependent ecosystem degradation. Among the most important issues the identification of environmental threats should be indicated. The knowledge of environmental hot-spots would supplemented by the integrated groundwater monitoring system. The permanent groundwater monitoring chemical components and a level of water table provided on the united methodology as well as exchange of information between riparian countries would allow to develop wider understanding of environmental processes which could influent human life standards.

4. CONCLUSION

The Bug river basin, comprising significant areas of Belarus, Ukraine and Poland, has been recognized by the international community as the area under the serious ecological stress. Working on transnational groundwater system could not be complete without taking into account the whole water circulation medium especially surface waters. It is a great challenge for scientist to work out the unified system of water issues monitoring as well as introducing the whole management structure and activities procedures. But on the other hand creating international projects and establishing a body for its management calls for enormous funds. That is one of the opportunities incorporate efforts to prepare basis for transnational scientific platform to solve regional water issues. The Bug river basin can be treated a test area and in future the project should evaluate into a regional one where more countries form the central and eastern Europe would be involved. Encouraging different groups of scientists from many European countries embroiled into close-subject issues to exchange their experience will also be one of the important benefit of undertook activities.

One should remember that Bug river basin is not only of tree riparian countries interest, but it is also an eastern border of European Union. That is why the scientific works on unification of water management system in that area should be fully supported by European society. Creation of united groundwater monitoring system in Bug river basin would be a test project to strengthen environmental initiatives in Eastern Partners countries. Today, when climate changes influence on our environment is well know, it is very important to solve transnational problems not only in areas of Europe, but also have a look at our neighbours. Unfortunately, due to the transition economies of Ukraine and Belarus, it is clear that these transboundary environmental problems requires assistance of worldwide community to implement common standards there.

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Towards a Regional Strategy for the Management of the Transboundary Aquifer Systems in the Americas

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ABSTRACT

The Internationally Shared Aquifer Resource Management (ISARM)-Americas initiative has been successful in promoting cooperation in the sharing of data and information on transboundary aquifer systems (TAS) amid 24 countries from Argentina to Canada. Over a period of seven years (2003-2009), the ISARM-Americas initiative, jointly sponsored and coordinated by United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Organization of American States (OAS), succeeded in inventorying 73 TAS in the American hemisphere. The initiative has produced two books; one containing the inventory of the 73 TAS in 2007, and a second one describing the legal and institutional aspects of the 73 TAS, in 2008. A third book is in preparation with a synthesis of the socio-economic, environmental and climatic aspects of the 73 TAS. The ISARM-Americas group is now preparing a regional strategy for the management of the transboundary aquifer systems in the American hemisphere. The regional strategy will be published as a fourth book in 2010 with a synthesis of the socio-economic, environmental and climatic aspects of the 73 TAS. This paper summarizes the current activities towards the preparation of the third book.

Key words: American collaboration, common goals, strategy, Transboundary aquifers, groundwater

1. INTRODUCTION AND OBJECTIVES

The ISARM-Americas initiative has been very successful in promoting cooperation in the sharing of data and information on TAS amid 24 countries from Argentina to Canada. Over a period of seven years (2003-2009), the ISARM-Americas initiative, jointly sponsored and coordinated by UNESCO and OAS, succeeded in inventorying 73 TAS in the American hemisphere (Figure 1). The initiative has produced two books; one containing the inventory of the 73 TAS in 2007 (UNESCO, 2007), and a second one describing the legal and institutional aspects of the 73 TAS in 2008 (UNESCO, 2008). The ISARM-Americas group is now preparing a regional strategy for the management of the TAS in the American hemisphere to be published in the book series in 2010. The Strategy of the American Transboundary Aquifer Systems (SATAS) will consider the provisions contained in the annexed draft articles of the UN resolution. SATAS will take full advantage of the data and information contained in the books published, as well as the successful network of national coordinators from the member National Government Organizations (NGOs) created by the UNESCO-OAS-ISARM–Americas initiative.

The SATAS will consider the various steps that need to be taken to achieve a shared and sustainable management of the transboundary aquifers of the Americas in cooperation with local NGOs. These will include a synopsis of the current management practices of the TAS; the basic scientific and technical knowledge needed for the adequate assessment and management of TAS; as well as the approaches to strategy implementation with practical operational actions. The SATAS promotes collaboration, good neighbourliness, and the adoption of common goals for a sustainable management of aquifers crossing two or more jurisdictions in the American hemisphere. The strategy is designed with strong scientifically-based content aimed at guiding the stakeholders toward informed joint-management decisions, joint resource evaluation, and to help meet the expectations of users of transboundary groundwater resources in terms of water security which is conjunctive use that sustains a reliable supply for all parties without impairing the quantity or quality of the water available to neighbours that overly the TAS.

The main principle adopted by SATAS is the full assessment, maintenance and protection of the groundwater resource to balance economic, environmental and human (social) requirements of the countries sharing the aquifer. The ***vision*** and the ***mission*** of ISARM Americas have been adopted by the National Coordinators of the 24 participating countries: VISION: *Improved sustainable management and protection of transboundary groundwater in the Americas;* and the MISSION: *To increase knowledge generation and exchange on transboundary groundwater and strengthen information sharing, communication and cooperation among countries in the Americas (ISARM, 2009).*

In support of the strategy's vision, ISARM-Americas will pursue five long-term objectives over 10 years. These objectives reflect the results of the working group meetings and the national coordinators workshops. These include the critical importance of knowledge and cooperation as the foundation of long-term groundwater sustainability of shared aquifers crossing two or more jurisdictions in the American hemisphere:

1. Transboundary groundwater resources (supply and use) are understood;
2. Transboundary groundwater management including groundwater availability and sustainability, aquifer vulnerability, and information sharing are ensured;
3. The science and technology knowledge base, information exchange, collaboration/cooperation and communication among Member States sharing transboundary aquifers help foster innovation and development of sustainable groundwater strategies with partners;
4. Common standard rules and protocols related to data, information, parameters and procedures on groundwater management, are developed and their adoption promoted amongst the Member States; and
5. The development and establishment of ad-hoc frameworks related to groundwater management; drawing on international instruments where appropriate are encouraged.

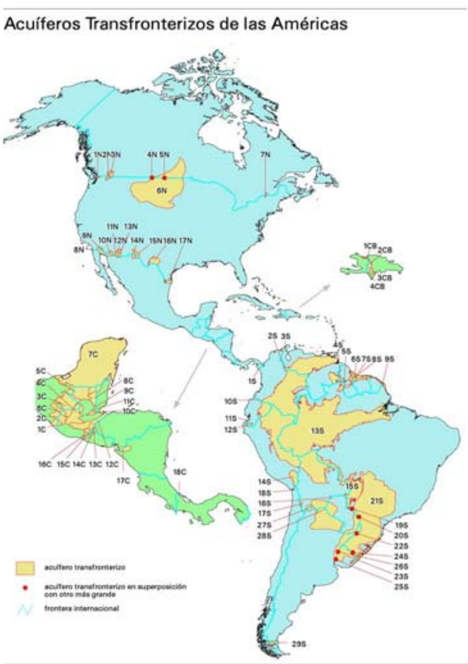


Figure 1: Transboundary Aquifer Systems (TAS) in the Americas (UNESCO, 2007).

2. CURRENT LEVELS OF KNOWLEDGE

A detailed analysis of the 73 TAS of the Americas revealed disparate levels of aquifer knowledge of the 24 countries investigated. The 73 aquifers were classified in four subjective categories with knowledge levels ranging from insufficient (25%), to basic (50%), good (75%) and sufficient (100%) (Figure 2). Results from Figure 2 show:

- Only one TAS contains sufficient data and information to be considered as having adequate knowledge for applying good management practices. The Guarani transboundary aquifer system, shared by Brazil, Argentina, Uruguay and Paraguay, represents a good example of active participation and strong collaboration amongst the four countries as a result of a large funded project by the Global Environment Facility (GEF) (Foster et al, 2006).
- The majority of the TAS investigated fall under the "basic" category, with 49 aquifers, of which various levels of data can be found in the countries sharing those aquifers. Five were found to fall within the "good" category. However, there are currently several ongoing international studies.
- Eighteen TAS have insufficient information, as there has been no a regional effort or study to develop a hydrologic budget, thus more collaboration and cooperation between the countries sharing the aquifers are needed.

- The overall results of this investigation are: the need for each country to continue the study of their respective TAS, and to continue developing collaboration with neighbouring countries in order to increase the knowledge, as well as the conjunctive use and management of their shared TAS.

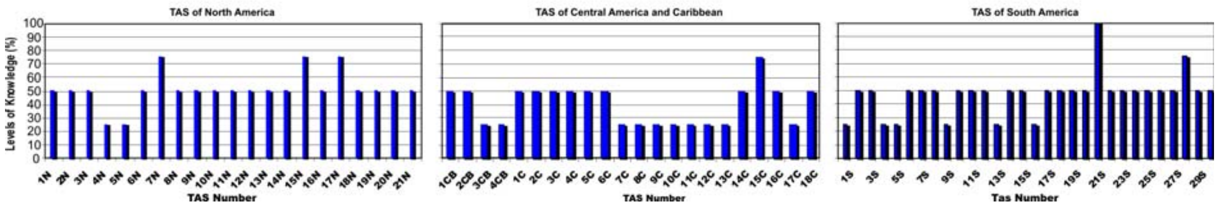


Figure 2: Levels of existing knowledge of the TAS in the Americas.

3. SYNOPSIS OF THE MANAGEMENT OF THE TAS-AMERICAS

The SATAS includes a summary of various aspects involved in the management of the TAS in the region. It presents a synopsis of the institutional, socioeconomic, cultural, and environmental and climatic aspects, as reported in book 2 of UNESCO ISARM-Americas (UNESCO, 2008).

An analysis of the legal and institutional frameworks to the TAS of the Americas was performed, including national legislations and international agreements on groundwater. The rules regarding ownership and jurisdiction on groundwater, groundwater institutional systems, rules regarding groundwater use and protection regulations, and transboundary aquifers were evaluated. Furthermore, regional agreements and treaties (if existing) were included. The results of this investigation show disparate levels of tools for the development and management of transboundary aquifers throughout the American hemisphere.

The review of socioeconomic and cultural issues highlights the potential benefits of shared development and management of transboundary aquifer systems to industrial, urban, and agricultural development, economic growth, poverty reduction, food security, better health conditions, improved environmental protection, and improved livelihoods in most of the 24 countries from the American hemisphere who participated in this survey.

Environmental and climatic aspects were also investigated. The potential effects of climate change on TAS in the Americas included: changing groundwater recharge patterns; increased demand for reliable domestic supply; localised depletion of the groundwater resource; and increased demand for groundwater for agriculture; as well as secondary effects such as impacts on groundwater quality. Furthermore, stresses on the benefits of environmental and climate aspects include: sustainable water abstraction; pollution control; better aquifer management; improved land management; and environmental protection.

The coordination workshops and the integration of data and information for the TAS-Americas occurred over seven years (2003-2009). During those years, a growing interest and capacity of the countries sharing aquifers to work and collaborate together under the UNESCO/OAS ISARM program was observed. As a result of this program, an increasing number of countries are adopting scientific advances in hydrogeology in an effort to develop frameworks for regulations in order to facilitate the development, use, and management of groundwater resources. In turn, this is reflected in the countries' will to face issues related to transboundary aquifers in a coherent and integrated manner.

Many of the challenges surrounding transboundary aquifer management are related to the lack of information. In most instances, data which are vital to good management are fragmented or not available. The lack of information affects the way in which politicians and the public perceive this valuable underground resource; it prevents and limits full comprehension of the importance of groundwater for food security and poverty alleviation in many countries. This is translated into fragmented policies and the absence of strategies for integrated management of groundwater as part of the entire hydrologic budget of transboundary watersheds.

4. BASIC SCIENTIFIC AND TECHNICAL KNOWLEDGE NEEDED FOR THE ADEQUATE ASSESSMENT AND MANAGEMENT OF TAS

This section includes two essential aspects reflecting the assessment and management of TAS in the Americas: one with a description of basic scientific and technical knowledge necessary for the assessment; and a second one with the management aspects. The collective goals for groundwater sustainability in the TAS-Americas are to provide principles and guidelines for the sustainable groundwater management of the TAS.

The main desired principle is to achieve sustainable groundwater development with the full assessment, maintenance and protection of the groundwater resource while balancing economic, environmental and human (social) requirements of the countries sharing the aquifer. This principle could ensure the accomplishments of the five following components:

1. The protection of groundwater quality from contamination;
2. The protection of groundwater supplies from depletion;
3. The protection of ecosystems health;
4. The application of good governance practices through close collaboration and monitoring; and
5. Conflicts resolution.

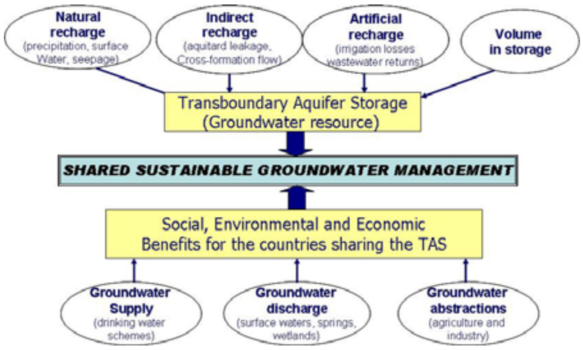
The ISARM-Americas strategy group is attempting to define the basic needs for scientific data to estimate groundwater availability through: the establishment of monitoring networks and databases; conceptual modelling of flow systems; general geology; groundwater levels; hydrography; and estimation of groundwater pumping and their spatial distribution. The benefits of using remote sensing technologies are also being described and recommended in the regional strategy for the TAS of the Americas. Furthermore, monitoring networks and databases for water quality, as well as potential conceptual modelling for quality are described. The application of consistent methods for assessment of aquifer vulnerability estimates, and the qualitative identification of sources of contamination will also be included in the strategy.

Transboundary aquifer assessment includes groundwater availability, aquifer vulnerability, and data needs analysis. As these components are interrelated, they represent a combination of interconnected networks of observations, modelling, and analysis. These components provide a basis for resource appraisal, development, management, and protection in the context of conjunctive use relative to a transboundary setting where multiple objectives and governance can be systematically evaluated in a holistic context. They provide feedback and information on the quantity and quality of groundwater resources, and the use and movement of water in the transboundary aquifer systems relative to the entire hydrologic cycle of the transboundary watershed. The estimation of the hydrologic budget and related analysis of sustainable yield are an integral part of the assessment process (Alley and Leake, 2004). In addition, the assessment of transboundary aquifers requires the assessment of the groundwater and surface-water components as one resource throughout the transboundary watershed.

To achieve the main principle described above, an overall framework was designed following the philosophy described by Hiscock et al (2002) and modified to fit SATAS, shown in Figure 3. In this framework the sustainable groundwater development at global and local levels is not the balancing of available aquifer storage to satisfy a single aim such as meeting water users' demands, but the development, maintenance, and protection of the groundwater resource to balance economic, environmental and human (social) requirements of the countries sharing the aquifer. This framework can be further utilized as a conceptual model to guide the development of a numerical hydrologic flow model of the transboundary aquifer that in turn, can provide a basis for a more systematic analysis of resource management.

Development of an aquifer management plan for each transboundary aquifer depends on specific technical, legal, social, economic and environmental issues, as well as respecting the sovereignty of the countries sharing the aquifer and related international agreements between these countries.

Figure 3: Diagram of elements of conceptual model of sustainable yield within a transboundary aquifer (ISARM, 2009; modified from Hiscock et al., 2002).



The management of aquifers requires activities to evaluate the various aspects that the responsible institutions must consider to support, assist and orient the corresponding management authorities in their decision-making process. Therefore, before a development strategy or management plan can be established, it is necessary to analyze the groundwater use, governmental institutions, socioeconomic and environmental status of the countries, as well as the available data.

5. APPROACHES TO STRATEGY IMPLEMENTATION

Strategy implementation should first take into account results of other successful groundwater management practices around the world, such as the Chalk aquifer in England (Robins et al, 1999). Management of the Chalk aquifer began in the early 1950's to protect the aquifer from urbanization and saline intrusion. Modeling in combination with monitoring and management has aided in sustaining the aquifer over the years.

The success of implementing the strategy outlined in this document depends on actions by and within the countries in which the transboundary aquifer crosses. It is necessary for the countries that contain the transboundary aquifer to cooperate and share information. For example, data compiled (water use, water quality, or water levels) or scientific studies must be made available for the success of aquifer development, management, and sustainability. It is unlikely that successful development and management of an aquifer can be accomplished without countries willing to cooperate and share available information.

Collection and processing of hydrogeological data, studies and implementation of works for management and protection of aquifers can result in large and sustained costs. Many developing countries have little capacity for public investment; therefore, it is important to establish consensus and compromise between two or more countries on the financing of transboundary aquifer studies and management. A path that has proved feasible to minimize these constraints is through the participation of multilateral development agencies and international donors such as the GEF or the Internationally Shared Aquifer Resources Management - ISARM and OAS. Combined with the technical and financial resources of local NGOs, these sources can help initiate long-term transboundary relations.

Simultaneously, cooperation, collaboration, communication, and social participation within a country are also necessary. Partnerships at different administration levels, such as national or federal, regional, and local levels need to be developed. The design for management may be at a federal level, but it often has to be implemented at a regional or local level for success. Reliable information communicated to the public related to the management (such as conservation measures) must occur if the public is going to participate in the effort at a local level. The success of implementing a strategy strongly depends on capacity building or human resource development. Educating the public on the importance of aquifer management for the future is pertinent for the overall success of transboundary aquifer and management. If people are able to develop a positive attitude towards change, they will likely work together to protect the aquifer.

6. DISCUSSION AND NEXT STEPS

Led and coordinated by UNESCO and OAS, the ISARM-Americas group has gone a long way in creating a network of partnerships with an inventory of 73 TAS in the American hemisphere; in sharing data and information with neighbors; and in cooperating in the preparation and publication of the various synthesis of knowledge of those TAS. However many challenges remain in the future implementation of the regional strategy for the management of those TAS, as described in this paper.

The challenges are those of combining the scientific and technical recommendations in the SATAS with the numerous legal and institutional instruments of the 24 countries as well as the UN's convention on TAS. The scope of SATAS was designed to establish linkages between science and policies and the existing instruments for the management of TAS. SATAS aims to explain and develop the role of science and the informed-decision approach for the collective understanding, developing, managing, and protecting of the TAS in the Americas. Thus its main message is "a strong scientifically-based strategy could be the backbone for good informed decisions."

The next steps are to complete the full strategy report and define the actions and approaches towards the implementation of the strategy. As such, SATAS will include relevant discussions on the importance of information sharing, communication; cooperation; collaboration; social participation; program (or study) development and related financing; as well as human resources development (capacity building). In defining these, the strategy will take advantage of the results of other successful groundwater management practices in the world (transboundary or not).

Countries participating in the ISARM-Americas initiatives recognize that a single global convention will be difficult to relate to the wide variations in transboundary groundwater conditions and problems encountered by people in countries of the American hemisphere. The key to groundwater management in TAS would lie in the local realities of hydrogeology and the socio-cultural patterns of water uses of the countries sharing the aquifers. However, with the actions taken by ISARM-Americas the group has taken a great leap forward to facilitate systematic development and management of TAS in the Americas.

Finally, it should be noted that international institutions such as UNESCO and OAS, play a very important role, one without which 24 countries could not have come together to agree to share and cooperate on transboundary aquifers. The SATAS country members hope that UNESCO and OAS will continue playing the leadership role they've played in the preparation, completion and implementation of the regional strategy for the management of TAS-Americas.

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The authors are grateful to the national coordinators of the 24 countries of the American hemisphere for sharing their data and information of their transboundary aquifer systems. Likewise, the authors acknowledge the kind support that UNESCO and the OAS provided in this multi-year, multi-national research Program of the "International Shared Aquifer Resource Management." This paper is an Earth Sciences Sector (NRCan) Contribution number 20100149.

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Comparing conflict in transboundary aquifer management: some insights from a comparative study between Spain and Australia
UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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ABSTRACT

The paper analyses and compares the main transboundary aquifer issues in Australia and Spain. It argues that increasingly ´transboundary´ has to be analysed also in the context of sub-sovereign politics. The aim is to analyse the current policies dealing with the potential and existing conflict in local, regional and inter-state aquifers in Australia and compare them to those in transboundary aquifer management in Spain, both in the case of international transboundary aquifers and inter-regional shared aquifers. This is pertinent because both Australia and Spain have large areas that are semi-arid where there is increasing attention and pressure on groundwater resources. Sharing of groundwater given the often competing uses requires particularly strong institutional frameworks. Upcoming issues, lessons and opportunities learnt from shared aquifers in Australia can be compared to transboundary aquifers such as the case of shared international aquifers along the Portuguese-Spanish border. In this case it is possible to compare policy and management challenges of transboundary international aquifers (Spain) to those within a single jurisdiction of a similar geographical scale and environment (Australia). The paper also provides specific examples on cases in Australia which have competing uses between agriculture, urban water supply, industry and environmental flows (surface water – groundwater interactions) such as the Gnangara Mound in Western Australia and look at how potential conflicts (and resolution and mediation) compare to similar cases on the Portuguese-Spanish border and inter-regional aquifers in Spain. Issues of scale related to policy measures will be explored in relation to these international and intra-national examples as well as how key lessons can be learnt from intra-national examples and applied to the international arena.

Key words: Scaling issues, semi-arid environment, policy, conflict, comparison

1. INTRODUCTION

This paper will analyse and compare the main transboundary aquifer issues in Australia and Spain, illustrating the key issues with reference to case studies. The paper argues that ´transboundary´ has to increasingly be analysed in the context of sub-sovereign politics. The aim is to analyse the current policies dealing with the existing and potential conflict in local and inter-state aquifers in Australia and compare common themes related to transboundary aquifer management in Spain. This is pertinent because both Australia and Spain have large areas that are semi-arid where recent climate variability and drought has lead to increasing attention and pressure on groundwater resources. Sharing of those resources - given the often competing uses - requires particularly strong institutional frameworks and good governance.

2. TRANSBOUNDARY AQUIFER MANAGEMENT IN AUSTRALIA

Australia has a semi-arid environment that has been exacerbated by 10 years of drought conditions in much of the country. In response to the rapid deterioration of water availability and environmental assets across the country the Council of Australian Governments (COAG)[1] initiated the National Water Commission to oversee the implementation of the National Water Initiative (NWI) in June 2004 - the key overarching directive in Australian water management. The ultimate objective of the NWI is to ensure the health of river and groundwater systems while increasing the productivity and efficiency of Australia’s water use. The key objectives include: transparent, statuary based water planning; statuary provision for environmental and other public benefit outcomes; complete return of all over-

[1] COAG is the peak intergovernmental forum in Australia, comprising the Prime Minister, State Premiers, Territory Chief Ministers and the President of the Australian Local Government Association (ALGA).

allocated or overused systems to environmentally-sustainable levels of extraction; progressive removal of barriers to trade in water such that an open water market is in place; and, recognition of connectivity between surface and groundwater resources such that connected systems are managed as a single resource.

The need to address groundwater management became paramount with the increased use of groundwater across the country partly due to the long-running drought decreasing surface water availability. Key issues around groundwater management across Australia include too many licences being issued (over-allocation) and, in some cases, too much groundwater being extracted (overuse) because of: licensed groundwater usage not being metered in many parts of Australia; provision of free or under-priced groundwater; and, failure of management plans to recognise the connectivity of groundwater and surface water.

Improved knowledge and understanding of groundwater-surface water connectivity, groundwater dependent ecosystems and the definition of sustainable extraction rates and regimes was identified as being critical to address the groundwater management issues.

The NWI was very much driven by the conditions in the Murray-Darling Basin (MDB). National legislature such as the *Water Act 2007* deal specifically with this. A key question however is how does the centralised policy direction in the NWI apply to all states and at all scales? This was highlighted by the resistance of Tasmania and Western Australia (non-MDB states) to sign the NWI for a couple of years after NWI acceptance by others. The relevance of it in Western Australia is being questioned in many regards. The development of a statutory water management plan for the Gnangara Mound in Western Australia will be of national significance, as it will test the application and workability of NWI approaches in a very significant urban groundwater source.

2.1. Murray Darling Basin Case Study: transboundary aquifer management at regional scale

The Murray-Darling Basin (MDB) is Australia's largest catchment – the nation's "food bowl" – covering five states and an area of 1,061,469 km² (twice that of Spain).

Figure 1 The Murray-Darling Basin covers five states and an area twice that of Spain.

Water resource management has revolved around surface water until recently for several reasons. There is currently a limit, called 'the Cap', on the amount of surface water that can be taken for consumptive use in the MDB. The existing Cap does not limit the use of groundwater. Surface water flows have declined significantly in the last 10 years because of over allocation and overuse of surface water in a drying climate. This scenario has resulted in a significantly increased interest in and use of groundwater as a resource (sometimes exclusively) however poor groundwater management has been evident.

Decentralized policy measures have resulted in significant conflict between the five states regarding their silo approach to management and policy. Widespread degradation of the MDB's natural resources was apparent in the 1980s. At the time, institutional arrangements for water resources management lay with the five state governments in the MDB, with no co-ordination between them. In response to this problem, the Murray-Darling Basin Commission (MBDC) was established in January 1988. However, there still was no centralised planning of water resource management and conflicting management practices between states continued. This has allowed situations to occur such that one farmer may have access to water whilst another across the road, but in a different state, does not. This has resulted in zero allocation to water entitlements in some years and severely degraded environmental assets including significant RAMSAR listed wetlands.

Despite the evidence of severe problems in the system the states had not been able to agree on a way forward. In 2007 the *Water Act 2007* was passed by the Australian Government. The most important aspect of this was the new Murray Darling Basin Agreement. The Agreement resulted in the formation of the Murray Darling Basin Authority (MDBA). The main difference between the MDBA and the MDBC is that the MDBA has statuary powers relating to compliance to a basin wide management plan (which the MDBA will develop). The five states surrendered their jurisdiction on water planning to the MDBA such that for the first time a single centralised agency will have statutory power for planning the integrated management of water resources of the MDB.

The MDBA is currently drafting the MDB Water Management Plan which will be a statutory basin plan based on Sustainable Diversion Limits that are defined through numerous past and current scientific studies including the CSIRO Sustainable Yields Report (CSIRO 2008). This action is supposed to relieve conflicting management practices and thus conflict regarding users of water upstream and downstream and ensure the sustainability of environmental assets. Whilst groundwater is already managed in many areas, the Basin Plan for the first time provides an opportunity to manage all groundwater proactively using consistent criteria and in conjunction with surface water, especially in areas where groundwater and surface water are highly connected.

2.2. Gnangara Mound Case Study: transboundary aquifer management at the local scale

Western Australia's Gnangara Mound is the largest freshwater urban groundwater resource in Australia with an area of approximately 2200 square kilometres. It is under stress from the current economic boom, rapid industrial and population growth in the city of Perth and climate change.

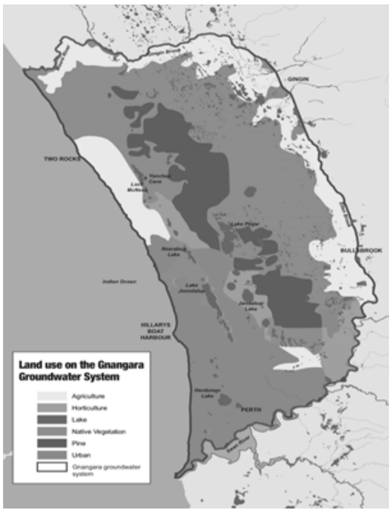


Figure 2 The Gnangara Mound land uses. (GSS 2010)

The system supplies approximately 60% of the water requirements for Perth metropolitan area (1.5 million people). Large volumes of water are also used for agriculture, forestry and market gardens. It is also an important source for maintaining wetlands and native vegetation.

Water levels are declining across most of the system such that the sustainability of supplies is threatened and conflicting water users are becoming more evident. Since the mid-1990s the rate of decline has increased due to: reduced recharge to groundwater resulting from the significant reduction in the average annual rainfall since the mid-1970s (which is likely to continue) and interception by extensive land use changes; and, abstraction of groundwater for public water supply and private use more than doubling over the last 20 years.

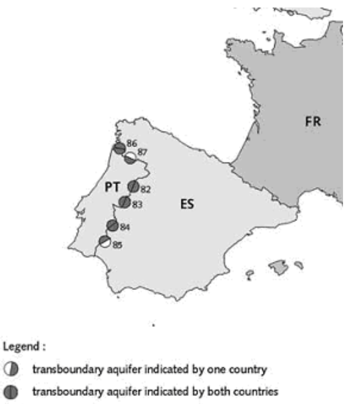
The Gnangara Sustainability Strategy (GSS) was initiated in 2007 to address issues relating to the impacts on groundwater levels. Results of the strategy will inform the development of a Statutory Water Management Plan for the Gnangara groundwater areas – which is consistent with the NWI. The Draft GSS was completed in late 2009 and released for public comment. Key recommendations include: reduce current abstraction by 20% for public water supply and private bore use; increase recharge through land use changes and artificial injection of recycled waste water (both low and high quality); take an adaptive management approach informed by monitoring; and, ensure land and water management actions are embedded in relevant statuary instruments.

The recommendations have been developed such that the system can continue to contribute to the sustainable socioeconomic development of the Perth region whilst also restricting the loss of environmental assets – again, also consistent with the NWI. However, even with the recommended management changes the area is still expected to lose some ecosystem functions (wetlands) and have declining groundwater storage in some areas. The climate will continue to be a major factor in management actions so the need to take an adaptive management approach is paramount.

The development of a statutory water management plan for the Gnangara Mound will be of national significance, as it will test the application and workability of NWI approaches in a very significant urban groundwater source. On this local level it is possible to derive a statutory management plan and enforce it with rigour – even if it is driven partially by a broader initiative (NWI). Conflict with management recommendations can be managed at a local level by considering and enforcing alternative solutions for both land use changes and reduced water abstractions from within the local area. This is not necessarily the case for larger, multi-regional systems (such as the MDB) where land use planning is influenced mainly by local demands whilst policy is centralised

3. TRANSBOUNDARY AQUIFER MANAGEMENT IN SPAIN

Spain and Portugal share a number of large river basins, which occupy almost 50% of the Iberian Peninsula, namely the Douro, Miño-Sil, Tagus and Guadiana (46%)[2](Octavio de Toledo, 2008). In the case of aquifers, the area where these river basins are located, in terms of groundwater, these resources mainly present local and shallow aquifers, as can be seen in the WHYMAP on transboundary aquifer systems [3]. In the recent UNECE 2009 assessment of transboundary groundwater, only 5 small shared aquifers were identified between Portugal and Spain[4].



Code	Name	Countries	Km^2
EU82	Nave de Haver / Ciudad Rodrigo-Salamanca (U. H.02-19)	Portugal, Spain	2 072
EU83	Toulóes / Moraleja (U. H.03-13)	Portugal, Spain	305
EU84	Mioplioquatenario de Elvas-C ampo Maior / Vegas Bajas (U. H.04-09)	Portugal, Spain	531
EU85	Mourão-Fic alho	Portugal, Spain	2 >170
EU86	Alluvões do Minho / Aluvial del Bajo Miño (U.H. 01.26)	Portugal, Spain	1 57
EU87	Veiga de Vilarelho da Raia	Portugal, Spain	
026 (CHE)	Larra	Spain,France	

Figure 3: Main transboundary aquifers between Spain and Portugal (UNECE, 1999) with descriptions (UNECE 2009)

The institutional arrangements have a relatively long modern history of international agreements between Spain and Portugal on water, over more than 100 years in relation to transboundary basins. A number of periods can be identified. The first period which is marked until the first third of the 20th century was centred on the delimitation of border and international boundaries. A second period followed focused on developing agreements for the different sectorial water uses, mainly those related to hydroelectricity. A third period can then be identified which was partly triggered by a drought experienced in the early 1990s which had impacts on river flows and which forced changes to the status quo, and culminated after a series of meetings in the 1998 Albufeira agreement. A final period is currently underway marked by overlying the existing international convention under the aegis of the Albufeira agreement with the planning process of the EU Water Framework Directive (WFD).

The result of the Albufeira agreement was the creation of, firstly, a high level political group (made up by Ministers from both countries), and secondly, the Commission for the Development and Application of the Agreement (CADC). CADC has a technical and coordinating role which encompasses a number of Working Groups focused on the main aspects of the Albufeira agreement:

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[2] The EU average is around 60% of a territory lies within a transboundary basins.

[3] http://www.whymap.org/nn_1055978/whymap/EN/Downloads/Global__maps/spec__ed__2__map__pdf,templateId=raw,property=publicationFile.pdf/spec_ed_2_map_pdf.pdf

[4] To this, one has to add a small aquifer shared with France and identified in the 2001 National Hydrological Plan.

WFD and water quality; flow discharge regime, droughts and emergency situations; exchange of information and public participation; and, infrastructure safety and floods (Estrela 2008). After 2008 a new operating structure was instituted with a Permanent Technical Secretariat made up of civil servants from both countries and rotating every two years between Madrid and Lisbon.

The main development since then has been the overarching context provided by the WFD which has provided a catalyst for a deeper level of coordination. The WFD establishes under Art 3[5] that each state will adopt the relevant administrative procedures for a program of measures such that the WFD objectives are met and are coordinated for the whole international basin, although these can be based on the existing structures from international agreements. As result the program of measures will be coordinated by the existing structure under the Albufeira agreement and in Spain through the relevant Water Basin Authorities in the preparation of their River Basin Plans.

Before the WFD, the River Basin Plans approved mainly in 1998 and 1999 were prepared independently by each country on the basis of national legislation, without a common framework, and with limited knowledge on the methodologies used by the reciprocal state. As a result of the WFD however plans will be prepared for each part of the international basin based on the exchange of information, knowledge, coordination of methodologies, and work programs which has now been strengthened as result of the common planning framework and guidelines provided under the WFD. Shared international transboundary aquifers will have to be characterized with similar procedures. However, it appears that the existing Albufeira agreement and the UNECE inventory provided a solid precursor to the current WFD process as the institutional arrangements, in the case of groundwater, currently operate under the CADC.

The main source of potential conflict in Spain is actually at the inter-regional level. A requisite under the 1985 Spanish water law and water planning was the identification of shared aquifers between different Spanish Water Basin Authorities. The 2001 National Hydrological Plan identified 51 shared hydro-geological units. For 16 hydro-geological units, a specific allocation of resources between basins was proposed under the National Hydrological Plan. This indicates that Spanish water planners were aware of existing (in some cases longstanding) potential conflicts at the local level in transboundary groundwater between neighbouring river basins. Addressing the problem of aquifer overdraft in a federal country relies on cooperation and success at inter-state level. The Jucar basin at present is halting the presentation of all River Basin Plans to Brussels – which is required to be compliant with the WFD calendar (draft plans were due 2009) – because water in Spain has become highly politicised and intensive groundwater use is very much at the epicentre of many of the key allocation decisions in these areas. Due to the combined difficulty to regulate groundwater use and the high (inherent) economic productivity of groundwater, aquifer drawdown has generated inertia to demand additional water resources in the form of inter-basin (surface water) transfers like those embodied in the derailed 2001 National Hydrological Plan (Llamas et al, 2008).

At face value it appears that there is little or no conflict on international shared aquifers between Spain and Portugal. This is for two main reasons; first, a physical resource reason, the aquifers in question are small and have little current use and little potential to be developed, and second, there is already a strong institutional and organizational structure layered under international convention (Albufeira agreement) and supranational EU law should issues arise. However, a much more substantial issue is related to intensive groundwater use, affecting e.g. the Jucar and Guadiana baseflow as a classic upstream/downstream problem, which in the case of groundwater as described in this section introduces new parameters that add complexity to potential policy design and measures.

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5 Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for European Community action in the field of water policy), a "River Basin District" means the area of land and sea, made up of one or more neighboring river basins together with their associated groundwater and coastal waters, which is identified under Article 3(1) as the main unit for management of river basins (UNECE 2009)

4. COMPARATIVE ANALYSIS OF TRANSBOUNDARY AQUIFERS IN SEMI-ARID ENVIRONMENTS (POLICY LEARNING ACROSS DIFFERENT POLICY DOMAINS)

This paper has aimed to shed additional light on how in some cases transboundary aquifers (in the sense of aquifers shared by sovereign states) do not necessarily generate conflict compared with transboundary regional aquifers at the intra-state level, which present challenges for domestic river basin agency coordination. In policy terms both Europe and Australia are similar in having over-arching directives, the NWI in Australia and the WFD in Europe. The paper therefore indicates a certain convergence to developing overarching frameworks which increasingly account for groundwater and gradually are able to institutionalise coordination efforts. The NWI and WFD are comparable as regards to compliance and implementation take-up (i.e. real commitment from states/countries and regions within them) in regards to the strong regulatory requirement to follow though on the objectives.

Historically there has been more focus on surface water policy. Political influence may partly be at play here as, broadly speaking, surface water is a more 'visible' resource. However in both Australia and Spain users have turned to groundwater because of the pressure on surface water resources in a drying climate. Groundwater resources, which have been much less regulated, are in many cases as equally stressed as surface water resources. Consequently users have to accept that new policy measures will not just be about reallocation but also about reducing consumption e.g. Gnangara Mound (Australia) is now contemplating a 20% abstraction reduction. In fact both countries now use new definitions for establishing water allocation limits as part of the overarching policy agenda which in effect mean a reduction in the net consumptive pool.

The Australian case highlights that land use planning and water allocation policy need to be highly cognisant of one another. Importantly the case studies have shown that at the smaller sub-sovereign level (local regional level) it is much easier to make these linkages through policy measures whereas at the inter-regional level (intrastate/ international) it may be more difficult. This is because although there may be water allocation agreements in place it is much harder to influence land use changes at this larger scale – as they are driven by local demands. The conflict at the inter-regional level is then manifested as a required land use change driven by water allocation policy in the instance when no compensatory system is in place (which can be put in place at the sub-sovereign level). This has also been identified as an issue for the inter-regional aquifers in Spain.

The Spanish case highlights that the real source of potential conflict is between regions regarding shared aquifers. The case of transboundary aquifers with Portugal is not a source of conflict for a number of reasons. Firstly, physical, as these are small aquifers and are not really in use nor do they have a high potential future use. Secondly, and most importantly, there is a long history of institutional arrangements between Spain and Portugal in numerous domains (not just water) which have evolved over a sustained period and, consequently, have an established a framework for negotiations on transboundary aquifers. As such, conflict can be avoided through the use of these tried and tested diplomatic negotiation frameworks. These have now matured to such a level through the requirements of the WFD that joint water planning may occur for the transboundary aquifers in a relatively fluid manner.

In both Spain and Australia – at all regional levels – the role of knowledge sharing between all parties involved in creating water policy decisions is critical. Knowledge sharing enhances transparency in decision making processes and consequently enhances the development of trust – critical in preventing conflict. This has been identified by both the NWI and WFD as paramount. Importantly this is also a key lesson derived from international law and good governance.

5. CONCLUSIONS AND FUTURE WORK

Through a comparative analysis of groundwater policy in two semi-arid countries this paper has highlighted that sharing groundwater has to be based on particularly strong institutional frameworks. The main result has been is to emphasise that in some cases international transboundary aquifers might not actually pose a problem (as is the case of transboundary aquifers between Spain and Portugal), compared to the upcoming issues and learning opportunities of shared aquifers in sovereign or sub-sovereign systems. As a result this paper emphasises not only issues of scale but also of sovereignty and demonstrates that the principles of international law and good governance can contribute to the sustainable management of transboundary groundwater resources.

Further consideration must be given to the so called 'two level political game' (Putnam 1988) when considering international negotiations which tend not to give enough attention to local, regional or national political scenarios (including elections). More and more water is becoming a key political issue. Decisions about water management are correspondingly becoming more political and increasingly, key decisions are permanently frozen or delayed due to the high potential political cost for elected decision makers. Any negotiations at the inter-regional or international level need to consider existing local, regional or national political scenarios and the consequences that these may present for any negotiation process.

The paper has highlighted that potential conflicts (and resolution and mediation) in the case of transboundary aquifers are diverse and identifies the need to develop a typology of potential conflicts and the most suitable policy measures and scales to address them. This will need to incorporate transboundary aquifers not only at the international level, but also shared aquifer at the sub-national or sub-sovereign level. This could prove rewarding in terms of experience and policy innovation that could be transferred to the international arena.

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Addressing socio-economic and institutional dimensions in Transboundary aquifer management by using hydro-economic modeling and serious gaming

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ABSTRACT

Transboundary aquifer management is subject to increasing pressures, complexity, uncertainty and connectedness at higher scales. A recent study reveals that transboundary aquifer management is based on the traditional engineering approach with a strong focus on hydrogeological aspects. Increasingly, this approach is criticized and adaptive management is recommended as an alternative that addresses socio-economic and institutional dimensions more explicitly. This paper addresses how hydro-economic modelling and serious gaming may support these dimensions of the process of transboundary aquifer management. Hydro-economic modelling may identify the consequences of groundwater extraction for other international stakeholders and the costs and benefits of (non-)cooperation. Serious gaming may be used to raise awareness, to analyze socio-economic conditions and institutional settings, to build trust between stakeholders and to facilitate discussions and negotiations over sharing transboundary aquifer resources.

Key words: transboundary aquifer management**,** hydro-economic modelling, serious gaming

1. TRANSBOUNDARY AQUIFER MANAGEMENT CHALLENGES

Management of transboundary aquifers (in addition to 'regular' management of domestic, non-shared water resources) is subject to increasing pressures, complexity, uncertainty and connectedness at higher scales. Increased pressures arise from growing water demand in order to meet the food security of an increasing population. Increased complexity results from changes in thinking about water management: from a more centralized top-down and engineering approach to a more participatory water governance type, including many scales and stakeholders simultaneously. Additionally, increasing complexity is caused by acknowledging the regulating, supporting and cultural ecosystem services of groundwater beyond its traditional use value. Climate and global change is causing a high level of uncertainty on the future water availability and on future water demand. Globalization stretches the interconnectedness from local and regional scales to even global scales. Hoff (2009) describes global tele-connections between water systems: rapid irrigation development in India (often groundwater-based) has affected the monsoon mechanisms in a large region including India and East-Africa; increasing food demand in China has lead to a situation that China's food is partly produced in countries like Brazil leading to environmental issues (e.g. groundwater depletion).

It is clear that the management of transboundary aquifers (TBA) must be seen in a wider context of country dependencies, increasing pressures, complexity, uncertainty and connectedness at various scales. Socio-economic and institutional aspects of TBA management are at least equally important as the technical (hydrogeological) side of it (Allan, 2003) in these rapidly changing contexts. This paper addresses how the hydro-economic modelling and serious gaming may support the process of transboundary aquifer management.

2. CHALLENGES AND NEW DIRECTIONS FOR ISARM

One of the authors of this paper is involved in a current study issued by the Global Environmental Facility, International Water (GEF IW) to assess the use and generation of science in the GEF IW portfolio. This portfolio includes ISARM-projects. Preliminary results from this study reveal that particularly hydrogeological research is dominating the science in reviewed TBA projects. Moreover, that this research is often in a descriptive mode using various surveying tools and occasionally in a forecasting and decision-making mode using tools like groundwater flow models. A limited number of the assessed GEF IW groundwater projects has or had institutional components. Socio-economics is modestly present in several of the projects.

This strong focus on hydrogeological research in the assessed projects is not surprising. TBA management is predominantly carried out by water resources managers. Water resources management has a strong engineering tradition based on controlling environmental problems with technical solutions (Pahl-Wostl, 2008). It is only human nature to reduce complex, multi-faceted problems into more simple, one-issue problems in order to try to solve them. So, the group of mostly geologists, hydrogeologists, hydrologist and civil engineers assigned with the task of the management of TBAs tend to reduce this complex problem (a social dilemma) comprising socio-economic, institutional and legal dimensions and frame it into a more or less hydrogeological exercise that can be tackled with surveys and modelling studies. There often appears to be a strong belief among the group of hydrogeologists, hydrologist and civil engineers that understanding the hydrogeological system is of primary importance in order to be able to manage TBAs.

There is also a methodological reason to focus on the technical (hydrogeological) aspects of TBA management, at least in its earlier stages. Management of TBAs can easily become a highly politicized exercise as groundwater resources in the shared aquifer are of national security concern for some countries. Both ISARM and GEF IW acknowledge that interests and claims on the shared (ground)water resources may diverge widely between countries and potentially form sources for tension and conflicts. Here, TBA management is viewed as a process where countries incrementally cooperate with each other. It starts with doing least-controversial activities like sharing of non-political data (often technical data on the aquifer systems) or doing joint-fact finding on this. Only after a period of joint learning, a stage of certain mutual trust is reached and more controversial parts of joint management are exercised (Scheumann and Herrfahrdt-Pähle, 2008).

Increasingly, the traditional engineering approach to water resources management (and natural resources management in general) is being criticised. As mentioned in the first section transboundary aquifers are subject to increased pressures, complexity, uncertainties and connectedness. In the engineering approach the non-linearity of dynamics, the interaction between environment, technology and humans tend to be under-estimated. Janssen et al. (2005) argues that the scientific tools commonly applied in the engineering approach such as groundwater models only have limited validity. Such tools should only be used when there is unified scientific knowledge and unified institutional interests among the stakeholders depending on the results of such tools. When the objectives are vague or diverse and if technical information is surrounded by uncertainty, complexity problems become part of a political process. For such processes, other tools are more suitable. Adaptive water management is being proposed as better alternative. In this latter approach, the understanding of the dynamics of physical systems (here the transboundary aquifers) is less important and knowledge on human society using and managing the physical systems is considered more explicitly.

We argue that for bringing ISARM to a next level, the adaptive water management approach should be fully adopted. By doing so, non-technical aspects of transboundary aquifer management, such as socio-economics and institutional issues are taken into account more explicitly. Furthermore, within the framework of adaptive water management, TBA management is regarded as a process of social learning. In this process, various stakeholders at international, national and local scales continuously interact and learn from each other (vertically and laterally) increasingly building trust between them.

Environmental economics and management science have already developed and applied various tools that are applicable in social learning processes. In the next sections, we focus on two of such tools/approaches that are useful addressing socio-economic and institutional dimensions of TBA management. Firstly, attention is paid to hydro-economic modeling which combines hydrological modeling (supply) with economic modeling (demand) of groundwater. Secondly, the role of serious gaming in awareness raising, socio-economic and institutional analysis, social learning and trust-building in TBA management is discussed.

3. HYDRO-ECONOMIC MODELLING AND TBA MANAGEMENT

Water users often consider only private costs and benefits in their water extraction decision. Because (ground)water extraction imposes externalities on other stakeholders (even in other countries), private costs and benefits do not equal social costs and benefits. Market mechanism are often not able to allocate water efficiently (often these mechanisms are even completely absent). However, when all affected individuals reside within one single country, government intervention can enforce efficient water allocation. In TBA, multiple countries are involved and independent international organisations often lack the power to enforce efficient outcomes.

From a pure economic point of view, countries are only willing to cooperate on TBA-management when its cost-benefit ratio is less than in the case of non-cooperation. Various economic analysis tools exist that articulate such cost-benefits ratios in an objective language that is intelligible to the stakeholders involved (Qadummi, 2008). Such tools may identify the consequences of groundwater extraction on other stakeholders. The use of such economic analytical tools is assumed to increase the degree of objectivity in the sometimes highly political exercise of TBA management. One of the tools that contribute to this objective is integrated hydro-economic modeling.

In the hydro-economic modeling approach, the aquifer is regarded as one entity regardless of its geographical borders. The model exists of a hydrological (supply) part and an economic (demand) part. Water allocation is simulated or optimized by maximizing economic benefits, constrained by water availability, physical feasibility, minimal water flow requirements and water use technology. Integrated hydro-economic modeling covers part of the IWRM approach by focusing on the benefits of water use for different economic sectors, both spatially and over time (Brouwer and Hofkes, 2008). Two modeling approaches exist: the compartment approach and the holistic approach. It is important to notice that in literature, few examples of integrated hydro-economic modeling exist applied to groundwater aquifers.

The holistic approach integrates the economic and hydrological aspects fully. The compartment approach keeps the economic and hydrological aspects separated in two models; the two models are coupled (the water supply in a certain node enters the economic model in the water availability constraint) so that the model output of one model is input for another. The choice between two model types is a trade off between information transfer difficulties in the compartment approach and the simplified economic and hydrological model in the holistic approach (McKinney et al., 1999).

An example of the holistic approach can be found in Gürlück and Ward (2009). In their paper, they present a dynamic, non-linear basin scale model for the analysis of several policy options in the Nilüfer River Basin of Turkey. The model includes hydrological aspects of the river basin, determining water supply in several nodes. The model's economics accounts for agricultural water demand, recreational values and water demand from industries. The model output shows the effects of policy measures on water flows, water volume, water depletion, agricultural land use and production, and total economic costs and benefits for several irrigation districts. One of the lessons learned is that the basin scale modeling approach provides a general framework for formulating water management policies, consistent with the principles underlying the EU WFD (Gürlück and Ward, 2009). Other examples following the holistic approach include Rosegrant et al., (2000) and Cai and Wang (2006). Lekoff and Gerelick (1990) follow the compartment approach by linking an economic, hydrologic and agronomic model in their study.

Several applications of hydro-economic modeling to transboundary water problems exist in literature. Fisher et al., (2002) apply integrated hydro-economic modeling to the Israel, Jordan and Palestine region. These countries share surface water resources such as the Jordan River and the Yarmuk River but also groundwater resources. Israel created a nationwide conveyance system to bring water from the Sea of Galilee tot urban centers and agricultural areas throughout the country. Jordan and Gaza also developed conveyance systems, but less complex as in Israel. The model is a single-year model that maximizes net benefits of water use. Water demand is calculated for various sectors, such as agriculture, households and industry. Maximum water supply in a certain district is calculated using a hydrological model and is used as a constraint in the optimization model. In this study, the effects of several (international) infrastructural measures on water availability and welfare are analyzed from an international point of view.

The study concludes that integrated hydro-economic modeling is helpful for policy makers in their water management and policy decisions, not only at a national level but also for transboundary issues. The use of integrated hydro-economic modeling for transboundary water management has two aspects. First, property rights in water are reduced to monetary values making it easier to measure water against other things and therefore support international negotiations. Second, water agreements that divide water quantities are not optimal. Instead, water trade and cooperation in combination with infrastructure development will mutually benefit.

4. SERIOUS GAMING AND TBA MANAGEMENT

Increasingly, serious gaming is being applied in natural resources management. Serious gaming comprises of a suite of game-like approaches in which stakeholders interact socially in fictitious settings. Serious gamers improve their understanding of the perspectives, preferences, interests, constraints and concerns of other actors (Pahl-Wostl 2007). Historically, simulation gaming has been used extensively in the military, by athletes and by scientists to discover effective new strategies and techniques as well as to develop skills needed to implement them.

Serious gaming approaches transboundary water resources management explicitly from a process perspective in which stakeholders constantly contemplate and exercise cooperation and/or competition based upon their knowledge of the resources base, the social-economic and institutional (including legal) conditions. The objective of serious gaming is to facilitate awareness raising, to analyze socio-economic conditions and institutional settings and to build trust between stakeholders (meanwhile it may be fun to be involved in such serious games). Nandalal and Simonovic (2003) developed a computer assisted negotiation model/software that can be used to facilitate multi-stakeholder discussions of water-related conflicts (so far TBAs are not included in the model but can be implemented relatively easily).

Serious games in water resources management can have different forms and purposes. In its simplest form, serious games are role-plays where the game participants take a certain role representing one type of stakeholder in a water resources setting. In such role games, participants are allowed to make decisions (like the increase in groundwater abstraction to meet domestic agricultural water demand) that are likely to affect other participants' options. The roles allow for negotiation and communication moments (mimicking real life) where the various stakeholders can discuss their diverse interests and try to come to more collective and optimal solutions. An example of such transboundary role-play is Calypso that is part of PCCP's and UNESCO-IHE's courses on Water Conflict and Resolution.

Serious games may use computer support that facilitates the process. In simple cases, the physical part of the role play setting (e.g., the transboundary aquifer system) is being represented by a computer-based groundwater flow model. The effects of a certain decision made by game participants can be put into the model and its consequences simulated on the fly. With current developments in computer technology and the computer entertainment industry, serious games exist that are fully placed in a virtual world and that can be played with multiple actors online on the internet. An example of such game is *Climate Quest*, an electronic game developed with support of UNESCO's PCCP. Its goal is to create awareness and to start a dialogue among youngsters about climate change and its consequences on the management of shared water resources (PCCP, 2010). In May 2010, IBM unveiled *CityOne*, a serious game for professionals to manage urban challenges like water management (IBM, 2010).

5. IGRAC'S TRAGEDY OF THE GROUNDWATER COMMONS

IGRAC developed a serious game called Tragedy of the Groundwater Commons. In this game, participants represent 10 countries sharing groundwater resources. Nine of these countries have an agricultural economy based on groundwater irrigation and one country's economy is based on inland fisheries in a groundwater dependent lake. The participants play multiple rounds in which each country decides how much land to cultivate and whether to fish or not. Groundwater levels decline as countries decide to irrigate more land. Fishing is only possible when the groundwater level has not declined below the lake bottom. A simple Excell-program calculates the groundwater levels in each country resulting from accumulated pumping. Furthermore, the program accounts for capital accumulation (positive and negative) in all countries. The countries' benefits result from their agricultural yields (function of amount of land under agricultural production). Costs predominantly consist of pumping costs, which is a function of the countries individual abstracted volumes of groundwater to meet its irrigation demand multiplied by the groundwater depth in their country during that round. The latter is partly caused by their neighboring countries and here is the typical transboundary externality. If no fish is produced during the game, all countries bear 'environmental' costs, as their diet is partly dependent on it.

Basically, this serious game addresses the tragedy of the commons dilemma translated into a TBA context. The game allows for cooperation and/or free-riding at multiple levels. Countries may invest in more efficient irrigation equipment resulting in less water demand. Investment costs bear on the countries that implement this irrigation technique while the positive consequences of less declined groundwater tables benefit neighbouring countries as well. The game allows for introduction a system of groundwater quota in order to regulate excessive groundwater abstraction. If sufficient countries support the regulation, countries exceeding the agreed groundwater abstraction quota are subjected to (negotiated) penalties. Enforcement of the regulation is only guaranteed when more than half of the countries agreed to support it. Implementation of the regulation imposes substantial costs that are equally shared by the supporting countries. The game allows for climate variability in the sense that at certain (unexpected) moments agricultural yields can decrease because of droughts.

The serious game has been played successfully in a number of settings with international students from Dutch universities. Feedback from participating students and their professors was very positive and revealed that learning by doing and experiencing greatly contributes to the students understanding of TBA management. We think this game has a large potential to be used in more professional settings, such as in ISARM projects and within River Basin Organizations which are often given the task to include transboundary groundwater as well.

The game could be improved in a number of ways. At this moment only one setting of hydrologeological (including meteorological), socio-economic and institutional conditions is simulated. The game could be developed further by 'installing' various settings depicting other transboundary aquifer situations. For this, the 6 archetypical TBA hydrogeological settings of Eckstein and Eckstein (2005) could be used. Players should be able to choose between various socio-economic settings (developed or developing economies and level of groundwater dependency of economies). From the institutional point of view, the game could be improved most. At this stage, game participants represent an entire country and it is assumed that the whole country acts as a homogeneous entity. Therefore, if a game participant decides to reduce groundwater abstraction, his whole country acts as if this happens. Obviously, this is not the case in reality. Whatever deal such a country representative makes during international negotiations, needs to be supported by the groundwater users within the country. In reality, the decisions-makers and top water resources managers need various policy instruments such as domestic regulations, monitoring and enforcement and various incentives to affect the domestic but likely heterogeneous group of groundwater users. The game might be improved by adding several layers of players representing various groups of stakeholders with diverse interests and influencing and by different levels of decision-making power. Possibly, part of the stakeholder groups could not be 'played' but simulated by using agent-based-modelling.

6. DISCUSSION

It is clear that the management of transboundary aquifers (TBA) must be seen in a wider context of country dependencies, increasing pressures, complexity, uncertainty and connectedness at various scales. For bringing ISARM to a next level, the adaptive water management approach should be fully adopted socio-economics and institutional issues taken into account more explicitly. The application pf approaches and tool such as hydro-economic modelling and serious gaming should become as standard in TBA management and in ISARM as hydrogeological surveying.

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Water as parameter of cooperation between Morocco and Algeria: the case of Angad-Maghnia transboundary stressed aquifers of Bounaïm-Tafna basin

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Abstract :

The hydrological basin of Bounaim-Taffna shared between Morocco and Algeria is an example of the politics of silence and non-cooperation. The basin is situated in the north of the Morocco-Algerian administrative border and it covers 2650 km² (70% of the basin is located in Morocco). The Angad-Maghnia aquifers constitute a large freshwater reservoir shared between two riparian countries. These two aquifers (confined and unconfide) symbolise a major asset for the regional socioeconomic development. To date, mismanagement due mainly to groundwater overexploitation has had ominous repercussions on both sides of the border. Currently, a remarkable decrease of piezometrical level has been recorded with a drying up of some wells, and the presence of contaminants (nitrate) on the Angad-Maghnia plain. These impacts are felt in both sides the border, but no action has so far been undertaken, although at the national level both countries have passed water laws and have adopted the principle of Integrated Water Resource Management.

In this region, the groundwater resources are vulnerable in term of to the highest severity on both quantity and quality. It is a hydrogeopolitically vulnerable zone, and should be the subject of an assessment and periodical surveillance, to ensure for a sustainable and equitable management.

Also, The geopolitical problems marking the diplomatic relationships between these two countries prior to the signing of the Union of the Arab Maghreb Agreement in 1989 cannot be ignored:

- 1963: the sad war of the sands
- 1975: 45.000 Moroccan families expelled from Algeria following the start of the conflict of the Sahara.
- 1994: closing of the borders until now: the border remains a military zone
- The war of words continues until now.

So in this conflict situation the questions that we can propose are:

- *Is water a priority of cooperation in this geopolitical context? And if yes:*
- *How to stimulate cooperation over this transboundary groundawater?*

The methodolgy adopted in this work is based on a a first “unofficial” cooperation in order to better understand the hydrologeological system and to assure its improved protection, to establish the confidence between the local actors of the two countries and to identify the objectives and actions to be undertaken, in order to move from non-cooperation to cooperation.

Keywords: transboundary aquifers, bounaïm basin, stressed aquifers, Morocco, Algeria, Cooperation

1- Introduction

Despite the engagements achieved in Johannesburg (World bank, 2007) towards the famous "millennium development goals", the situation has not yet improved in many coutries. On the contrary, it seems to have deteriorated. The fast economic development of Morocco and Algeria, demographic growth together with climatic changes has contributed to, on the one hand a strong mobilization of available water resources and on the other hand the pollution of the groundwater. The alarming report of the World Bank (April 2007) on the water situation in the MENA region calls the governments of this entire region to undertake deep political reforms, in order to avoid the consequences of serious shortages of water in the future. A better governance of water in the MENA region is an emergency requirement.

This alert highlights some elementary truths and should attract the attention of the political leaders to their short-term responsibility. Water is a precious commodity in Maghreb region as everywhere else, where the water demand exceeds the water supplies. Morocco and algeria must mobilize efforts to preserve the resource in order to rationalize its management in a more efficient manner, mainly in the agricultural sector (taking into account that 88% of water withdrawal is allocated to irrigation). In 2025, the expected water availability for Algeria is 300 m^3/person/year and for Morocco is 500 m^3/person/year.

Dams and unconventional water will provide new means to mobilize additional water resources. Morocco could boast of its achievement in dams construction and its water strategy started in absolute priority since in 1967 (16.1 km^3 is the estimated total dam storage capacity of Morocco). Algeria, the other large country of the Maghreb region facing this problem, is currently investing in alternative water resources through a program of construction of desalination plants of sea water (42 units with a total capacity of 59 Million m^3/year in 2004 and 28 units programmed for 2009). The two neighbours, Morocco and Algeria, could participate in the setting up of water geopolitics, showing evidence of realism at the same time, and work together to mobilize their energies and expertises.

It's in this context that Morocco and Algeria need to promote mutual cooperation and politics of good transboundary water governance, in order to safeguard this "blue gold". Morocco and Algeria can learn from their own experience and also their neighbours success and other regions can also learn from them.

2- Methodolgy

Most of the published literature on transboundary waters addresses transboundary rivers. However, transboundary groundwater is also a significant issue. None of the transboundary aquifers in the region is managed and exploited under a multicountry cooperative framework.

The hydrological basin of Bounaïm-Tafna contains two reservoirs that are the Angad-Maghnia unconfined aquifer and the Jbel-Hamra confined aquifer. These aquifers constitute a large freshwater reservoir shared between two riparian countries (Morocco and Algeria). They symbolise a major asset for regional socioeconomic development. , To date, mismanagement due mainly to groundwater overexploitation has had ominous repercussions on both sides of the border. Currently, a remarkable decrease of piezometric level has been recorded with a drying up of some wells, and the presence of contaminants (nitrate) on the Angad-Maghnia plain. The groundwater resources in Morocco and Algeria are vulnerable in terms of both quantity and quality in this region.

The methodology adopted in this work is shown in Figures1 and 2. For a first "unofficial" cooperation and also in order to establish confidence between the local actors of the two countries, the choice of the aquifer proposed here has been based on the quantitative importance of the groundwater resources and their contribution to the economic development on both sides of the border. In this case the extension of the aquifer is limited to the south of the zone (Hauts-Plateaux aquifer). The second criteria is the quantity and the quality of the data that allow us to analyze, diagnose and identify the effects, the main problem as well as the reasons and the constraints (Fig. 1). The diagnoses will make it possible to identify the objectives and actions to be undertaken, in order to move from non-cooperation to cooperation.

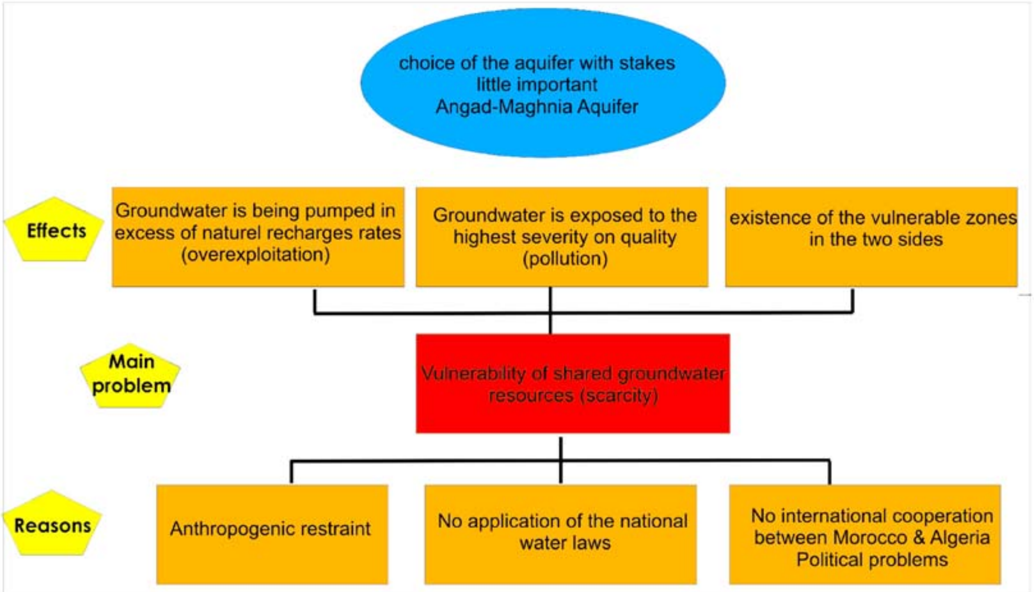

Figure1. Analysis, diagnosis and identification of the problem

In the setting of this working paper, the motivation and the scientific curiosity of the stakeholders from the two sides, rather than the decision-makers, are two components that can promote cooperation through the sharing and processing of data (Fig. 2). On the other hand, at the national level, and outside an official bilateral cooperation, a small part of the stakeholders feature an elevated degree of engagement.

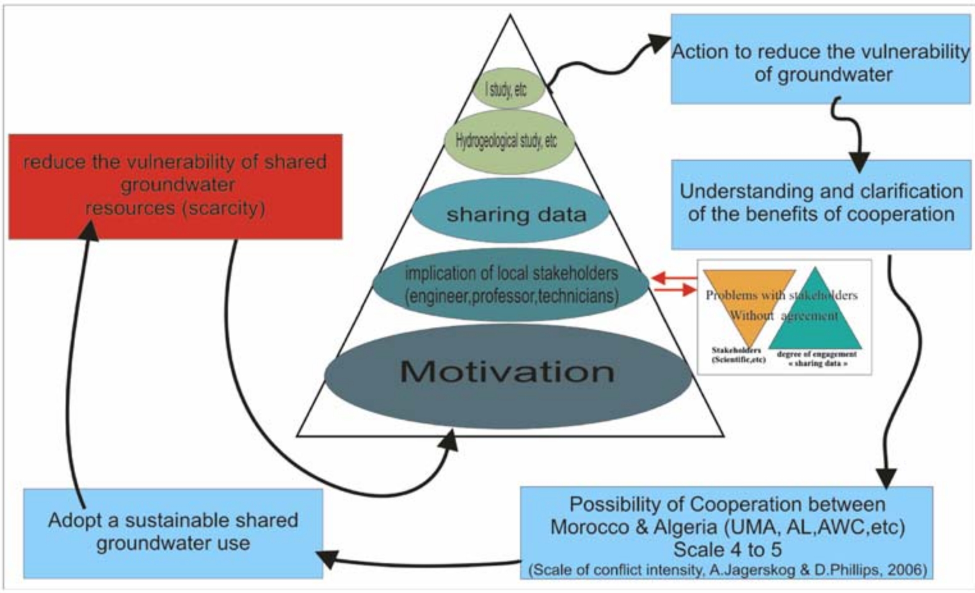

Figure2. Assets and actions

In addition, this survey will identify the vulnerable zones and propose actions that could be the precursors of a potential official bilateral cooperation and therefore the adoption of sustainable shared groundwater utilisation in this aquifer.

3- Political issues and general context

The geopolitical problems marking the diplomatic relationships between these two countries prior to the signing of the Union of Arab Maghreb Agreement in 1989 cannot be ignored :

- 1963: the sad war of the sands
- 1975: 45,000 Moroccan families expelled from Algeria following the startof the conflict of the Sahara.
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So in this conflict situation, the questions that we can propose are:

- *Is water a priority of cooperation in this geopolitical context? And if yes:*
- *How to stimulate cooperation over this transboundary groundawater?*

Located in the North-Eastern part of Morocco and North-Western of Algeria, Bounaim-Tafna basin covers 2650 km ² (70% approximately is located in Morocco) (Fig. 3).
The current population of the Basin is estimated at 615000 habitants: 114.000 habitants in the plain of Maghnia (Algeria) and over 500,000 habitants at the plain of Angad (Morocco). The largest city in the basin is Oujda (Morocco), with nearly 430,000 inhabitants and a growth rate of 1.2%.

The region has suffered both economically and socially because of the conflict between Morocco and Algeria. In this area, the water of the aquifer is used mainly for agriculture (80%) with little economic return. No control of water abstraction is carried out, and the crops produced in this region have only a minor positive impact on the quality of life of the population. The water use in this region is without added value, as long as poverty and illiteracy remains a major handicap. The unconfined aquifer is polluted heavily by nitrate (Boughriba et al 2010), and in the some places the population use untreated groundwater for drinking, implying potential adverse health impacts (especially to children). The unconfined aquifer is overexploited and the water is used for drinking water in Morocco and for agricultural activity and drinking water in Algeria
The hydrological basin of Bounaim-Taffna and the aquifers shared between Morocco and Algeria are extensively stressed and impacted not only by the aridity of the climate, but also by anthropogenic activities (overexploitation and pollution). These impacts are felt in both sides the border, but no action has so far been undertaken, although at the national level both countries have passed water laws (04 September 2005, newspaper official N°60 for Algeria and Junary 1995 for Morocco) and have adopted the principle of Integrated Water Resource Management.

The hydrological basins of BouNaïm-Tafna and the aquifers (Figures 4 and 5) are located in the north of the Morocco-Algerian administrative border. These two basins represent examples of the politics of silence and non-cooperation. In this region, mutual accusations have been recorded in relation to wastewater disposal and its adverse effects (Fig. 4). This is a hydrogeopolitically vulnerable zone, and should be the subject of an assessment and periodical surveillance, to ensure sustainable and equitable management.

Figure3. Transboundary basins shared between Morocoo and Algeria.

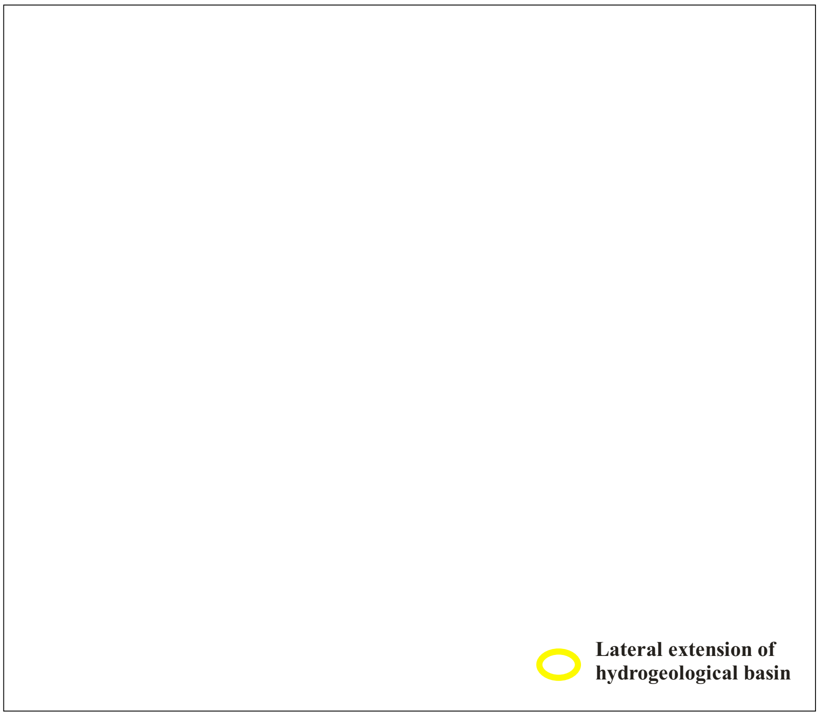

Figure4. The localisation of the Angad-Maghnia aquifer

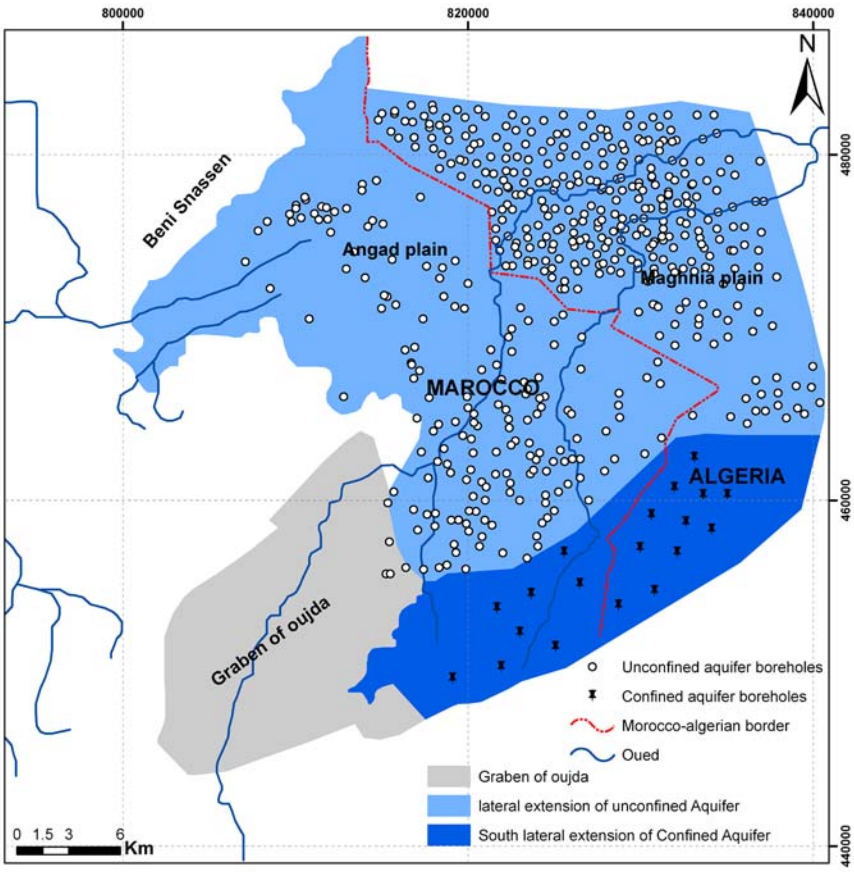

Figure5: Transboundary Aquifers (confined and unconfined)

4- Hydrogeological context

4.1-Unconfined aquifer: Angad-Maghnia aquifer:

The region has an arid climate, with large temperature and rainfall variations. Average annual temperature and rainfall are about 18°C and 230mm respectively, and the region is characterized by a high evaporation rate.
The important aquifer (780Km2) shared between Morocco “upstream” and Algeria “downstream” is located in the Plio-Quaternary layer system (Figures 5 and 6) which is constituted by heterogeneous rock (sand, grava, basalt and silty clay, etc.). The thickness of the aquifer varies between 20m and 120m. The water table varies in depth between 10m and 80m. The aquifer is intercepted by more than 4000 wells at both sides of the border (Fig. 5).

Groundwater recharge is assured by a direct infiltration of received surface water on the Angad-Maghnia plain, and also water flow from the Moroccan part to Algerian area (34Mm3/year, Lahrach 1999).

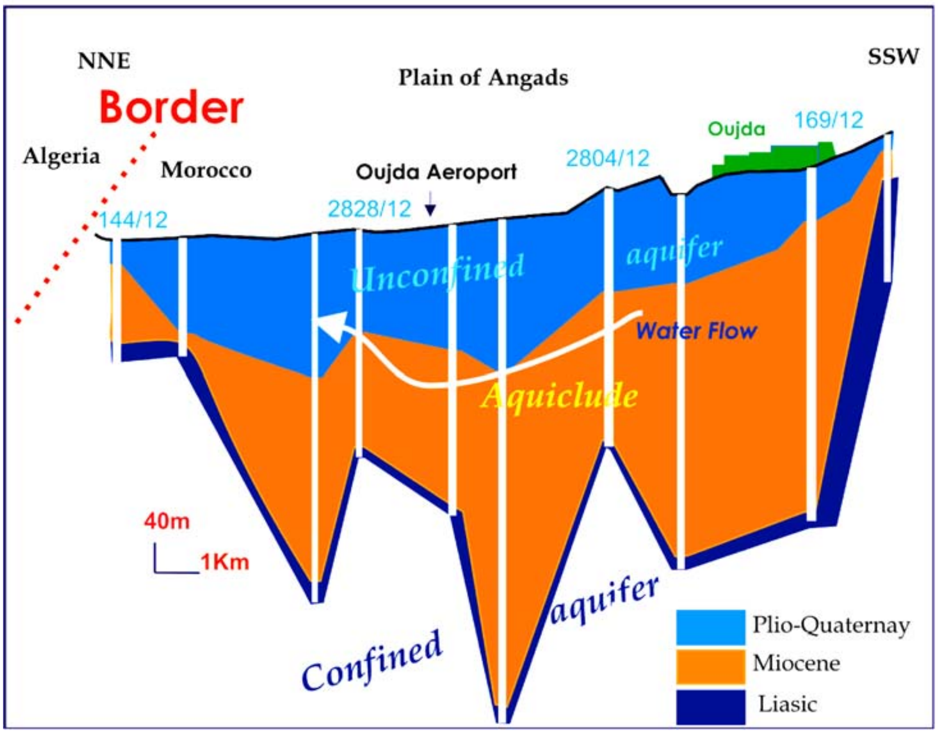

Figure 6. Hydrogeological cross section

- **Groundwater deterioration in the Moroccan side**

On the quantitative term, the piezometric map (June 2007) shows the fall of the Angad water table with the onset of depression in some areas ,south and north of the Angad plain (Fig.7), in qualitative terms the measured salinization reflects the progressive growth of this parameter. Not only are we assisting to a decrease in groundwater resources but also the beginning of a qualitative deterioration (Boughriba et al 2010).

- **Vulnerability assessment**

Vulnerability is a construct designed to help planners to protect aquifers as an economic resource. There has not yet been a general agreement on what the strict definition of vulnerability should be (Vrba and Zoporozec 1994), and the term vulnerability has come to mean different things in different contexts. It's refers generally to the sensitivity of groundwater to contamination. This concept is based on the assumption that the physical environment may provide some degree of protection to groundwater against human activities. The modified DASTIC model was used in this case to identify the vulnerable area in the Moroccan side. DRASTIC is an acronym for the most important hydrogeological features

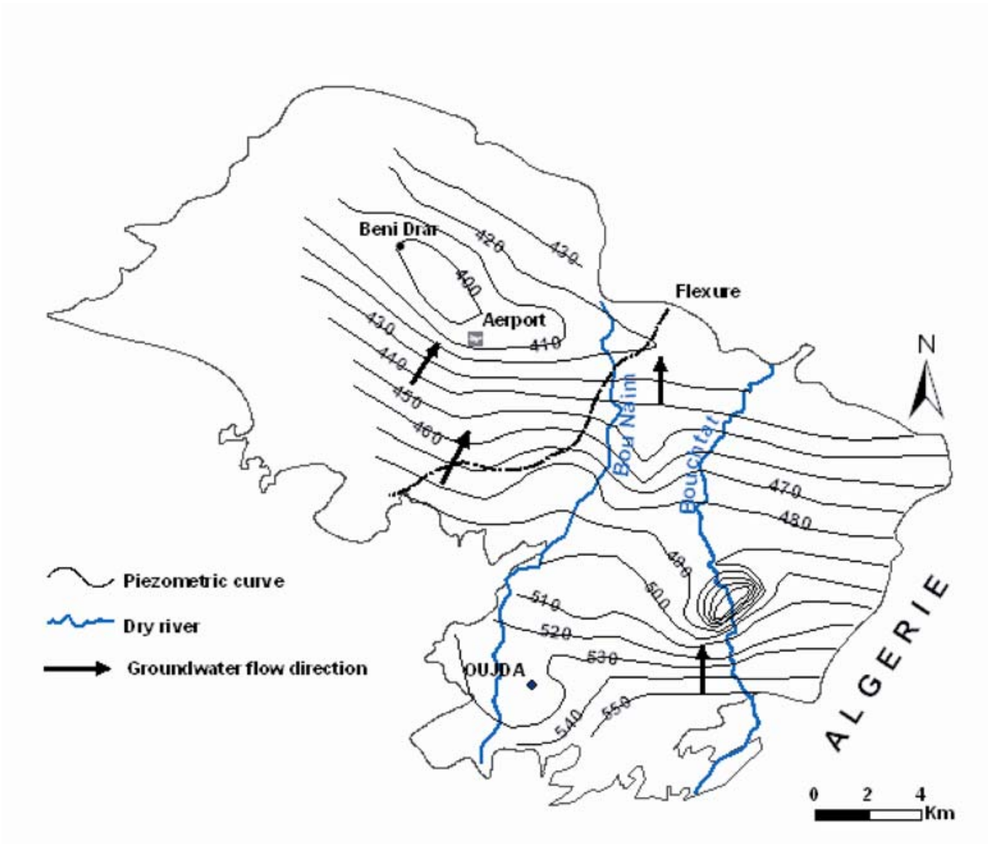

Figure7. Piezometric map

which control groundwater pollution: Depth to water, Net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone media, and hydraulic Conductivity of the aquifer. The seven parameters cut—in a schematic way a local hydrogeological unity into its main components, which, in varying degrees, affect the processes of transport and attenuation of contaminants in soil and their transit time.Each of the hydrogeological factors is assigned a rating from 1 to 10 based on a range of values. The ratings are then multiplied by a relative weight ranging from 1 to 5. The most significant factors have a weight of five; the least significant have a weight of one. A Geographic Information System (GIS) is used to compile the geospatial data, to compute the DRASTIC indices, and to generate the final vulnerability map. The equation for determining the DRASTIC index is:

$$ID = Dr\,Dw + Rr\,Rw + Ar\,Aw + Sr\,Sw + Tr\,Tw + Ir\,Iw + Cr\,Cw$$

Where D, R, A, S, T, I, C represent the seven hydrogeologic factors, r designates the rating, and w the weight.

The resulting DRASTIC index represents a relative measure of groundwater vulnerability.
The higher the DRASTIC index the greater is the vulnerability of the aquifer to contamination. In this study the DRASTIC method was modified responding to certain characteristics of the Angad plain, indeed, depth to water alone does not provide a protection for groundwater against the contaminants infiltration, it is possible that the pollutant attaint easily the aquifer with the presence of fractures even if the aquifer is deep (Lee S. R and al 1998). Following this logic, the Modified DRASTIC system is sum of DRASTIC system and Fractures density which is obtained by using aerial photographs and geological maps. Higher fractures density values may represent more potential to groundwater contamination.

Modified DRASTIC index = DRASTIC index + (Distribution density rating x 5)
The modified DRASTIC map show three degree of vulnerability: Moderate, High and very (Fig.8).

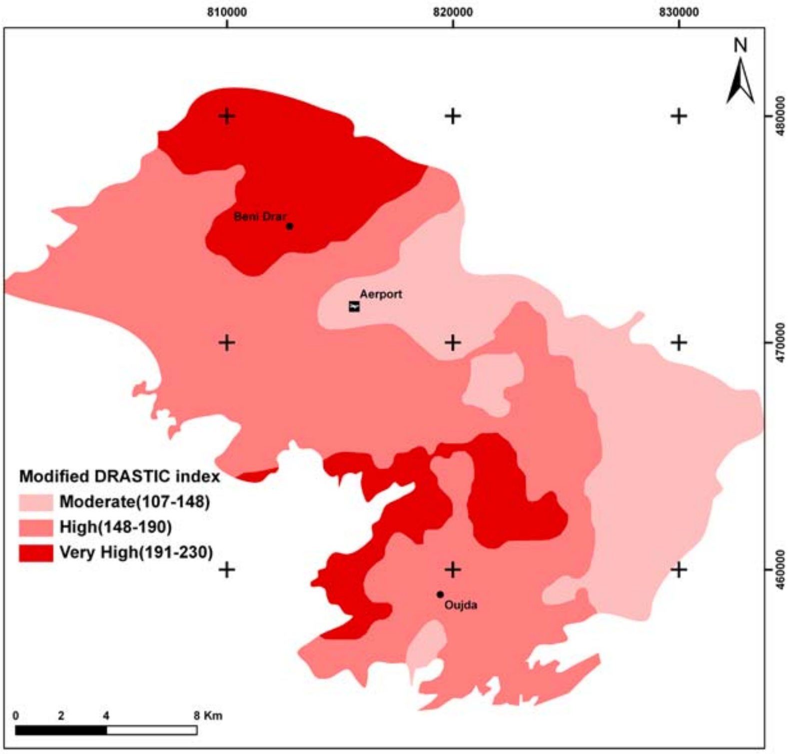

Figure 8. Vulnerability map of the unconfined aquifer (Moroccan side)

4.2- Confined aquifer: Jbel Hamra aquifer

Jebel Hamra is an asymmetrical anticline whose axis is oriented roughly east-west. His heart is made up of Paleozoic and Triassic formations and its flanks by dolomitic limestones and dolomites of the Lower and Middle Lias. These levels are overlain by calcareous marly formations of Upper Lias age. In the north, the foundations of Jebel Hamra continues under the plain Angad.

These formations constitute the reservoir of Jbel Hamra. . The impermeable Triassic deposits adjusted and the faults bounding the horst are building the lateral limits of the aquifer. The bedrock is formed by marls and Triassic basalts and the roof is composed by Miocene marls at the plain.

The depth of the aquifer is variable. Its thickness is 250m. The static level of the water is between 40 and 110 m / ground in the Moroccan territory and about 25-145 m in Algeria. The boreholes are deep 100-400 m from the Moroccan side and 320 to 650 in Algeria.

The aquifer is characterized by good hydrodynamic parameters. The transmissivity is particularly high; it is about 1.10-1 m2 / s. The storage coefficient is around 10-3.

- **Grouwndwater quality and chemical facies**

In the confined aquifer, the salinity varies between 0.5 to 1.2 g / l in Morocco and from 1.1 to 2.8 g / l in Algeria. The temperature is from 21 ° C to 52 ° C. In chemical point of view, three facies are represented: bicarnonate, chloride and sulfate.

The high levels of sodium, chloride and sulphate were probably acquired by a localized leaching (in space or deep) of gypsiferous deposits and salt-bearing Triassic, it’s the case in

Algeria with the boreholes MOH1 et SAL (deep > 600 m) and the boreholes 253/12, 2916/12 and 159/12 in Morocco.

- **Recharge of the aquifer**

The recharge of the aquifer is estimated at 9.5 Mm3/an. It's realised by a direct infiltration of runfull through a impluvium 15 km² and by downward seepage from a pool of 300 km².
A further contribution is provided through hydraulic connections with the adjacent basins, and this is to allow the infiltration of flood waters around the neck of Metsila (Oued Sedra) and the Guenfouda Gully (wadi Isly)

- **Exploitation of the aquifer**

The Jebel Hamra aquifer was used exclusively for supplying drinking water to the city of Oujda. Initially, the operation was limited to the catchment of Sidi Yahia source, with 300 l/s. Then, from the 60s, the samples have started to raise by the achievement of a battery of wells, reaching over 750 l/s in 1982. The operation was reduced thereafter to around 600 l/s through a dozen holes.
Since 2004, eleven (11) other holes were drilled on the Algerian side to meet drinking water needs of the Algerian population in the Bounaim Basin.
The boreholes are operated with 10 to 60 l/s. The reservoirs built in the Zouia area (Algeria) are seven (7) (radius of 5-35 m and height of 3 m). Unfortunately, exact data about the mobilized volumes in this sector are not available at present, and even the number of reservoirs and their dimensions are undefined, they were determined from the satellite image. (7 reservoirs of capacity estimated between 150 and 1200 m3 depending on size) (Fig.9).

Figure 9. Reservoir in the morocco-algerian boundary (Algerian side)

5- **Climate change and groundwater stress**

The Basin is characterized by irregular rainfall, brutal and usually torrential, causing an important ran-off and disadvantaging the natural recharge of aquifers. The treatment of rainfall data (Fig.10) shows that rainfall trend shows a downward trend in the three weather stations (stations Oujda (Morocco), Beni Maghnia and Ouassini (Algeria)). Also, the overexploitations associated with climate change have caused a decrease of groundwater level of 2 to 3m/year from 1982 (Fig.11). After the commissioning of wells in Algeria (Bensouala and Adjim, 2006), a decrease of 6 to 7 m/year was recorded between late 2004 and late 2006 (7m / year for 2005).

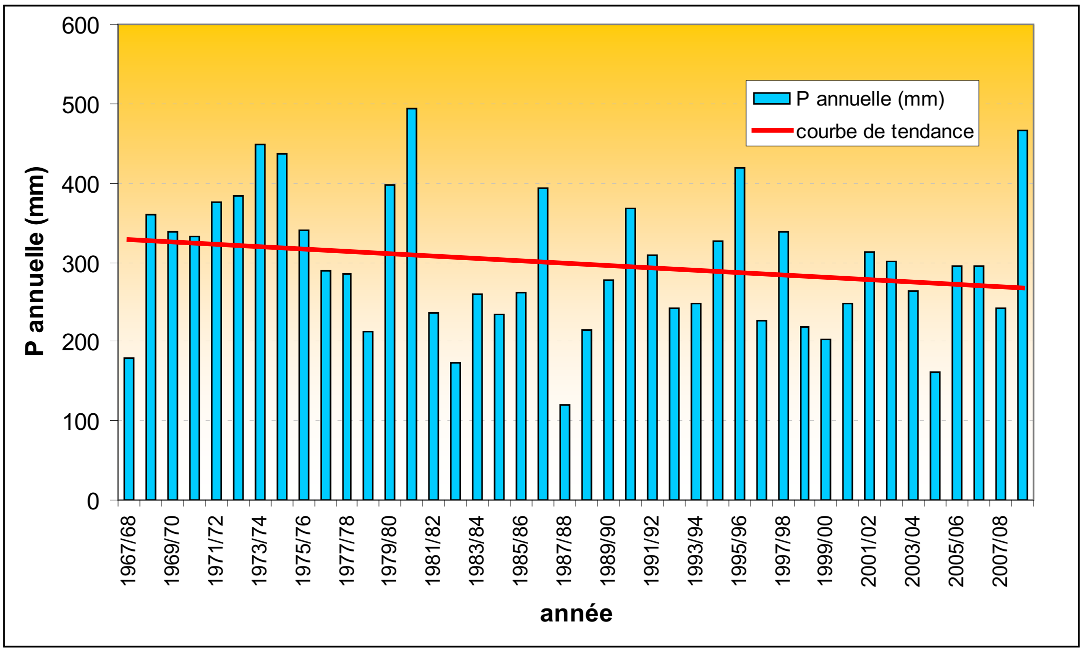

Figure10.Evolution of rain-off in the basin

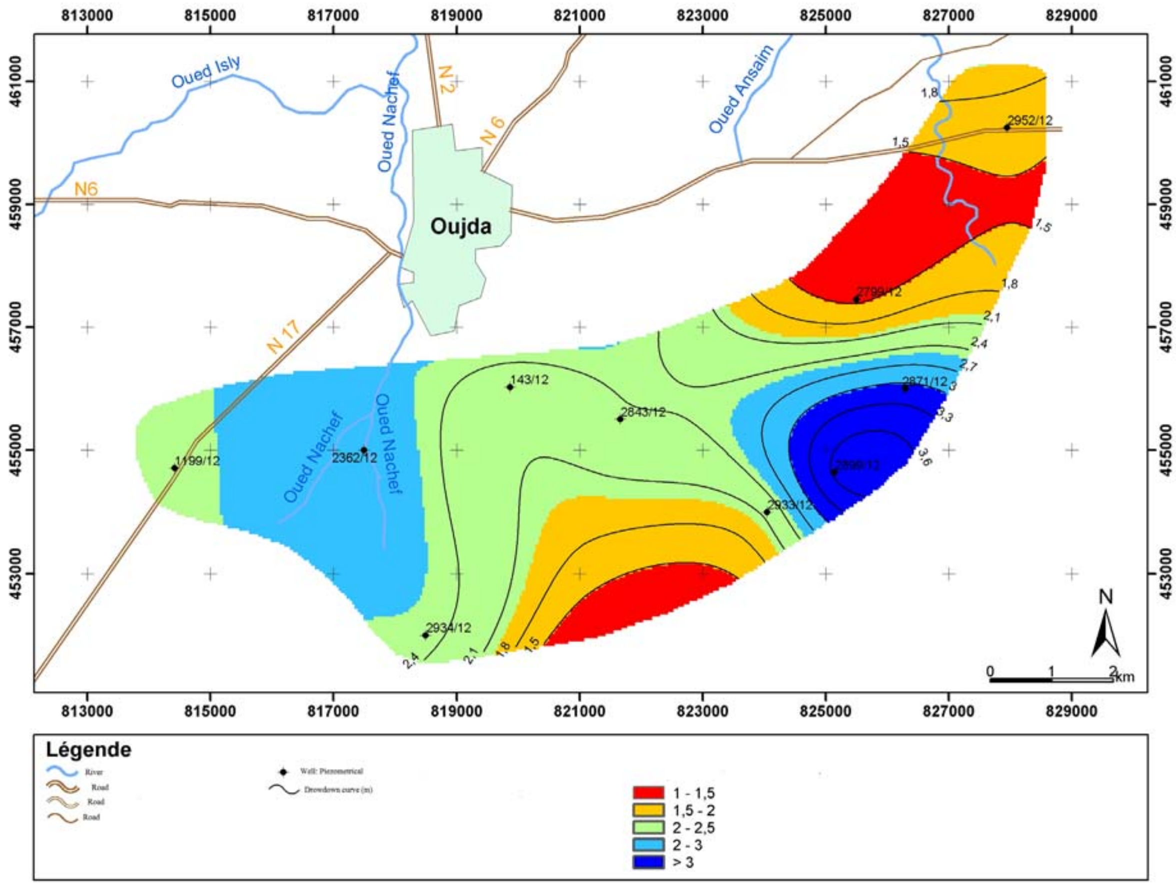

Figure11. Drowdown of the confined aquifer (Moroccan side) (ABMH, 2004)

6- Conclusion and discussion

Transboundary groundwaters are more vulnerable than surface waters, and the present study reveals adverse anthropogenic impacts on the Angad-Maghnia aquifer, both in relation to quantity and quality of the aquifer. These affect both the Moroccan and Algerian use of the aquifer.

To better understand the Angad-Maghnia aquifer and to assure its improved protection, a first step of merit would involve technical cooperation between the scientific communities of Morocco and Algeria. This could be promoted through the creation of a Maghreb Scientific Association, through which data exchange and technical discussions could occur. During the course of the present study, Algerian colleagues assisted in the provision of data and in discussions of these.

- Action needed in the short and medium term:

The current exploitation of the aquifers in the basin exceed its potential, and in transboundary context the management of the resource cannot be unilateral; such management would be ineffective if no similar action is taken by other users and Manager there the same resource. On the other hand, a credible and indisputable management should integrate all the basin resource as well as opportunities for development. In this logic, some actions are proposed in this study for an adequate and plausible IWRM of the Bounaim-Tafna basin:

- Sharing data
- Make a board a joint committee of reflection and monitoring the water resources state of the Bounaim-Tafan basin, in view of preparing the start of negotiations on the management of transboundary water resources
- Consider the confined aquifer as a strategic resource
- Reduce withdrawals from the unconfined aquifer
- Reuse of treated wastewater in irrigation in the Agnad plain (Moroccan side) and the transfer of surface water from to the Maghnia plain for agricultural purposes (Algerian side).

- Constraints to cooperation

Transboundary cooperation relating to groundwaters is more complex intime and the space than that for surface waters because:

- groundwater moves in 3 dimensions;
- the groundwater recharge and discharge rates vary in various timescales, from within a few hours to thousands of years;
- groundwater basin boundaries are not as obvious as those of river basins, and can change with the rates of groundwater abstraction;
- unconfined aquifers are more vulnerable than confined aquifers; and

agreements should integrate all the stakeholders (farmers, domestic users, etc.), making cooperation more challenging.

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POSTERS

Recharge Mechanism To North-Western Sahara Aquifer System (NWSAS) Using Environmental Isotopes

UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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1. INTRODUCTION

1.1. Methodologies and Techniques

Palaeoclimatic condition were assessed from the isotopic composition of groundwater samples taken from the foregoing water bearing formations using stable isotopes of O-18 ,H-2, and radioactive isotopes of H-3 and C-14 .

A statistical package "SSC-Stat v2.nn" developed by Statistical Center of Reading University as well as isotope hydrology program 'Diagram" were acknowledgeably used for the analysis of isotopic data

1.2. Hydrogeological Setting

The North –Western Sahara Aquifer System(NWSAS)(Fig. 1) can be categorized as a multi-layered system of aquifers which embodies a huge stock of non-renewable, fossil water. It displays a mostly porous and fissured / fractured structure (Struckmeier / Richts 2006). Among its different layers, two have to be distinguished as being of major size and importance. The so called *Continental Intercalaire* (CI) is located on the lower level (Fig.2).

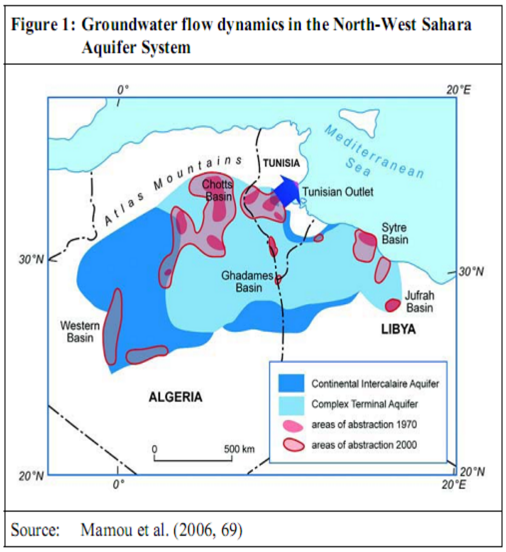

Figure 1: Groundwater flow dynamics in the North-West Sahara Aquifer System

Source: Mamou et al. (2006, 69)

Fig.1 Location map

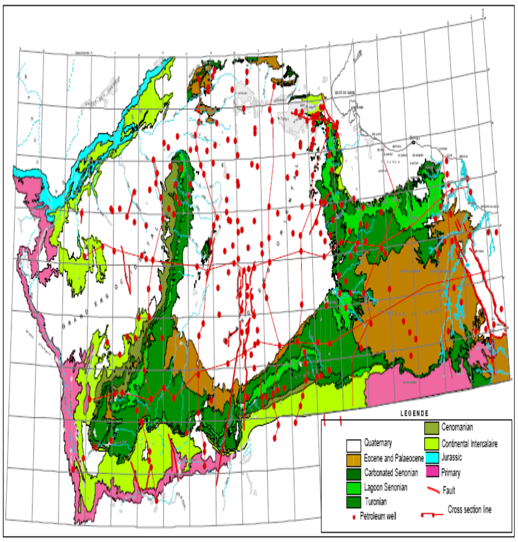

Fig.2 Geological map of NWSAS.

2. RESULTS AND DISCUSSION

2.1.Evidences Enhancing the Renewability of NWSAS

2.1.1.Statistical evidence

Isotopic data were treated using the boxplots for water isotopes of $\delta^{18}O$ and $\delta^{2}H$. The inspection of the boxplots for $\delta^{18}O$ for the three countries shows that the isotopic data of Algeria are completely skewed and to a lesser extent the data of Libya .However, the isotopic data of Tunisia are totally non-skewed.The mean value for C.I. in Lybia amounts to -8 ‰ with coefficient of variation of 14% compared to -9‰ and coeffienct of variation of 5 % for Tunisian C.I.The foregoing situation reflects a rainfall originating from homogenous air masses in both countries.However, the mean $\delta^{18}O$ for the Algerian C.I. is -7‰ with coefficient of variation of 62% which reflects non-homogeneity in isotopic data and confirm that C.I. aquifer in Algeria receive recharge originating from different air masses with different isotopic composition.

2.1.2. Geochemical evidences

2.1.2.1. Evidence using $\delta^{18}O$ - depth relationship

The relationship between depths to water level, in meters versus $\delta^{18}O$ was established. The inspection reveals a clear cut relationship in which, two isotopically different water are mixed down to depth of about 400 m, in the Libyan C.I. and that, the range of stable isotopes contents is interrupted as a result of mixing between deep water depleted in heavy isotopes with shallow modern water enriched in heavy isotopes.

2.1.2.2. Evidence using salinity - $\delta^{18}O$ relation

Salinity versus $\delta^{18}O$ was established.The inspection of this relation reveals that the isotope data in Tunisian part of aquifer in which, though the big difference in salinity, groundwater samples have the same isotopic signature no matter they present high salinity concentration or not. This implies a homogeneous mixing inside aquifers. However, this is not occurring in the whole system as can be seen in the Algerian part of aquifer where aquifer shows the same signature versus a wide range of salinity variation.

2.1.2.3. Evidence using the characteristics of d-excess

The maximum for d-excess for C.I. in *Tunisia is 10.‰ ,the minimum is 1‰ and the mean is 6 ‰ while maximum for the Algerian part of C.I.* is 11‰, Minimum is -1‰(a negative value of d –excess) and *mean is 5.45‰* .This implies that the anomalous samples are derived from local isolated moist air masses with anomalous low d values. The‘d-excess’ values in groundwater of C.I. are less than ten in most part of C.I.in the three countries. However, the d-excess values ~8–10‰ in Sahara Atlas in Algeria and the Dahar and the Dj. Nefoussa in Tunisia and Libya may be inherited from the precipitation. The low ‘d-excess’ values (≤6‰) in major part of the C.I. areas suggest that there is significant evaporation of rainwater leaving the residual groundwater with lower values of ‘d-excess’.

2.1.2.4. Evidence using C-14 (pmc) and H-3 data

The frequent occurrence of significant amount of ^{14}C >2 % expressed as percent modern carbon (pmc) and ^{3}H , expressed as tritium unit (TU) in the isotopic data of NWSAS(OSS internal report,Vol. II/annex 8) should be attributed to a mixing with shallow and modern water, where old water practically contains neither ^{14}C nor ^{3}H.

2.1.2.5. Evidence using the conventional relationship of $\delta^{18}O$ and δD

Most of the groundwater samples of C.I.in Libya plot on the GMWL while a considerable number plot slightly below the GMWL , and has thus a lower slope than GMWL. The slight deviation of C.I .of Libya samples from the GMWL suggests that some evaporation occurs prior to or during infiltration, or that recharge represents a mixture of isotopically enriched and depleted waters.

2.1.3..Hydrologic evidences

The groundwater flows at velocities between 0.1 meter per day and 1 meter per year (Foster/ Margat / Droubi 2006; Mamou et al. 2006) represents a real mismatch. In the latter case it would take recharge water which entered the NWSAS on its western border, nearly 2 million years to reach its eastern border and **900,000** years to travel from the south to the north and would therefore, contradicts the fact of having frequent data of pmc up to 60 % and Tritium data up to 16 T.U., which corresponds to an age resolution of about ± 16 to ± 40 years. Even at a speed of 1 m/day, a full turn –over of the present water stock will therefore never occur within human life time dimensions.

3. CONCLUSIONS

Isotopic data interpreted in conjunction with conventional hydrologic data has confirmed the fact that NWSAS is receiving a considerable fraction of modern water recharging the aquifer. This was clearly indicated by the frequent occurrences of significant amount ^{14}C >2 % pmc, ^{3}H ≥5 T.U. and the abnormally low values of d-excess (-1‰).

Accordingly, the description of NWSAS as non renewable, devoid of any meaningful recharge , a rather stagnant water body, disconnected from any surface water body in addition to its classification as "non-renewable" would therefore be misleading and represents one of the most obvious inaccuracy as well.

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Tools for the management of large transboundary aquifers: OSS experience

UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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ABSTRACT

The focal area of the Sahara and Sahel Observatory (OSS) is located in the Sahara and Sahel zone which contains large sedimentary basins covering each a surface of several hundreds of thousands of km². OSS promotes the concept of "basin awareness" by encouraging the countries sharing transboundary basin to work together in order to manage the groundwater resource in a rational manner. This was experimented in the North Western Sahara Aquifer System (NWSAS), shared by Algeria, Libya and Tunisia, and the Iullemeden Aquifer System (IAS), shared by Mali, Niger and Nigeria. The key element of this management is the consultation based on the development of decision making tools: Database, Geographic Information System (GIS) and Model. In this context, data and information were collected, treated, harmonized and then gathered into a common database, associated with a Geographical Information System (GIS) which supply the groundwater model. Layers of the (GIS) consist of treated and homogenized thematic maps (topographic, hydrogeological, etc.). The development of models enabled the countries to build forecasting simulations for optimal and rational management of the shared resource. The development of all these tools contributed in updating the aquifers knowledge, improved the exchange and strengthened cooperation between countries.

Key words: Data base, GIS, model, aquifer

1. INTRODUCTION

The aquifers of the large shared basins of OSS area contain considerable reserves of fresh water estimated at 1 to 75 thousand billion m^3 per basin (Margat, 1992). Studies were undertaken and others are still ongoing on some of these basins (Fig. 1). OSS plays a role of facilitator between the countries in encouraging them to dialogue in order to manage the resource in an optimal and rational way. The adopted approach consists in developing common decision-making tools (models and data bases), which justify setting up a consultation mechanism between the countries, having for role, amongst other tasks to perennialize the assets. This reflexion is based on the results of SASS and SAI projects.

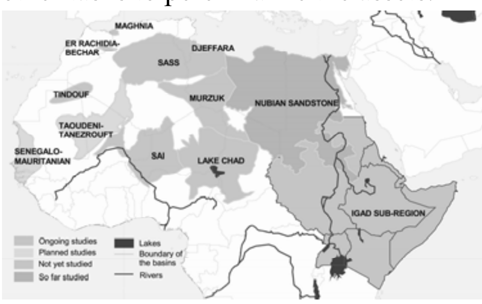

Fig. 1: The large shared basins in OSS area

2. OBJECTIVES

The objectives of these studies consist primarily of the actualization of knowledge by setting up common tools for the shared resource management; and setting up a consultation mechanism between the countries.

3. METHODOLOGICAL APPROACH

3.1. The Databases and Geographical Information Systems

The methodology adopted for setting up of SASS and the SAI Databases are mainly based on: the separation between structure of data (stable element) and treatments (dynamic aspects); and the description of the system at three levels (conceptual, organisational and physical) allowing to progress methodically in the comprehension of the problem and to propose the solutions adapted to the context (OSS, 200à; OSS, 2007a). On the organisational level, an adequate diagram of exploitation in conformity with the internal organization of the national administrations (ANRH, DGRE, GWA) must be defined (Fig. 2). Procedures and rules of exploitation and administration of the system must be elaborated. The Geographical Information System (GIS) plays a significant role in the system set up as it is used at each stage during data treatment and helps to develop thematic maps.

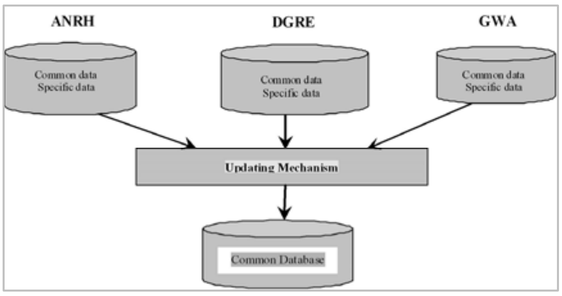

Fig. 2: Organisational solution considered for SASS Database

3.2. The models

The model facilitates the comprehension of the studied system and enables to make forecasts. In a more precise way, the global objective of the modelling carried out within the framework of the OSS projects is the actualization of knowledge. We distinguish three stages in the process of modelling: i) the conceptual stage which consists of describing and specifying the phenomena which will be taken into account in modelling; ii) the mathematical stage corresponds to the transcription in the form of equation the phenomenon describes in the conceptual phase; iii) the numerical stage corresponds to the numerical resolution in a computer code of the equations established at the mathematical stage.

4. RESULTS

The models enabled to understand the hydraulic behaviour of the studied systems and are used as decision-making tools for the rational management of the water resources. The OSS experience in the field of modelling, acquired within the framework of SASS (OSS, 2002b) and SAI (OSS, 2007b) projects, enabled to instigate the use of modelling for groundwater management and to implement capacity building sessions in the countries. The groundwater abstraction scenarios defined by the countries and explored in the model of the SASS enabled to identify the risks zones and to agree on a permanent monitoring piezometric network. The set up of a mechanism of dialogue aims to perennialize the assets through a periodic updating of the developed tools (database and model).

5. DISCUSSIONS

One of the innovations of SASS project is not to consider the mesh as the elementary entity of entry of the data for the digital model. It is at the water point that quantitative information of abstraction, piezometry are linked… and it is at this level that the user carries out the modifications.

Gathering data and totals by mesh are carried out by means of queries executed automatically during the preparation of the data for the model. Thus, the changes of the parameters of the grid do not constitute any more a constraint. This vision allows a better flexibility but requires that a permanent connection be established between the data base and the GIS so that any modification on the water points is reflected immediately and in a transparent way to the level of the data by mesh. A form was elaborated to carry out these operations of connection and to ensure the synchronization Database-GIS-model (Fig. 4).

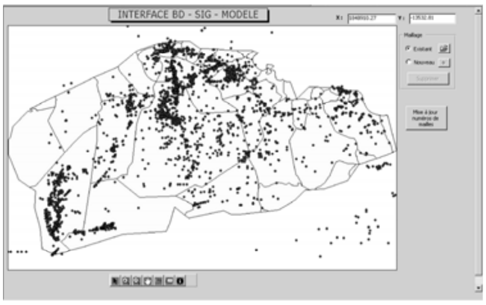

Fig. 4: Interface BD-GIS-Model

6. CONCLUSION

The installation of the data bases of the SASS and the SAI enabled to gather and make homogeneous the whole information available on these two basins in coherent relational structures. Without such opened architectures, it would have been difficult to carry out all the treatments, queries and thematic maps which these projects have produced.

In the field of modelling, the development of the hydrogeologic models led to significant progress regarding water resources management. Their use for better knowing the hydraulic behaviour of the aquifer systems is in full rise and becomes essential. The development of the technical tools undertaken within the framework of the OSS projects led to the installation of a framework of dialogue between the various stakeholders (OSS and representatives of the countries) which is maintained for their regular updating. OSS will continue its role of development coordination at the scale of the basins, which none of the countries can do alone.

7. AKNOWKEGMENTS

I acknowledge here all the OSS water team and all experts who worked with us in the framework of SASS and SAI projects.

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TRIFINIO: Transboundary Aquifer Systems in the Upper Lempa River Basin, El Salvador, Guatemala and Honduras, in Central America

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ABSTRACT

The Trinacional Commission for the Trifinio Plan is managed by the respective national deputy presidents and works under the slogan 'Water without borders', recognizing the importance of water resources for these three countries. This study includes homogenization of existing geological descriptions of different geological units in the Trifinio region. Physical and chemical parameters were measured in the field for about 140 samples. Geoelectrical campaigns were carried out in selected areas to reveal information about the location and hydraulical properties of the principal aquifers. Thus, the first hydrogeological map of the Trifinio region was generated with a scale of 1:100 000. The preliminary results have shown the chemical and isotopic similarities between most surface waters and groundwaters, suggesting both a fast dynamic for most systems and the relevance of local sources of recharge. The precipitation presents a high temporal variation in deuterium (-105.60 ‰ $\leq$ δ2H 21.66 ‰) and oxygen-18 (-14.76 ‰ $\leq$ δ18O $\leq$ 1.37 ‰), due to the combined effects of amount and altitude. Also, a strong seasonally effect can be found. Tritium was determined in 29 samples from wells, springs, rivers and lakes from El Salvador. Observed maximum activity was of 2.09 UT and a minimum of 0.00 UT. Tritium concentration in precipitation shows a tendency to decrease their activity to background noise. The results indicate that at least four samples showed no Tritium activity, which could be interpreted as water corresponding to intermediate and regional flows where the Tritium in the system has disappeared. 20 samples showed an activity greater than 1 TU reaching even 2.09 UT. Taking into account that the natural concentration of tritium when it enters the hydrogeological system is of approximately 4 UT, the trend observed at the Ilopango Station (outside the Trifinio region) and the half-life of tritium (12.3 years), there is a significant component of young water (less than 12 years) in the majority of the sites.

Key words: Trifinio, Transboundary Aquifers, Isotope Hydrology, Lempa River.

1. INTRODUCTION

In 1998, the governments of El Salvador, Guatemala and Honduras in Central America established the "Comisión Trinacional del Plan Trifinio" a platform to promote a sustainable development of water resources in this environmentally valuable and sensitive transboundary area. This commission is managed by the respective national deputy presidents and works under the slogan 'Water without borders', recognizing the importance of water resources for these three countries. Its strategy for development of Trifinio highlights water as the resource with the greatest impact on life, society, food production and the environment. The principal research objectives of the study are twofold: first, to assess the dominant types of recharge and stream-aquifer fluxes, and second, to compile and complete the hydrogeological information of the three countries in a transboundary hydrogeological map.

With International Atomic Energy Agency (IAEA) assistance through the project: "Sustainable Development of the environment and water resources in the Upper Lempa River Basin" (RLA/8/038) between 2006 and 2008, the studies were coordinated by the commission and implemented by more than 30 professionals representing national counterparts from the following institutions: Honduras: ENEE, DEFOMIN, and SNM. El Salvador: SNET-MARN, CEL, ANDA, UES and MAG. Guatemala: INSIVUMEH.

2. STUDY AREA

The Trifinio (Figure 1) area has over 4343 km^2; of which El Salvador occupies about 29.5%, Honduras 11.6% and Guatemala 58.9%.

The Trifinio region is one of the most complex regions from an geological point of view. The geological formations extend from the volcano-sedimentary Complex "Complejo Espinal" from the Jurassic age up to lava and pyroclastic rocks of the Ipala graben from the Pliocene to the Holocene and are related to the volcanism behind the volcanic arc (BVF), these structures have a major effect on the existence of aquifers in the region.

3. METHODOLOGY

The initial work included homogenization of existing geological descriptions of different geological units in the Trifinio region. Due to the limited amount of hydrological information available at the begin of the study, the first phases of the project consisted of several field work campaigns between 2006 and 2008, aimed at creating and updating a comprehensive inventory of water points - mostly springs, dug wells and drilled wells. Physical and chemical parameters were measured in the field for about 140 samples, representing surface waters and about 110 groundwater samples. Geoelectrical campaigns were carried out in selected areas to reveal information about the location and hydraulical properties of the principal aquifers. Complementary hydrogeological mapping was conducted in areas with sparse information available. Additionally, precipitation, surface and groundwater samples were collected for analysis of environmental isotopes and about 244 $\delta^{18}O$ and $\delta^{2}H$ analyses were carried out at the stable isotope laboratory in El Salvador. The results were synthesized in preliminary conceptual models of stream-aquifer interactions in the principal zones and contributed to the finalization of the transboundary hydrogeological map.

4. RESULTS AND DISCUSSION

The first hydrogeological map of the Trifinio region with a scale of 1:100 000, is presented in figure 2. The map indicates three main hydrogeological: units:
a) Porous media aquifers: Thirteen units were identified and mapped in fluvial valleys and terraces. These units are mostly formed by alluvial sediments transported by rivers, or are result of landslides. Sedimentary units reach thicknesses ranging from 30 m to 80 m and have a very heterogeneous grain size distribution, mostly formed by fragments of igneous rocks. Hydrochemical and isotope data confirmed the meteoric origin of these locally recharged waters with fast dynamics. The dominant hydrochemical feature of these waters is calcium bicarbonate with low mineralization (250 –600 µS/cm). Nitrate levels are above the drinking water limit at only a few locations. **b) Fractured aquifers**: This hydrogeological unit type is formed by volcanic rocks affected by intense fracturing, mainly in the western part of the Trifinio region (Guatemala). Groundwater usually manifests itself in the form of large springs. The dominant hydrochemical type of these waters is also calcium bicarbonate with low mineralization (300–600 µS/cm). Stable isotopes provided estimation of the recharge area altitude of various springs. **c) Low porosity fractured rocks:** These units (approximately 10) extend over most of the Trifinio region, especially in the eastern part. Despite a moderate fracturing, these volcanic rocks demonstrate poor conditions for groundwater flow. The local population nonetheless exploits most of the existing springs. These waters show a more complex geochemical evolution, with electrical conductivity reaching values of up to 1200 µS/cm and chemical facies ranging from calcium bicarbonate to calcium bicarbonate/chloride. Environmental isotopes revealed that most of these waters also derive from local recharge.

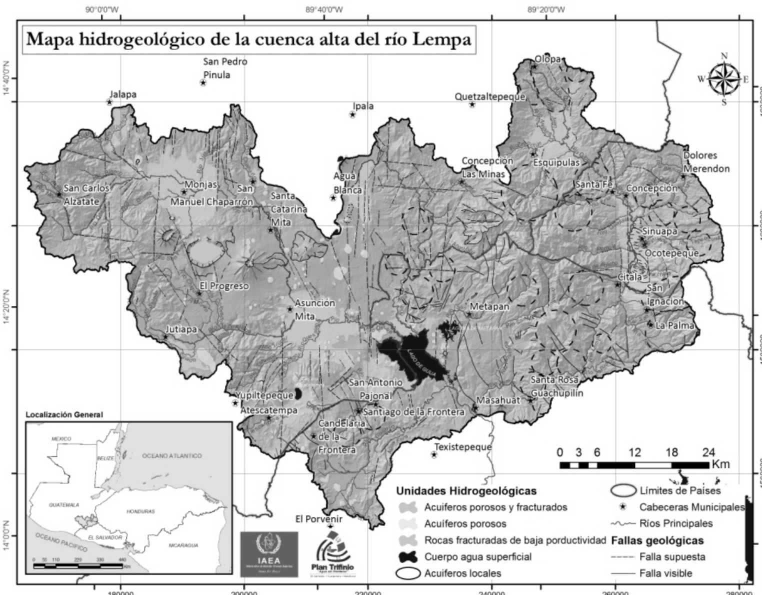

Figure 2. Hydrogeological map of Upper Lempa River Basin.

As a synthesis, the hydrogeology of Trifinio is characterized by the importance of significant fracture systems, which create deep circulation of groundwater in certain areas, and the existence of both local and regional flow systems. Tritium isotope indicated groundwaters with various degree of admixture of recent waters to waters probably recharged several decades ago. Chemical and isotopic similarities between most surface waters and groundwaters, however, suggest a dominantly fast dynamic for most systems and a high relevance of local sources of recharge via isolated aquifers.

Conceptual flow models demonstrate that the main discharge points takes place through springs and other structures in valleys. Isotopically enriched groundwater was observed in the zones of Güija and Metapán, suggesting a recharge of evaporated water from the adjacent lakes. This can be seen in Figure 3, which shows a Craig diagram with the local meteoric line and δ^2H $\delta^{18}O$ results of all samples of surface and groundwater.

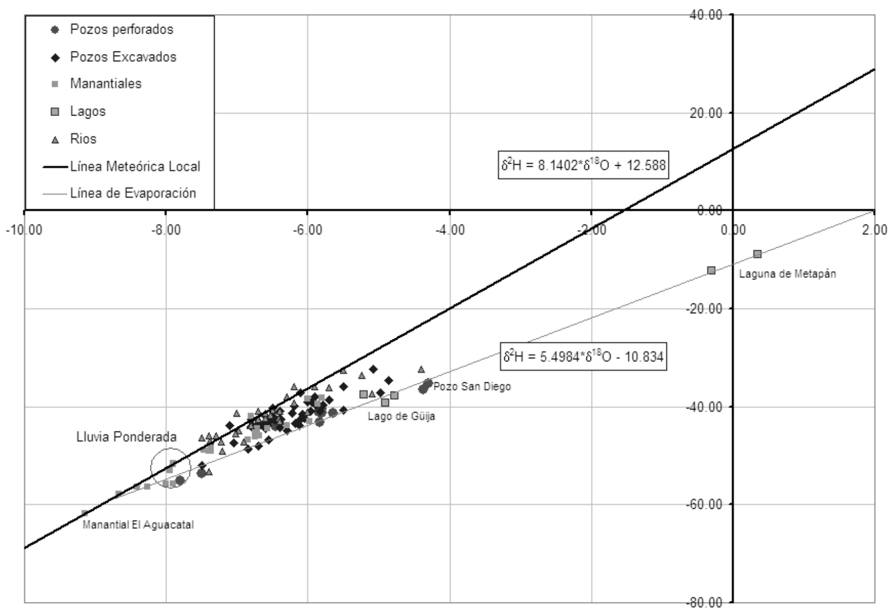

Figure 3. Isotopic composition of δ^2H $\delta^{18}O$ in groundwater and surface waters

More pronounced stream-aquifer interactions possibly with spatial or temporal shifts between aquifer recharge and discharge from and to streams was observed in certain valleys (for example the zone of Nueva Ocotepeque in Honduras). Additional work on a possible interaction with deeper groundwaters is in progress.

5. CONCLUSIONS

It can be concluded that the Trifinio is a highly dynamical shallow hydrogeological system with a dominance of rapid circulation between aquifers, springs and streams, and a portion of fractured aquifers with potential hydraulic communication via deeper regional flow systems yet to be better understood. The rapid recharge and discharge imply a high degree of vulnerability through contamination fluxes and must be considered in local and regional water management plans of the Upper Rio Lempa basin. Current work is focusing on the assessment of vulnerability of selected larger transboundary porous aquifers, such as Nueva Ocotepeque or Guija-Metapán, and their interactions with the fractured aquifers. The preliminary results have shown the chemical and isotopic similarities between most surface waters and groundwaters, suggesting both a fast dynamic for most systems and the relevance of local sources of recharge. Most of the identified shallow aquifers are isolated and the base flow of the Upper Lempa River is maintained through discharge by these aquifers, mainly located in the eastern zone (Olopa-Ocotepeque-La Palma).

The Metapan lagoon and Lake Güija behave as discharge areas for the groundwater flow system in the Trifinio region, this behaviour was deduced from the piezometric heads and the hydrogeochemical characteristics of the surface and groundwater. The isotopic signature of both water bodies is enriched by evaporation, but this phenomenon has a stronger impact in the Metapan lagoon as in Lake Guija since the lagoon is relatively shallow. It was also estimated that the Metapan Lagoon discharges into the Lake Güija through a barrier of highly fractured and scoriaceous lava forms that separates them, and also because the Metapan lagoon has a higher elevation.

Even though the former mentioned surface water bodies behave as regional discharge areas, the direction of the groundwater flow could be locally reversed by the pumping of deep wells, as is the case of the San Diego well, which is located less than one mile from the Metapán lagoon, which could be extracting waters that are a mixture of local and regional flows and water of the lagoons. The precipitation presents a high temporal variation in deuterium (-105.60 ‰ $\leq \delta^{2}H$ 21.66 ‰) and oxygen-18 (-14.76 ‰ $\leq \delta^{18}O \leq$ 1.37 ‰), due to the combined effects of amount and altitude. Also, a strong seasonally effect can be found.

Tritium was determined in 29 samples from wells, springs, rivers and lakes from El Salvador. Observed maximum activity was of 2.09 UT and a minimum of 0.00 UT. Tritium concentration in precipitation shows a tendency to decrease their activity to background noise. According to Tritium data from precipitated water monitored at the Ilopango Station of El Salvador during the period 1968-1981(outside the Trifinio region), Tritium shows and exponential and asymptotic behaviour toward the values 4.0 to 4.5 UT. The results indicate that at least four samples showed no Tritium activity, which could be interpreted as water corresponding to intermediate and regional flows where the Tritium in the system has disappeared. 20 samples showed an activity greater than 1 TU reaching even 2.09 UT. Taking into account that the natural concentration of tritium when it enters the hydrogeological system is of approximately 4 UT, the trend observed at the Ilopango Station and the half-life of tritium (12.3 years), there is a significant component of young water (less than 12 years) in the majority of the sites. In order to give a accurate estimation of groundwater age on the Trifinio region d14C or CFC studies should be carry out.

5. ACKNOWLEDGEMENTS

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TOWARDS THE SUSTAINABLE MANAGEMENT OF THE GUARANI WATER SYSTEM IN THE ARGENTINE REPUBLIC

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ABSTRACT

This investigation is intended to summarize the relevant institutional and legal aspects related to the environmental protection and to the sustainable development of the Guaraní Water System in the Argentine Republic and the present work has been carry out following the qualitative-comparative research method of investigation. At present the institutional and legal frames related to underground water in the Argentine provinces that comprises the SAG, are in general signed by a great number and superposition of legislations and organisms that manage the mentioned resource. The depicted situation risks the elaboration and consequently implementation of an appropriate model of sustainable management applicable to the SAG in the Argentine Republic. Consequently, the following points must be emphasized and considered as relevant axes regarding the environmental protection and sustainable development of the SAG within the territory of the Argentine Republic: 1) The creation of a Unique Water Authority for the Provinces of Santa Fe, Formosa, Misiones and Entre Ríos that centralizes the actions of the hydric sector in one single administration; 2) The creation of a Basin Committee formed by all the Argentine Provinces involved in the SGA in order to harmonize and adopt common directions in the matter of environmental ordering of the territory, control System on the development of the anthropic activities, environmental education, economic system of the promotion of the sustainable development, technical norms for the construction of deep wells and systems for the drainage of the waste thermal resources.

Key words: management, legislations, protection, sustainable.

1. INTRODUCTION

The research summarizes the relevant institutional and legal aspects related to the Environmental Protection and Sustainable Development of the Guaraní Aquifer System Project – GASP - in Argentina on behalf Argentina's legal system.

The paper was developed during 2007 and 2008 years as part of the Environmental Protection and Sustainable Development of the Guaraní Aquifer System. It was used a qualitative-comparative method that includes the compilation of existing water resources legislation, in addition to a tour and implementation of an institutional questionnaire to the water authorities of Corrientes, Misiones, Entre Ríos, Chaco, Formosa and Santa Fe Provinces.

2. INSTITUTIONAL AND LEGAL ASPECTS OF THE GAS IN REPUBLICA ARGENTINA .

The institutional and legal frames related to underground water in the Argentina´s Provinces that comprises the GAS, are in general signed by a great number and superposition of legislations and organisms that manage the mentioned resource. The depicted situation risks the elaboration and consequently implementation of an appropriate model of sustainable management applicable to the GAS in Argentina as it´s mandated on the Article 41 of the National Constitution of Argentina, NCA. The above situation is often repeated all along the national territory and this motivated the initiative launched by the Secretary of Water Resources, national authority on water, which led to the signing of the "Federal Water Agreement" of September 17, 2003, through which were agreed to the "Guiding Principles of Water Policy in Argentina", hereinafter referred as PRPH.

Basically the PRPH report indicates the significance of water for the Argentina, they are utilized as an engine of the sustainable development, foster the creation of a Unique Water Authority in each jurisdiction, and intends to establish the principle legislative centralization and stress the importance of relying on water management unit of the hydrological cycle.

Argentina is politically organized under a federal system under which various levels of government coexist: the National State, the Provinces, Municipalities and the Autonomous City of Buenos Aires, Articles 1 and 129 CNA (Iza and Rovere, 2006). The National Constitution itself has distributed the powers to legislate from the National State, Provinces, Municipalities and the Autonomous City of Buenos Aires under the provisions of Articles 5, 41, 121, 123, 124 and 129 NCA and stressed that among the subjects not delegated by the Provinces to the National Government is the ownership of water resources. In this sense it is understood that sustainable water management requires a functional reorganization of the responsibilities assumed by the various institutions as well as a deep adaptation of existing legislation as mandated by Article 41 of NCA, its regulations and directives prescribed by the PRPH.

It´s important to remark that Article 41 of NCA, guarantees the right to a healthy and balanced environment for all inhabitants of the country and imposes on them the duty to preserve it. Also the authorities have the obligation to provide the protection of that right, the rational use of natural resources, preservation of natural heritage, cultural and biological diversity, and environmental information and education. The Article 41 CNA since 1994 establishes the paradigm of sustainable development and therefore the management of water resources in Argentina must be sustainable, as well to protect and preserve them. These are fundamental duties both for authorities and the society.

It's important to remark, that Argentina's legal system, defines sustainable development in the 1st. paragraph of Article 41 NCA: "the needs of actual productive activities have to accomplish without compromising those of future generations" and later, the General Law on Environmental Policy Nº 25 675 of 2002 in Article 4 specifies that sustainable development is that where "the economic and social development and exploitation of natural resources must be made through proper management of the environment, so that does not compromise the potential of present and future generations."

In order to plan and implement activities aimed at environmental protection and sustainable development in Argentina's GAS, it's intends of the paper to synthesize the legal framework of the existing water resources in our country. In this regard, it is understood and shared with the majority doctrine that water law is a branch of environmental law and highlight the provisions of law Nº 25 675, Nº 25 688 and PRPH.

Related to environmental protection and water resources in particular, the Nº 25 675 law in it's article 1, sets out the minimum budget to achieve a sustainable and proper management of the environment, preservation and protection of biodiversity and the implementation of sustainable development. Also on it's Article 8 refers that the environmental management tools, must be applied throughout the national territory aimed at implementing sustainable management of water resources and the preservation and protection of themselves. The legal tools are listed below:

- Environmental ordering of the territory.
- Environmental impact assessment.
- Control system on the development of the anthropic activities.
- Environmental education.
- Mechanisms for citizen participation.
- Diagnostic system and environmental information.
- Economic system of the promotion of the sustainable development.

Complementary law Nº 25 688 on minimum budgets for environmental management of water in Articles 3 and 4 provides for the creation of basin committees for inter-jurisdictional watershed, this rule is grounded in the 1st. paragraph of Article 125 NCA which said: "The Provinces may enter into partial treaties for purposes of administration of justice, economic interests and work for common benefit, with knowledge of the Federal Congress (...)" and PRPH Nº 25.

Under the above context, the following points must be emphasized and considered as relevant axes regarding the environmental protection and sustainable development of the GAS within the territory of the Argentine Republic (Chiesa, 2007);(Chiesa, 2008):

1) The creation of a Unique Water Authority for the Provinces of Santa Fe, Formosa, Misiones and Entre Ríos that centralizes the actions of water resources sector in one unique administration. Under the provisions of PRPH Nº 24, the authority must have sufficient self-sufficient institutional and financial support to ensure proper performance of their duties, as well as to implement the water legislation and have the necessary police power for it's implementation. Not with standing the above, can be seen at the institutional level a trend towards the establishment and consolidation of Unique Water Authority in those jurisdictions.

2) The creation of a Basin Committee conformed by the Argentina's Provinces involved in the GAS in order to harmonize and adopt common policies in the matter of:

- Environmental ordering of the territory.
- Control system on the development of the anthropic activities.
- Environmental education.
- Economic system of the promotion of the sustainable development.
- Technical norms for the construction of deep wells.
- Systems for the drainage of the waste thermal resources.

CONCLUSIONS

The dominant characteristic at institutional level in Argentina, is the fragmented management of water resources and sector management by numerous agencies, at national, provincial and municipal level. Due to this, the implementation of a Basin Committee would provide a common space to design and initiate actions to implement environmental protection and sustainable development of the GAS in the country.

The existence of regional groups such as COHILI (which includes Corrientes, Entre Ríos and Santa Fe Provinces) and COHINEA (which includes Misiones, Chaco and Formosa Provinces), under the Federal Water Council could provide the necessary institutional support for creation of this Committee.

It is recalled that under current legal system, sustainable management of groundwater should be developed taking into account the economic, social and environmental aspects of the water sector, where the principles of prevention, accountability, sustainability and intergenerational equity should be the pillars of that administration and to thus ensure that productive activities meet present needs without compromising those of future generations as it stipulates the 1st. paragraph of Article 41 CNA.

Finally it is estimated that when the institutions adopt and pay off the loopholes in environmental protection and sustainable development described on the paper, (the goverment o the country) will be in position to make effective and operational, a rule applicable to the GAS in its capacity as a transboundary aquifer, be it from international law -UN- or right integration -MERCOSUR-.

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Transboundary Aquifer of Northern Thailand

UNESCO-IAH-UNEP Conference, Paris, 6-8 December 2010

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Abstract

Detailed hydrogeology of the Chiang Rai and Pha Yao Provinces in northern Thailand was studied by the Department of Groundwater Resources, aiming for a proper groundwater management. Conjunctive use of surface water and groundwater is planned as a part of a green society development project. The area covers 11,000 square kilometers of alternating hills and plains that is divided into five basins, namely Mae Sai, Chiang Rai, Mae Suai, Wiang Pa Pao, and Phan–Pha Yao basins. The Mae Sai and Chiang Rai basins are located in the northernmost part of Thailand and is hydraulically connected to Mekong River and the adjacent areas of Myanmar and Lao PDR. The aquifers in the basins are characterized by both hard rocks and unconsolidated sediments. Included are granite, sandstone, limestone, and volcanic rock aquifers at the depth of 20-80 meters with a yield of up to 30 m^3/hr, and the sand-gravel aquifers that may reach the depth of 250 meters with a yield of up to 50 m^3/hr. Groundwater quality is generally characterized by high iron content, and in some places, by high manganese and fluoride contents. Groundwater flow direction, aquifer hydraulic properties, groundwater potential and groundwater uses are also assessed.

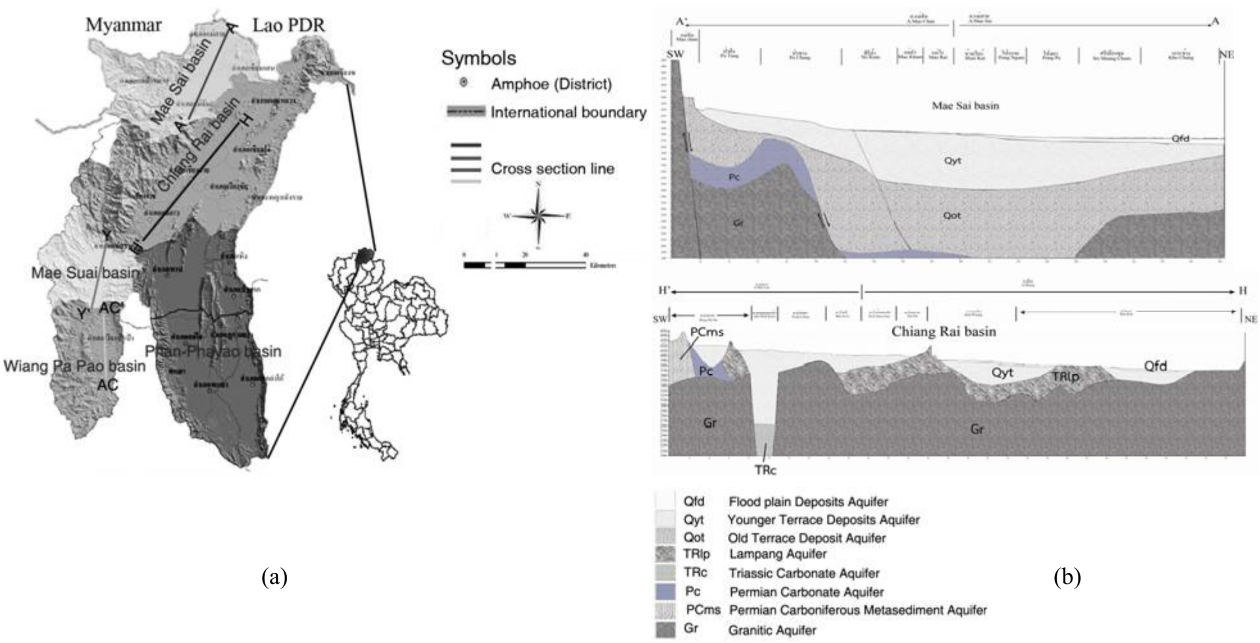
This study provides a basic knowledge that benefits the Mekong River Commission (MRC) countries and also Dialogue Partners of the MRC, i.e. Cambodia, Lao PDR, Vietnam, Thailand, China and Myanmar. Joint management of their shared water and related resources would form a strong foundation for sustainable development and poverty alleviation in the Greater Mekong Subregion.

Keywords: Transboundary Aquifer, Northern Thailand, Mae Sai Basin, Chiang Rai Basin, Mekong River

1. INTRODUCTION

Detailed hydrogeology of the Chiang Rai and Pha Yao Provinces in northern Thailand was studied by the Department of Groundwater Resources, aiming for a proper groundwater management. The area covers 11,000 square kilometers of alternating hills and plains, characteristics of a basin and range topography, and is divided into five basins, namely Mae Sai, Chiang Rai, Mae Suai, Wiang Pa Pao, and Phan-Pha Yao basins (Fig.1). Towards the north, northeast, and east of the area are Myanmar and Lao PDR. The Mae Sai river marks the border between Thailand with Myanmar while the Mekong river marks the border between Thailand, Myanmar and Lao PDR. The oldest rocks in the area are Precambrian high-grade metamorphic rocks, and the youngest is unconsolidated sediments of Quaternary period (Department of Mineral Resources, 2005). The geological structures of northern Thailand are characterized by folded Paleozoic-Mesozoic sediments and metamorphics superimposed by a series of Cenozoic extensional basins. The tectonic model explaining the formation of these intermontane basins is ascribed either as pull-apart basins associated with strike-slip faulting or extension and changing stress system related to the Tertiary-aged escape tectonics of Southeast Asia (Morley,2002).

The study aims to assess the groundwater potential of the area for a proper groundwater management. Conjunctive use of surface water and groundwater is planned as a part of a green society development project. This paper focuses on Mae Sai and Chiang Rai basins, which are hydraulically connected to Mekong river and areas of Myanmar and Lao PDR.



(a) (b)

Fig.1 (a) The Mae Sai, Chiang Rai, Mae Suai, Wiang Pa Pao, and Phan –Pha Yao basins in the northern Thailand, and (b) geologic cross-sections of the Mae Sai and Chiang Rai basins.

2. METHODS

To collect information used for assessing the groundwater potential of the study area, the following activities were performed:

1. Collection of available existing data on hydrogeology of the area, such as groundwater maps, well locations with well information and tests.
2. Resistivity surveys across the basins with Schlumberger and dipole-dipole configuration, with a maximum depth of about 200 meters.
3. Borehole drilling in 10 differences consolidated and unconsolidated aquifers. Core samples and cuttings were collected. Geophysical loggings were performed.
4. Setting up the composite monitoring wells with one test well and two observation wells at each site.
5. Pumping tests of 12 and 72 hours pumping period with a constant rate were performed in wells perforated in targeted aquifers, with a number of 100 wells and 16 wells, respectively. Data were analyzed using Aquifer Test v 2.57
6. Water level measurements and water samplings for complete chemical analyses.
7. Installation of piezometers in monitoring wells.

3. AQUIFERS AND HYDRAULIC PROPERTIES

The Mae Sai basin covers an area of 2,300 square kilometers. The recharge areas are located along the basin margin. The aquifers in the basin are both hard rocks and unconsolidated sediments. Included are carbonate aquifer at the depth of 20-80 meters with a yield of up to 30 m^3/hour, and the sand-gravel aquifers reaching the depth of 250 meters at the basin center, with a yield of up to 50 m^3/hr. The unconsolidated aquifers can be divided into (1) floodplain aquifer, 20-30 meters thick, composed of fine to medium sands, with a yield of 5-10 m^3/hr. (2) young terrace aquifer, 30-65 meters thick, composed of sands and gravels with interbedded clays, with a yield of 10-20 m^3/hr, and (3) old terrace aquifer, more than 150 meters thick, composed of sands and gravels with interbedded clays, with a yield of over 50 m^3/hr. Well drilled at Ban Hong Hae School, located near the center of the basin, yields flowing artesian water about 1.5 meters above ground surface (Fig.2).

The Chiang Rai basin covers an area of 2,500 square kilometers**,** with the recharge area and bedrock outcrops around basin periphery. The aquifers of the Chiang Rai basin are both hard rocks and unconsolidated sediments. Hard rock aquifers include granite, sandstone, limestone, and volcanic rock, at the depth of 30-80 meters with a yield of less than 2 m^3/hour. Sand and gravel aquifers may reach the depth of 50 meters near the basin center, with a yield of 10-20 m^3/hr.

The NE-SW cross-sections of the Mae Sai and Chiang Rai basins are shown in figure 1. The hydraulic properties of aquifers resulted from pumping test analyses are shown in table 1.

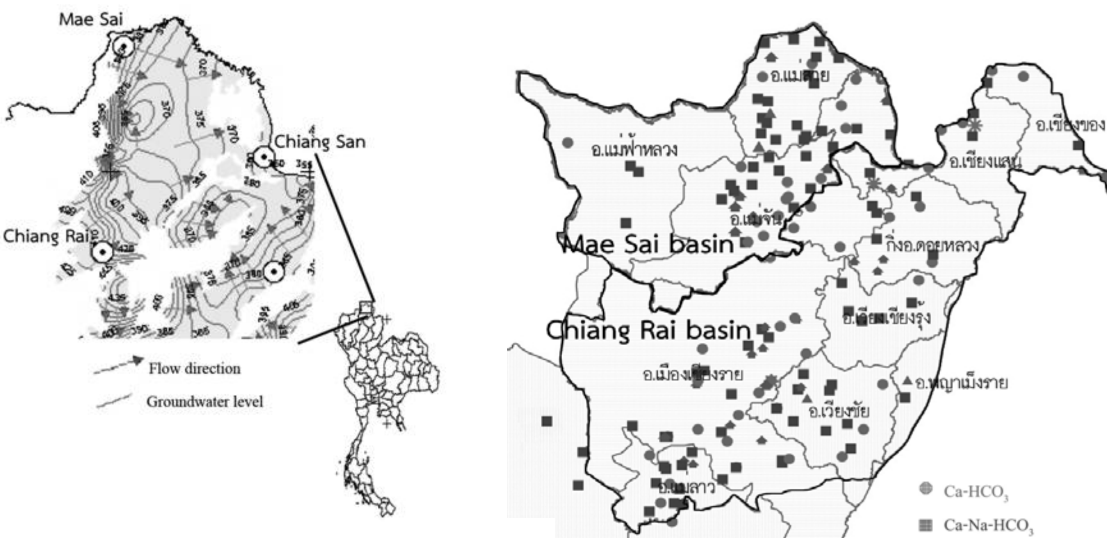
Table 1 Hydraulic properties of difference unconsolidated aquifers (Department of Groundwater Resources, 2009).

Aquifers	Transmissivity (m^2/d)	Hydraulic conductivity (m/d)
Floodplain (Qfd)	1.18 - 2,956.00	0.19 - 493.00
Young Terrace (Qyt)	0.50 - 569.33	0.08 - 189.73
Old Terrace (Qot)	0.24 - 698.00	0.02 - 42.88

Fig.2 Flowing artesian well in Mae Sai basin, depth of 200 meters with 50-60 m^3/hour.

4. FLOW DIRECTION AND QUALITY

Groundwater level of inventory wells in the Mae Sai and Chiang Rai basins were measured and plotted as the flow net diagram to assess the flow directions. In the Mae Sai basin, the flow directions are from west to east and from south to north. The flow direction in the Chaing Rai basin is from southwest to northeast (Fig.3). Groundwater samples were also taken for physical and chemical analyses twice a year, one in January (winter) and another in April (summer). The plots in Piper diagram show slight variation for both sampling periods. The major cations are calcium and in some places calcium and sodium while the major anions are bicarbonate. The typical hydrochemical facies of three different types of unconsolidated aquifers are calcium-bicarbonate, and calcium-sodium-bicarbonate (Fig.3). Groundwater quality is characterized by high iron content, and in some places, by high manganese and fluoride contents.



(a) (b)

Fig.3 Groundwater flow direction (a) and hydrochemical facies (b) of the Mae Sai and Chiang Rai basins.

5. CONCLUSIONS

The preliminary data reported here do not constitute a complete assessment of the transboundary aquifers in this region. However, the results reveal several key indicators to support the existence of the Mae Sai and Chiang Rai transboundary aquifers: (a) the thickness of unconsolidated sediments with a high yield of flowing artesian water, (b) geologic cross-sections showing the extent of aquifers beyond the borders of Thailand, Myanmar, and Lao PDR, and (c) groundwater flow of north and northeast directions toward the Mekong river.

This study provides a basic knowledge that benefits the Mekong River Commission (MRC) countries and also Dialogue Partners of the MRC, i.e. Cambodia, Lao PDR, Vietnam, Thailand, China and Myanmar. Joint management of their shared water and related resources would form a strong foundation for sustainable development and poverty alleviation in the Greater Mekong Subregion.

Acknowledgements

The project on "groundwater potential assessment of Kok watershed (Chiang Rai and Pha Yao Basin) was funded in 2009 fiscal year by the Department of Groundwater Resources. We thank the Department of Groundwater Resources for access to these data and for permission to publish this manuscript.

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Scaldwin Project
Sustainable aquifer management

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ABSTRACT

Since the beginning of the 20th century, the Carboniferous aquifer was known as a high potential aquifer. Groundwater has been exploited for decades to provide drinkable water and supply heavy factories in north of France and Belgium. Over-pumped during the last century, the Carboniferous aquifer has seen its water level dramatically decreased. Since the end of industrial period, groundwater consumption has decreased and water table is now stabilized and slowly coming back to a more "natural" level in some areas. However, this recent water level rise has triggered some chemical problems, such as the increase of sulphurs.

The "Carboniferous limestones aquifer" is composed by two rock layers: the Visean and the Tournaisian, representing the lower parts of the Carboniferous era. The higher part of the aquifer is very productive and generally considered as a karstified zone. Recharge areas are located on the eastern part of the aquifer, in Belgium, where limestones laid under a few meters thick soil. Slightly dipping toward south - west, the geometry of the aquifer is not accurately known due to a lot of east - west faults and the presence of a faulted synclinal near Tournai (Be).

In the past, a lot of hypotheses have been made regarding geometry and piezometry of this aquifer. Thanks to the "Scaldwin" project (launched in 2009), the assumptions are going to be set against more recent hydrogeological data and information provided by new borehole logs.

In one hand, this project should encourage and stimulate international cooperation at large scale: studies and methods standardisation, data transfer and sharing, common reporting process. On the other hand, this cooperation will reduce scientific uncertainties about the Carboniferous aquifer: more accurate geometry, building of hydrogeological referentials, extension of piezometrical maps, hydrochemical and isotopic characterization of different groundwaters…

New data from next field campaigns should help to generate a conceptual model of the aquifer behaviour, build a numerical model, and eventually modelize transfer functions between surface water and groundwater, in order to organize a sustainable management of the Carboniferous aquifer between France and Belgium.

Key words: limestones, karst, management, France, Belgium.

HISTORY

Since the beginning of the 20th century, the Carboniferous aquifer, mainly composed by partly-eroded sedimentary rocks, was known as a high potential aquifer. Groundwater has been pumped for decades to provide drinkable water and supply heavy factories in France (Lille and its suburbs representing 1 million of inhabitants) and Belgium.

Over-pumped during the second part of the last century, the Carboniferous aquifer has seen its water level dramatically decreased, until 90 m deep in France. From the 90's until now, corresponding to the end of industrial period, groundwater consumption has decreased and water table is now stabilized and slowly coming back to a more "natural" level in some areas (Fig. 1). However, the recent water level rise has triggered some chemical problems, such as the increase of heavy chemical compounds and sulphurs (Fig. 2).

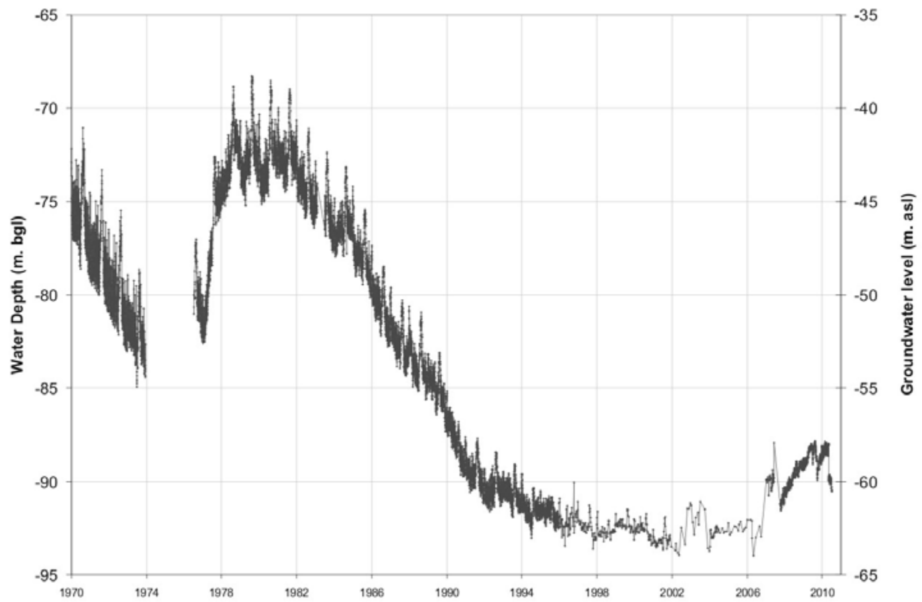

Figure 1: Piezometrical level (m) in a monitored borehole in Bondues (Fr), from 1970 to 2010.

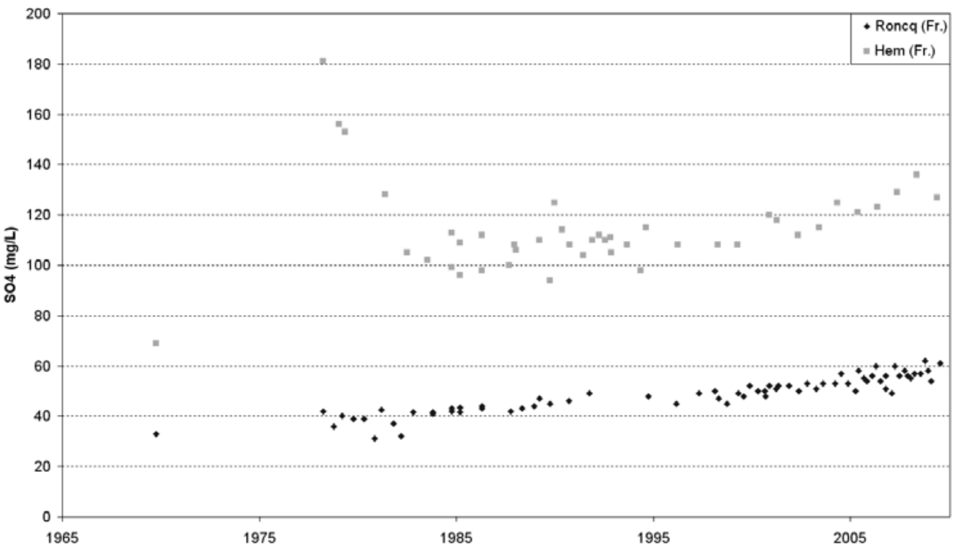

Figure 2: Sulphur concentration (mg/L) from two boreholes in France, from 1965 to 2010.

TRANSBOUNDARY COOPERATION

In 2000, European Union decided to globally protect water and published the directive 200/60/EC, establishing a framework for community action in the field of water policy. In this document, some articles directly refer to an "international cooperation for the management of transboundary aquifers". In 2002, Belgium, France and Netherlands signed the Gand agreement, confirming their will to coordinate the application of the EC law for the Escaut hydrological district. It reinforced the role played by the Escaut International Commission, created in 1994. One of its work topics was the groundwater vulnerability, with a focus on the Carboniferous limestones aquifer.

AQUIFER CHARACTERISTICS

The Carboniferous limestones aquifer is composed by two rock layers: the Visean (limestones and dolomites) and the Tournaisian (limestones, dolomites and shales), representing the lower parts of the Carboniferous era. The higher part of the aquifer, with an approximate thickness of 30 - 130 m, is very productive and generally considered as a karstified zone. The study area is 120 km long, from the west of Lille (Fr) to the east of Ath (Be), and 30 km wide on both sides of the administrative boundary (Youssof, 1973).

Recharge areas are located on the eastern part of the aquifer, in Belgium, where limestones laid under a few meters thick soil (unsaturated zone). Slightly dipping toward south - west, the geometry of the aquifer is not accurately known due to the number of east - west faults and the presence of an faulted anticline near Tournai (Be). Therefore, groundwater is mainly considered as confined in the west part of the study area, due to the impermeable cover by clayey layers (Secondary and Tertiary, depending on location). Nevertheless, some previous studies tended to prove that direct flow connections may exist between surface water and the Carboniferous aquifer (Mania, 1974).

A lot of studies have been carried in the past regarding aquifer geometry and groundwater flows (Talbot *et al*., 1979). And tries of mathematical modelling (Mania, 1974 and 1976) suggested that spatial data density (transmissivity, piezometrical level, pumping volume…) was too weak to have confidence in modelling results. One scope of these works was to create management rules for water supply in Lille (Besbes and Talbot, 1983), even if some areas of the Carboniferous aquifer are not well known (Fig. 3).

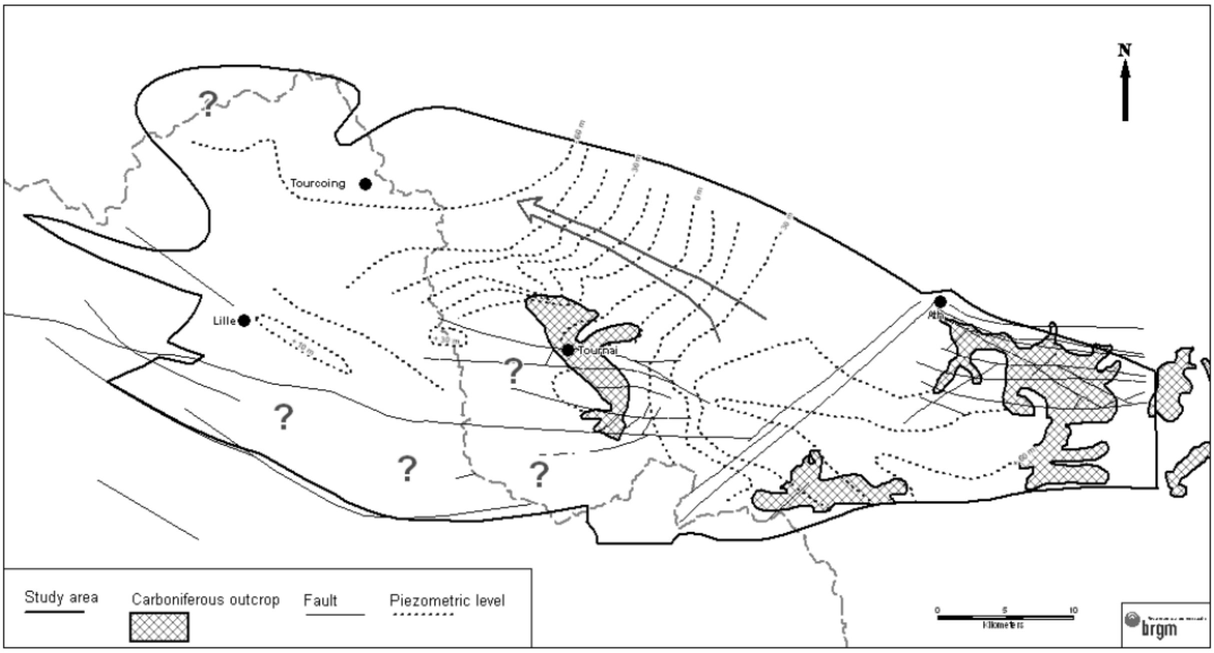

Figure 3: Map showing global groundwater flow and uncertainty areas (data from a piezometrical campaign in 2006).

SCALDWIN PROJECT

This international project, established in 2009, has two main goals. First, it should encourage and stimulate international cooperation at large scale: studies and methods standardisation, data transfer and sharing, building of geological and hydrogeological referentials. Then, further studies could help to reduce scientific uncertainties about the Carboniferous aquifer: more accurate geometry, extension of piezometrical maps, hydrochemical and isotopic characterization of groundwater…

Thanks to the next field campaigns, all the past results and assumptions will be compared with geological and hydrogeological data from new boreholes drilled in different parts of the study area. All the contributors are expecting to be able to generate a conceptual model of the aquifer behaviour, to build a numerical model, and eventually to modelize transfer functions between surface water and groundwater, in order to organize a sustainable management of the Carboniferous aquifer between France and Belgium.

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Multi-disciplinary approch to improve the knowledge of southeastern border of Taoudeni sedimentary basin

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ABSTRACT

South-west Burkina Faso shares with south Mali a regional scale aquifer which is a part of the West Africa's large sedimentary basin of Taoudeni. This aquifer represents about 40,000 km² inside Burkina Faso with à maximum depth of 2,000 m so that it provides a significant part of the country needs for domestic purposes and irrigation.

The region is characterised by semi-arid climate and more specifically a notable decrease in pluviometry observed in the last 40 years. Demographic explosion added to the climate context lead to highly increased needs of water for human consumption and economic development. In view of this concern, the groundwater management has become a priority not only for the Burkina Faso authorities, but also for the international community.

A hydrogeological multi-disciplinary approach (stratigraphy, hydrodynamic field-data, geochemistry and isotopic techniques) combined with geological and hydrogeological modeling was implemented to improve the knowledge of the aquifer system and the efficiency of its management.

Keywords : Taoudeni, sedimentary basin, hydrogeology.

1. INTRODUCTION

South-west Burkina Faso shares with south Mali a regional scale aquifer which is a part of the West Africa's large sedimentary basin of Taoudeni.
A hydrogeological multi-disciplinary approach (stratigraphy, hydrodynamic field-data, geochemistry and isotopic techniques) combined with geological and hydrogeological modeling was implemented to improve the knowledge of the aquifer system and the efficiency of its management.

2. LOCATION OF TAOUDENI SEDIMENTARY BASIN

Taoudeni basin is the largest sedimentary basin of Upper Precambrian and Palaeozoic age in Africa. It stretches across Mali, Mauritania and the two Guineas and overlaps slightly into Algeria, Senegal, Sierra Leon and Burkina Faso (Fig.1).

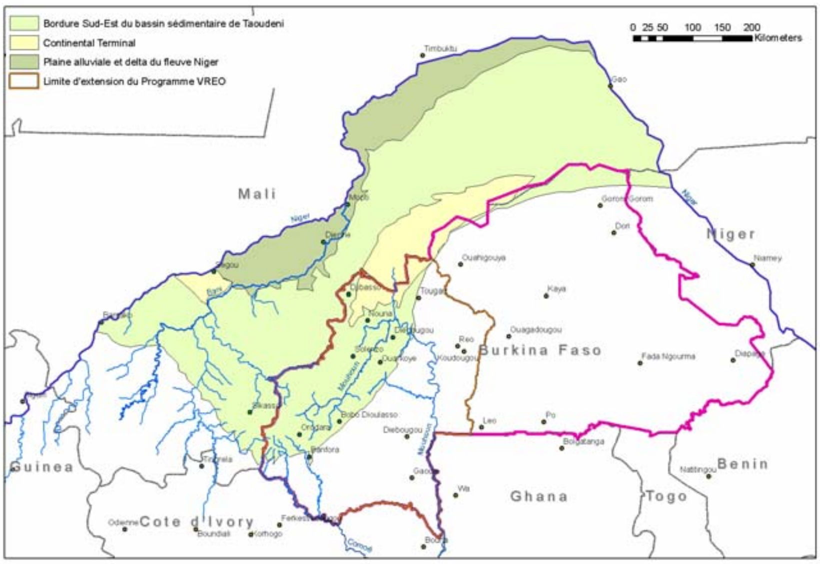

Figure 1. Overall view of the south-eastern margin of the Taoudeni basin.

Overall, its structure is simple: the most recent formations crop out in its sandy centre and the dip rarely exceeds 1°. The surface area of the south-eastern margin of the sedimentary basin (Mali and Burkina Faso) is close to 260,000 km^2 with 20% in Burkina Faso border. It is partially covered by surface formations of Tertiary and Quaternary among which the so-called Continental Terminal Tertiary formation and the recent and modern claysand alluvia found along the main rivers.

3. HYDROGEOLOGICAL DESCRIPTION OF THE AQUIFER SYSTEM IN THE TAOUDENI SEDIMENTARY BASIN

The hydrogeological characteristics of the Taoudeni sedimentary basin series can be determined toward quantitative and qualitative data collected in the study area. Data come from more the thousand drilled wells and were used either for statistical analyses by formation or analysis of the whole basin.
Spatial interpretation of the piezometry gave the following informations:

- Study area shows mean piezometric heights ranging between 600 and 200 m;
- Administrative border of Burkina Faso and Mali largely coincides with the boundaries of the main surface basin. Boundaries between main watershed basins and hydrogeological basins also coincidence meaning that no groundwater exchanges occur between the two countries along the administrative border. Hence, administrative border between Mali and Burkina Faso follows a hydrogeological ridge playing the role of groundwater divide. This is clearly indicated on piezometric map of the south-west extension of Bandiagara cliff where groundwater divides along the Mali border. Thus, main groundwater exchanges between the two countries are located in (i) the north close, to the Continental Terminal and to the Sourou (ii) in the west at the piezometric trough of Banifing and (iii) in the south-west in the Comoé basin. At the present state of the knowledge, groundwater transport at depth cannot be excluded as another way of boundary exchange.
- Concerning cross-border water resource management, attention should be paid to the fact that no groundwater flow occurs from Mali in the sedimentary formations. All the flow comes exclusively from Burkina Faso and derive from its rainfall recharge.

The evolution over time of the piezometry, albeit based on a small number of observations, shows a general decrease of the water levels over the last five decades.

The groundwater quality was assessed using hydrochemical facies in the different formations. The facies were defined by statistical analysis, interpretation on Piper and Schoeller diagrams and Principal Component Analyses. Data show that majority of the samples are calcium bicarbonate type (86%), indicating a high degree of pollution. Schoeller diagram shows uniformity in data at regional scale and reflects hydraulic continuum across the various basins.
Isotopic studies (Dakouré, 2003) show that most ofthe sedimentary reservoir water is old (from 50 to more than 1000 years) which is not incompatible with the the present aquifer recharge. Current interpretation proposes a mixing model containing contemporary/recent water with old water.

4. CONCLUSION

On the basis of the results and interpretations of field data, a conceptual representation of the hydrogeological situation was built into a geological (aquifer geometry) model. Further studies on each side of the border separating Burkina Faso and Mali should contribute to validation of some assumptions still being considered as conceptual hypotheses.

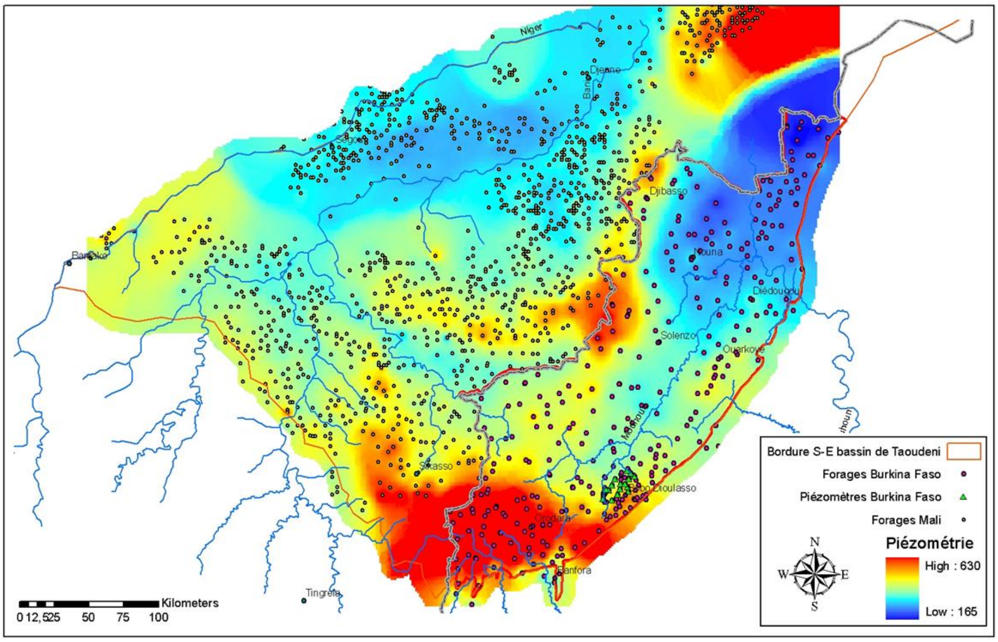

Figure 2: Piezometric map of the southeastern border of Taoudeni sedimentary basin

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International Groundwater Management in the Amazon Transboundary Aquifer System:
An Analysis to the Implementation of the United Nations International Law Commission Draft Articles on the Law of Transboundary Aquifers

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ABSTRACT

Introduction. In South America, based on United Nations estimates, 50 to 60 percent of the total domestic and industrial water supply comes from groundwater resources. Recently, the UNESCO/OAS ISARM Americas Programme has identified a large regional aquifer system called "Amazon Transboundary Aquifer System (ATAS)," appearing to involve six countries: Bolivia, Brazil, Colombia, Ecuador, Perú and Venezuela. Initial data collected indicate the principal use of the ATAS is for human consumption, and for many communities where surface waters are polluted it may be the only source of clean water. Currently, there are no established mechanisms for ATAS regional governance and management, and there remains much uncertainty regarding not only its physical characteristics but also its socioeconomic impact on riparian communities. ***Purpose.*** The intent of this project was to identify and analyze opportunities and challenges the ATAS States face in developing a collaborative framework to govern and manage the ATAS. Additionally, an analysis was conducted for how the principles and mechanisms advanced by the International Law Commission (ILC) draft articles on the Law of Transboundary Aquifers could be employed in order to enhance and address the opportunities and challenges identified. And finally, recommendations for improving the applicability of the ILC draft articles were developed. ***Conclusions.*** Before the ILC draft articles can be successfully implemented for achieving governance and management of the ATAS, the ATAS States must reach a certain level of action, cooperation, knowledge and understanding. The ILC draft articles, thus, should provide further guidance or be complemented with guidelines to aquifer States with insufficient knowledge basis. This guidance should include information on how to undertake joint fact-finding approaches, how to develop appropriate monitoring and assessment frameworks, and emphasize the importance of coordinating surface water regimes with groundwater regimes.

Key words: Amazon, Aquifer, Draft articles, Transboundary, Management

1. INTRODUCTION

In 2007, the UNESCO/OAS ISARM Americas Programme published an inventory, which identified 29 transboundary aquifers across 12 countries (UNESCO, 2007). This inventory indicated the existence of the Amazon Transboundary Aquifer System (ATAS). The ATAS appears to be one of the largest transboundary aquifers in South America, shared by six countries: Bolivia, Brazil, Colombia, Ecuador, Perú and Venezuela. Preliminary data indicates the ATAS has good water quality; its principal use is for human supply; and it is the only source of clean water in many communities where surface waters are naturally or anthropogenically polluted (UNESCO, 2007).

Currently, international arrangements to govern the ATAS do not exist, thus, its management still remains within a splintered domestic scope. The latest development in international transboundary groundwater policy has been the United Nations International Law Commission (ILC) draft articles on the Law of Transboundary Aquifers. The ILC draft articles provide principles, tools and mechanisms that could offer important guidance to ATAS States for developing a coordinated transboundary aquifer management framework.

2. OBJECTIVE

The principal objective of this independent research graduate project was to identify current opportunities and challenges for the regional sustainable management of the ATAS. And, to determine strengths and limitations in the ILC draft articles for enhancing and addressing the opportunities and challenges identified, when implemented toward developing a coordinated framework for governing and managing the ATAS.

3. RESULTS AND DISCUSSION

3.1. Opportunities and Challenges for a Coordinated Framework for the ATAS

The ATAS States present two major opportunities for justifying the need, and facilitating the development of a regional governance and management framework for the ATAS. Initially, *the ATAS appears to be one of the largest groundwater aquifers in South America, and the source of water supply for many riparian communities* (UNESCO, 2007). *The ATAS also appears to have high water table, thus, significant vulnerability to water pollution and probabilities of connections with surface water bodies* (UNESCO, 2007). These characteristics meaningfully validate the need for a regional governance framework for the ATAS. A second opportunity that might help facilitate the development of a regional framework for the ATAS is that *there is a Treaty for the sustainable management of the Amazon River Basin in place* (UNESCO, 2007). The Amazon Cooperation Treaty (ACT) and its implementing agency, the Amazon Cooperation Treaty Organization (ACTO), are legal and institutional tools already adopted by the six ATAS countries. Thus, this existing legal and institutional infrastructure could be leveraged for any future international agreement for the ATAS. Furthermore, by coordinating the new ATAS regime with the ACT, interdependent regimes for surface waters and groundwaters in the Amazon Region could be developed, promoting an integrated management of water resources.

Conversely, there is a major challenge that the region would need to overcome for achieving a regional approach for the sustainable management of the ATAS. *The ATAS States lack a fundamental understanding of the ATAS attributes and needs* (UNESCO, 2007), which is essential information for guiding the development of a sound governance framework. Before governing, it must be clearly understood what exactly is to be governed. However, the fact that water resources appear to be abundant in the Amazon region has seemingly hindered the realization of the importance of the region's groundwater resources, and therefore, the interest in further understanding the ATAS.

3.2. Implementation of the ILC Draft Articles in the ATAS: Strengths and Limitations

The ILC draft articles are important policy instruments that could guide the ATAS States toward achieving a collaborative framework to manage the ATAS. The draft articles provide some *standard definitions* that help facilitate the understanding among the ATAS States. Also, the draft articles promote a *comprehensive scope*, encouraging ATAS States to focus efforts not only in the uses of the transboundary aquifer, but also the utilization which includes other activities that could have impacts on the aquifer. Lastly, the draft articles *support principles* essential for a sound coordinated framework *such as cooperation, and collection and exchange of information*.

However, the ILC draft articles also present two fundamental limitations in trying to guide the development of a regional management framework for the ATAS. First, *the draft articles do not provide sufficient guidance to aquifer States on how to achieve the required level of action and knowledge about their transboundary aquifer*. If the ATAS States want to develop a multilateral framework that involves the principles, tools and mechanisms embraced by the ILC draft articles, they first must reach a benchmark level of cooperative action and understanding regarding the transboundary aquifer. Thus, the ILC should also consider providing guidance on joint fact-finding initiatives, and developing or adapting monitoring and assessment guidelines.

Second, the ILC draft articles *do not underscore the importance of coordinating groundwater and surface waters management*. In many cases, groundwaters are interconnected with, and provide the source of recharge to surface waters or vice versa (Dellapenna, J. & Rocha, F., 2010 forthcoming). Therefore, both regimes should be interrelated to ensure integrated protection of water resources (Eckstein, G. & Eckstein, Y., 1998). Furthermore, the ATAS has not received significant attention, in part because it is located in a humid and surface water-rich region, and connections between surface waters and the ATAS are not well understood yet. Thus, if the draft articles were to promote the conjunctive management of waters, the ATAS would likely have more opportunities of not only promoting an integrated water resources management approach, but also reaching public awareness and political will for a regional governance framework.

4. CONCLUSIONS

In summary, ATAS States have important opportunities for developing a regional management framework for the ATAS. For example, the ATAS appears to be one of the biggest groundwater aquifers in South America, and the source of water supply for many riparian communities. Therefore, effective governance of the ATAS across geopolitical boundaries is paramount for its long-term sustainability, in supporting dependent human consumption. Additionally, there is a Treaty for the sustainable management of the Amazon River Basin in place (the Amazon Cooperation Treaty –ACT) that could be used as a foundation to promote the integrated management of waters. However, a major challenge ATAS States will have to face is the lack of appropriate understanding regarding the ATAS' attributes and needs. The ILC draft articles are important instruments for guiding ATAS States toward addressing this challenge. Yet, they do not provide sufficient guidance on how to achieve the appropriate and required level of action and knowledge about the transboundary aquifer. Lastly, the ILC draft articles do not underscore the importance of coordinating groundwater and surface water management.

The period of time before the UN General Assembly decides the final form of the draft articles in 2011 is important for the future of the draft articles (Yamada C., 2009). It provides the opportunity to re-evaluate any gaps or limitations of the draft articles, in order to ensure that adequate principles and tools are provided to guide aquifer States in overcoming the challenges associated with the sustainable management of transboundary aquifers (Eckstein G., 2007).

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Assessment of the groundwater quality status and vulnerability of the coastal aquifer systems of Benin, Nigeria and Togo (West Africa)

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ABSTRACT

The coastal sedimentary transboundary aquifer of west Africa is partly shared by three countries including Benin Republic, Nigeria and Togo. The groundwater resources in the area are mainly for domestic water supply in both urban and rural areas. However, with the pressure on groundwater some problems exist which include but not limited to overexploitation, contamination and pollution from poor waste disposal and intrusion of sea water. The present work entails the identification of aquifers, determination of the quality status of the groundwater and assessment of the coastal aquifer vulnerability to pollution. The results showed that within the coastal area, seven (7) aquifers were identified as follows: Lower and Upper aquifers (Benin Republic), Deltaic and Benin Aquifers (Nigeria) and Continental Terminal (CT), Eo-Paleocene (Eo-Pa) and Maestrichtian (Ma) aquifers in Togo. The average physicochemical compositions are generally within the levels of portability. The mean concentration of nitrate however, exceeded 10mg/l in all the aquifers except the Deltaic Aquifer (mean 2.82mg/l) in Nigeria and Eo-Pa Aquifer in Togo (mean 7.88mg/l). The major factors controlling the water chemistry in the study area are sea water intrusion (enhanced Cl), carbonate dissolution/weathering (enhanced concentration of Ca & HCO_3) and human activities (enhanced concentration of NO_3). Vulnerability assessment according to GOD method indicates that the aquifer systems are lowly (Upper, Eo-Pa & Ma aquifers) through moderately (Deltaic Aquifer & CT aquifers) to highly (Lower & Benin Aquifers) vulnerable. Management of the groundwater resource will include mainly legislation towards construction and use of shallow wells/boreholes and regulation of abstraction to reduce saline contamination and proper waste management ate to reduce the concentration of nitrate as is presently done in Nigeria.

Keywords: Aquifer, hydrochemical, pollution, transboundary, vulnerability

1. INTRODUCTION

The coastal sedimentary basin of West Africa straddles several countries including Benin, Nigeria and Togo (Fig. 1). Almost all communities in the coastal area depends on groundwater for drinking and domestic purposes. However, despite the urbanization in the west coast of Africa, natural processes and indiscriminate disposal of waste forms a major threat to these aquifers.

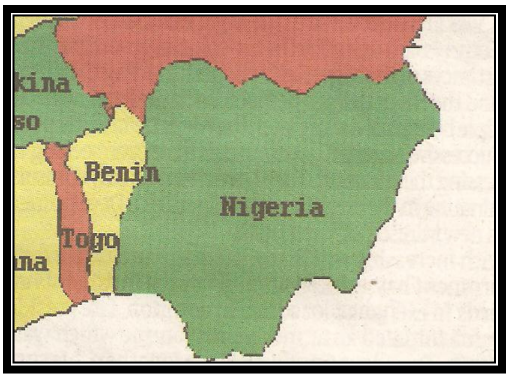

Fig. 1 Map of West Africa including Benin, Nigeria and Togo.

1.1 Objectives

The main objective of the present work therefore is to identify the major aquifers in the coastal parts of Benin Republic, Nigeria and Togo; determine the quality status of groundwater and assess the vulnerability of the aquifers to pollution as a basis of identifying major threats to the different aquifereous layers to enable proper management of the groundwater resource. The climatic and geological conditions for these areas are presented in Table 1.

Table 1 Area characteristics and vulnerability of aquifers in Benin, Togo and Nigeria

Country	Age	Aquifer	Lithology (Geology)	Climatic Conditions	Temp °C	Rainfall mm	Vulnerability Class
Benin	Quaternary	Upper	Sand and clay	Sub-equatorial type			High vulnerability
	Miocene-Pleistocene	Lower	Sand, gravel and clay	Two rainy and two dry seasons			Low vulnerability
Nigeria	Quaternary	Deltaic	Sand, silt, clay and peaty materials	Tropical rainforest	27	2400-4800	High vulnerability
	Tertiary	Benin	Sand and clay	One rainy and one dry season			Medium vulnerability
Togo	Quaternary	CT	Sand, gravel and clay	Guinea equatorial type			Medium vulnerability
	Eocene	Eo-Pa	Limestone and marl	Two rainy and two dry seasons	24-30	800-1400	Low vulnerability
	Maestrichtian	Ma	Sand and clay				Low vulnerability

1.2 Data

The hydrochemical data for coastal sedimentary of Benin was adapted from Boukari *et al.* (2008); Edet (2008) and some recently acquired data for Nigeria and from the work of Akouvi *et al.* (2008) for Togo.

2. GROUNDWATER QUALITY

2.1 Statistical assessment

The basic properties of groundwater are listed in Table 2. The mean values of the parameters in the groundwater samples for all the aquifers fall within the safe limits prescribed by WHO (1993) for drinking water. The only exception was pH for the Ma aquifer in Togo.

Table 2 Mean values of physicochemical Parameters for the different aquifers

Country	Aquifer	SEC µS/cm	TDS mg/l	pH	Na^+ mg/l	K^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^- mg/l	HCO_3^- mg/l	SO_4^{2-} mg/l	NO_3^- mg/l	Hardness mg/l	Na Hazard	RSC	SAR
Benin	Upper	543.94	362.12	7.27	56.68	20.55	28.82	7.06	65.06	96.76	37.92	46.36	100.998	62.417	-0.443	3.172
	Lower	583.46	416.62	7.19	48.12	26.47	49.33	4.79	55.72	141.12	28.83	57.93	142.969	49.593	-0.552	1.803
Nigeria	Deltaic	272.49	150.50	6.56	33.16	5.55	28.13	4.29	80.60	56.93	7.19	2.82	87.938	48.036	-0.831	1.663
	Benin	228.58	117.40	6.30	18.94	2.30	2.22	0.46	10.84	44.81	2.82	27.55	7.465	87.608	0.585	3.631
Togo	CT	728.00	466.67	5.37	90.21	2.80	26.52	17.32	143.45	166.13	16.02	15.83	137.307	60.648	-0.046	3.335
	Eo-Pa	1099.00	704.49	7.55	68.90	7.83	110.34	37.99	105.58	581.54	50.19	7.88	431.610	28.126	0.851	1.534
	Ma	156.67	100.43	5.30	9.12	1.60	14.47	4.12	14.34	68.84	4.64	14.05	53.059	36.700	0.062	0.636
Standards	*WHO (1993)*	*1400*	*1000*	*6.5-8.5*	*250*	*10*	*200*	*100*	*250*		*250*	*10*				
Maximum value		Eo-Pa	Eo-Pa	Eo-Pa	CT	Lower	Eo-Pa	Eo-Pa	CT	Eo-Pa	Eo-Pa	Lower	Eo-Pa	Benin	Eo-Pa	Upper
Minimum value		Ma	Ma	Ma	Ma	Ma	Benin	Benin	Benin	Benin	Benin	Deltaic	Benin	Eo-Pa	Deltaic	Ma

CT-Continental Terminal; Eo-Pa-Eocene-Paleocene; Ma-Maestrichtian

Strong correlations exist between Na and Cl; Ca and HCO_3 and K and NO_3. These relationships identify sea water intrusion, carbonate dissolution and anthropogenic input as the main elements contributing to groundwater chemistry in these areas.

The R-mode factor analysis indicated three factors accounting for 85.516% of the variance in the data set. Factor 1 (56.473%) has high loadings for HCO_3 and Ca is interpreted as mainly due to carbonate weathering. This is attributed to the limestones and marls of the Eo–Pa Aquifer (Togo). Factor 2 (16.152%) indicates the effect of anthropogenic input given the high loading for K and NO_3 as in the Lower and Upper Aquifers in Benin (Boukari et al., 1996). Factor 3 (12.891%) with high loaders for Na and Cl is as a result of seawater contamination in Benin, Nigeria and Togo.

2.2 Quality Status and vulnerability of aquifers

Based on the %Na the groundwaters were classified as very good to good for irrigation. On individual basis only few samples for the Lower and Upper Aquifers (Benin Republic), CT and Eo–Pa Aquifers (Togo) were grouped as good to permissible and doubtful to unsuitable. The sodium adsorption ratio (SAR) indicates that the groundwater is satisfactorily for irrigation use in almost all soil types. In addition, the Residual Sodium Carbonate (RSC) values ranged of between –0.831 and 0.661 mg/l which is < 1.25 mg/l and thus safe for irrigation (Richards, 1954).

Vulnerability of the different aquifers in the area was based on **G**roundwater occurrence (aquifer type), **O**verall aquifer class (lithology and porosity) and **D**epth to water table (GDD, Table 1) designed by Foster (1987). The data show that the aquifers are lowly (Upper, Eo-Pa & Ma Aquifers) through moderately (Benin & CT Aquifers) to highly (Lower & Benin Aquifers) vulnerable.

4. MANAGEMENT ISSUES AND CONCLUSIONS

The study demonstrates that three main factors control the groundwater quality in coastal parts of West Africa namely:

(i) sea water intrusion due to elevated concentration of Cl^-; (All aquifers except Benin aquifer in Nigeria and Ma Aquifer in Togo).
   - For the purpose of management, wells/shallow boreholes should be encouraged and abstraction regulated.

(ii) anthropogenic as a result of enhanced concentration of NO_3^- (as in Benin)
   - In order to safe guard the resources, proper management of waste should be put in place (as presently seen in most cities in Nigeria).

(iii) carbonate dissolution due to high concentration of Ca^{2+}, Mg^{2+} and HCO_3^- (especially, in Eo-Pa Aquifer in Togo)
   - These waters will require some form of treatment. However, detailed studies will guide the siting of boreholes in areas of relatively soft water.

Generally, proper site investigation should be carried out in these areas before a waste dump or landfill is sited due to high vulnerability of some of the aquifers.

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Prospective Regulatory Environmental Services Provider for Aquifer Recovery

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ABSTRACT

Aquifers are source of potable water in many sites in Egypt. For years, farmers have dug many wells to drink, supply the rainfall and to grow crops. But then, overexploitation of this groundwater became a major concern especially with climate change problems. In most of Egyptian sites, the aquifer system doesn't have the capacity to support full irrigation. Thus, traditional and modern techniques were both employed to artificially recharge the groundwater. Also, optimization of water use efficiency became necessary to face the droughts and the declining freshwater resources; especially when only 20 to 75 % of water extracted from underground aquifers is recovered through natural recharge, which is a leading factor to a continuous decline in available groundwater.

Meanwhile, mangrove *A. marina* ecosystems, growing in the intertidal belt at the interface between land and sea, play vital roles in preserving the environmental ecosystems. Because besides supporting wind breaking, sediment retention and erosion control, supplying aquifers is one of these roles. Mangroves also contribute to water quality maintenance. In addition to these direct support provided by mangroves to the economic activity and property, the indirect used for domestic, agricultural and industrial purposes.

Key words: Environmental services, mangrove, aquifers, economic values.

1. INTRODUCTION:

There are 238 million ha of dryland forests in the world and Africa alone has 64% of these forests. A total of 124 countries and areas were identified as containing one or more mangrove species. Mangroves are intertidal plants that occur in the interface between land and sea. Mangroves possess a range of features which make them uniquely adaptable to their stressful environment (e.g., they are holophytic or salt tolerant, have aerial roots for gathering oxygen, and seeds that germinate on the tree). The ecological role of mangrove ecosystems is, economically and socially, highly significant. They are well known for their high biological productivity and their consequent importance to the nutrient budget of adjacent coastal waters. They are the most typical forest found on the coastlines in the tropics and subtropics (Singh and Odaki, 2004) and the areas where they exist are rich in biological diversity of flora and fauna (EEAA, 2005). In Egypt particularly, the most abundant species are *Avicennia marina* and *Rhizophora mucronata* (FAO, 2007).

This paper briefly explains the importance of mangroves such as *A. marina* to aquifers recharging and its vicinity, and the opportunities that may result from its rehabilitant.

2. OBJECTIVE:

This review aimed to explain the biological and economical importance of mangroves A. marina to aquifers recharging and its vicinity, and the opportunities that may mitigate most of the environmental concerns raised by farmer community, policy makers, and governments.

3. ENVIRONMENTAL IMPORTANCE OF MANGROVES:

3.1. Importance to Water resources and aquifers:

Mangrove ecosystem serves as ground water pump and barrier between the aquifers and the sea. Ground water recharge involves water movement from the mangrove to an aquifer can (1) remain as part of the shallow groundwater system, which may supply water to surrounding areas and sustain the water table recharged (Al-Mufti, 2000) or (2) may eventually move into the deep groundwater system, providing a long term water resource. While, the function of discharge of groundwater into surface water like springs involves the role of mangroves in releasing water from aquifer sources which may be important to prevent flooding when upland water tables are high, just like a control valve. Also, mangrove may contribute to water quality maintenance functions by nutrient transformation, retention of toxins and particle suspension which may be caused by salt water intrusion to aquifers and leaching of heavy metals present in fertilizers (Camille B., 1997).

The flood and flow control services of mangroves is usually important. The valuation methodology is similar to that for groundwater discharge. Thus, it is necessary to know the extent and frequency of flooding in the flood plain area that would occur if this mangrove function did not exist (Camille B., 1997). The retaining of flood and the control of flow may also lead to a higher chance to ground water recharging by this flood.

3.2. Importance to Water de*salination:*

Mangroves normally have aerial dark brown roots which grow apparently on the land level forming an intrinsic network which work as desalinator of the sea water so that enough moisture is available for growth (EEAA, 2000). In Egypt, mangroves are found forming part of the coastal marsh and high terrestrial dune vegetation (Sabkha), and totally lost their aerial roots. Mostly, they have adapted to this harsh environment by becoming completely terrestrial by a natural alteration (Khalaf Allah, 2002). This resulted in a high density of terrestrial vegetation consisted of terrestrial mangroves (Elnwishy *et al*. 2008). However, this natural alternation may bring up a new definition of mangroves varies from the common one, and it may push condense genetic investigation (Elnwishy, 2009)

3.3 Biological importance

Mangroves provide habitat, nutrients, and protection; thus preserve biological biodiversity of marine and terrestrial ecosystems. This may provide both food and shelter to organisms which is important for the life cycle of important plants and animal species. For some species, mangrove may provide elements required to complete their life cycle. Other species may depend on the mangrove for more complex life cycle, including several aquatic animals such which depend on mangrove areas for spawning and juvenile development (EEAA, 2005); also migratory birds depend on mangroves for part of their life cycle for resting or feeding while on migration (Baha El Din, 1999).

3.3. Importance to Soil and landscape:

Mangroves have the ability to accumulate sand dunes around the net of roots of mangroves. These dunes can reach up to 1- 1.5 m high (Elnwishy *et al,* 2008). Apparently, these dunes are caused by the deep roots (pneumatophores) of mangroves which trap terrestrial sand blown by wind, and/or caused by seasonal rain floods waters from highland wadis which may bring down sediments to lowland and coastal areas, causing much of the sediment to run-off into the sea. In either cases, the two functions may result in accumulation of land in the coastal plain, leading to extending the land slowly out to sea. According to Hefny (1997) this function result in reducing the risk of losing the surface nutrients sediment of the soil by water erosion into the sea, the loss can reach up to $>100 \times 10^3$ m^3 of sediments into the sea at a high risk level, and 50×10^3 in a low risk level.

4. SOCIO-ECONOMICAL IMPORTANCE OF MANGROVES:

4.1. *Recharging aquifers*

Groundwater recharge made by mangroves is a possible aquifer refill supplier which supports domestic agricultural and industrial purposes in the surrounding regions (EEAA, 2005) which is an additional value of mangrove. Moreover, the nutrient and energy flows of mangroves is believed to be able to stabilize local climatic conditions, particularly humidity and temperatures which has a valuable influence on any agricultural or resource-based activities, besides its ability to maintain water quality and retaining water toxins (EEAA, 2005) by its large net of wooden roots.

4.2. *Avoided floods' damage costs:*

Frequent flash floods were reported to cause significant damage (Hefney, 1997). The avoided damage costs with the presence of mangroves, or the flood prevention expenditures or the replacement cost technique were reported significant (EEAA, 2006). These sediments in most cases may contain high contents of organic nutrients, including those from animal waste which add the value of nutrient retention to mangrove.

Protection provided to economic activity and property by the mangroves regulatory environmental services are significant (EEAA, 2005). The damage mangroves are exposed to by strong wind is significantly limited (Galal 1999), therefore it functions as a strong and effectively tolerant wind breaker. The total of avoided damaged caused by storms provided by mangroves is valuable cost. In addition, the avoided costs of building alternative wind breaks or sea walls other than mangroves are also high. For instance, as reported by WRM in 2005, studies of the 2004 Asian tsunami showed that areas near healthy mangroves suffered less damage and fewer loss of life. In Myanmar, mangrove forests could have reduced damages resulting from the waves caused by cyclone Nargis (FAO, 2008).

4.3. *Raising new activities:*

Mangroves are significant plant for sea water agriculture approach to mitigate the severe lack of fresh water (Elnwishy *et al*., 2009). Seawater agriculture is to grow salt-tolerant crops and plants such as mangroves on land using water pumped from the sea for irrigation (Boyko, 1967). It is based on breeding a common salt tolerance high yield crop, or select wild plants that already have high salt tolerance. It is also known as Saline Agriculture, salt farming, Irrigation with sea water or ocean farming. Mangroves are the best potential plant for this approach due to its ability to use saline water up to 45.000 ppm.

Fishing is an activity raised in drylands near shorelines (El Bastawisi, 1995), introducing bees to mangrove areas for apiculture was possible using *Apis mellifera* (FAO, 1994). Also the landscape afforded by mangroves to tourists in national parks and reserves is valuable to Bedouins who are increasingly getting involved in tourism (EEAA, 2005).

CONCLUSION:

A. marina can serve as a potential alternative and /or additional species of vegetation in coastal drylands where fresh water is scarce to support recharging aquifers, & to benefit from its environmental & economical services to promote the sustainable development process to local communities.

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Fresh ground water resources in Georgia and management problems of the transboundary artesian basins

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ABSTRACT

As it is known fresh water represents conditioned factor for human body's life. That's why the superiority of drinking water is recognized (acknowledged) as human body's priority according to the international declarations. In spite of this nowadays annually caused by low quality water diseased number of people is more than 500 million in the world and material loss is more than 1 billion dollar. World is experienced deficit of quality water today, therefore 1.5 billion people don't have means to use it. Future prognosis is disturbing – according to the data of UN for 2025 year 2/3 of world population will be under the water deficit conditions. Above-mentioned show how important is fresh water for humanity. Below we present briefly review about the situation of fresh ground water resources and the analysis of the problems in transboundary artesian basins of Georgia.

Keywords: Groundwater; Transboundary; Artesian basins; Georgian regions; Quality drinking water; Hydrogeological structure; Exploitation resources, Two-way movement

Rational mastering and defence of fresh groundwater resources is in the national importance and considerable qualifies health of Georgian population, ensures the development of almost all fields of agriculture and follow this, presents as one of the factor of independent state's safety guarantee and economic activity success.

Natural recourses of fresh ground water in Georgia compiles 573 m^3/sec (49, 5 million m^3 in day-night) and with its side it is redistributed in the 4 big hydro-geological system:

- 295 m^3/sec (25.5 million m^3/day-night) comes on big Caucasus wrinkled water stand system;
- 165 m^3/sec (14.3 million m^3/day-night) comes on south Caucasus artesian basin;
- 54 m^3/sec (4.67 million m^3/day-night) comes on small Caucasus water stand basin;
- 59 m^3/sec (5.1 million m^3/day-night) comes on Artvin-Bolnisi Hydro-Geological massive;

Territorially fresh ground water recourses are distributed unequally. Particularly: 65% comes on West Georgia, East Georgia – 25% and 13% comes on South Georgia.

Fresh groundwater resources not only by territorially and hydro-geological structures, but according to the location in the earth crust still is distributed distinctly (unequally). To the scale of the country circulation length of the cold (average 20^0 C) groundwater fluctuates from several ten meters until 500 meters and on the whole it changes between 100-300 meters. Thus we can conclude, that formation of fresh groundwater natural recourses clearly expresses as territorially (regional), as vertical and hydro-geological zonation.

For the future perspective demand for drinking-economic water for the whole Georgia compiles 60m^3/sec (with the norm of 500 liter water for one person in family). In spite of this according to the current norms, exploitation resources of fresh groundwater must not be higher than half of their resources. So in Georgia's case it must not be higher than 286 m^3/sec. It is clearly shown that Georgia has excess exploitation supply about 226m^3/sec. Here we also want to note that fresh water existing in the country is distinguished with high quality, best drinking features and not rarely with the medical features.

As we mentioned above there is the deficit of quality drinking water in Georgia and therefore it is possibility that drinking water deficit should become reason of big social dissatisfaction with its negative results. This problem is more acute and strained in the assimilation conditions of fresh ground water from artesian basins existing in transboundary zone, because in such zones there is not rare such hydro-geological situation, when the area of groundwater feed and formation is in the area of one state and the load-shedding area is in another state, or on the contrary.

In case of Georgia, problems with Russia Federation are less, because the border of this 2 country practically coincides with big Caucasus ridge, that's why groundwater overflow has the less scale. There are situated 3 big Hydro-geological structure – Artesian basins of Alazani, Iori and Marneuli-Gardabani within the Azerbaijan border zone. Hydro-geological researches conducted in last period, demonstrated that fresh groundwater is overflowing from the area of Georgia to the area of Azerbaijan. There are also few difficulties with the Turkey. Border between 2 countries (Georgia and Turkey) goes between the Caucasus system and Samckhe-Javakheti Hydro-geological massive. Because of different reasons this region is less studied and researched with the hydro-geological view and that's why we abstain (refrain) for evaluating. As for the Armenia, the state border goes on the centre of Hydro-geological system of Samckhe-Javakheti highland. The Hydro-geological picture shows us that fresh groundwater have two-way movement, as from Georgia to Armenia, also on the contrary.

Follow from above mentioned, we considered that it is inevitable, to conduct hydro geological researches with the border countries of Georgia by common methodic along the border zone and on its base arrange hydro monitoring observation network for carrying out together future monitoring researches. This will indisputably conduce to remove the tensity in the region caused by different reasons, to stabilize the peace and maybe considered as one of the important political decisions.

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Transboundary Groundwater Management: A Case Study for the Eastern Border of Egypt

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1. INTRODUCTION:

Groundwater resources are unique water supply in arid regions such as Sinai Desert and Negev Desert that locates along the eastern border of Egypt. The Eastern Mediterranean Aquifer (EMA) is crossing the border between Egypt and Gaza Strip. It is located in the coastal plain, along the eastern shore of the Mediterranean Sea. It is delineated on the World Map of Transboundary Aquifer Systems and depicted with number 502 (Struckmeier et al., 2006). It is defined on the world map as priority aquifer for water stress areas (Fig. 1). It is locally known as Kurkar Group (Calcareous sandstone, Sandy clay, Calcareous, clayey sandstone, Sandy limestone). Groundwater is recharged by precipitation at an average volume of 372 MCM/yr and generally flows westward toward the Mediterranean Sea. Groundwater is withdrawn primarily from sand, gravel, and Calcareous sandstone of Quaternary age (USGS, 1998). Groundwater levels are influenced by precipitation and pumping and generally fluctuate about 1–2 meters per year. Groundwater is generally of fresh water quality, with chloride concentrations between 50 and 250 mg/L. The EMA in Egypt has been greatly affected by pollution across the boundaries (Geriesh et al., 2004). The political situation is not stable and residents along both sides have continues emerging and unstable socio-economic conditions. The local inhabitants are greatly affected by deterioration of groundwater resources and spoiling soil environment. The EMA has been greatly deteriorated due to the continuous bombing for the border line. These aggressive activities may exaggerate the pollution of this aquifer that is used in Egypt for supplying drinking water and for irrigation.

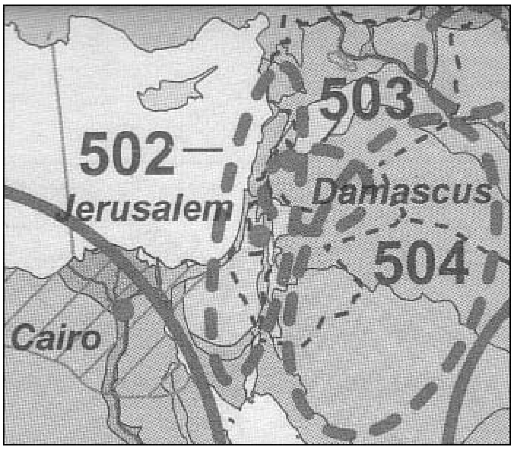

Figure 1: Distribution of EMA (no. 502) on the World Map of Transboundary Aquifer Systems (Struckmeier et al., 2006)

2. OBJECTIVES:

The specific objectives of this study include the following:

- Investigate the EMA aquifer (delineate aquifer hydrogeology, identify problems: pollution, bombing, issue of heterogeneity and governance issues)
- Review international practice in transboundary aquifer management and how it relates to the EMA case (emphasize on financial mechanisms such as benefit sharing and polluters pay)
- Formalize proposals for moving forward on the EMA management and possibly some generic recommendations for zones at war?

3. CHARACHTERISTICS OF THE EAST MEDITERANIAN AQUIFER

The EMA Aquifer along the border between Egypt and Gaza strip is consists primarily of Pleistocene deposits (mainly calcareous sandstones). The total thickness of the aquifer is about 100m at the border zone (USGS 1998). The border zone receives an average annual rainfall about 300mm/y. Groundwater is mainly recharged by the rainwater. About 10% of the rainwater feeds the Quaternary aquifers in the study area (RIWR, 1988). The groundwater level is about 20 m below land surface, and average well yield is about 100 m^3/h. Groundwater constitutes the main source of water supply for drinking, domestic and irrigation purposes. Groundwater is generally flows westward toward the Mediterranean Sea (Fig. 2) . Drinking well fields near the international border are suffering from pollution. Almost 90% of the groundwater wells of the Gaza Strip showed nitrate concentrations two to eight times higher than the WHO standards (Shomer et al 2008).

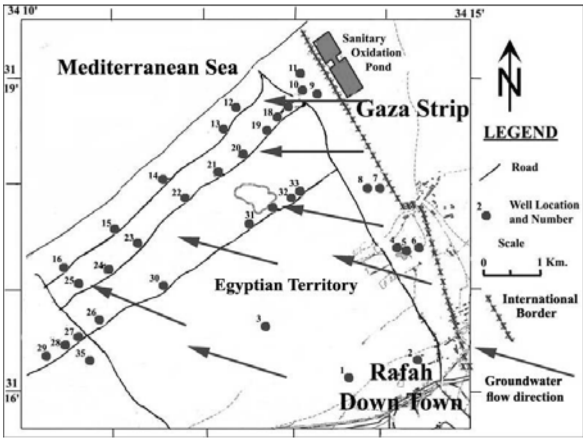

Figure 2: Distribution of wells, general groundwater flow direction and potential sources of pollution in Rafah environs.

The huge exploitation in both sides and subsurface activities along the border has facilitated the migration of contaminants towards the Egyptian territory. The physical nature of the EMA (calcareous and cavernous nature) facilitates migration of pollution across borders. The continuous Israeli invasions along the borders greatly threat sustainability of the aquifer. Aquifer vulnerability increases along the areas covered by sand dunes belts. The political setting is not stable and there is no water resources management institutions working regular in Gaza Strip. Egypt has strong institutions for water resources management but they do not give attention to water issues along their eastern border.

4. INTERNATIONAL CONVENTIONS GOVERNING SHARED GEOUNDWATER

Groundwater is first identified in Article II of the Helsinki Rules (ILA 1966). The United Nations' 1997 Convention on the Non-Navigational Uses of International Watercourses (UN 1997) is regarding the use, protection, preservation, and management of international watercourses for purposes other than navigation. It sets the principle of "equitable and reasonable utilization and participation in Article 5. Environmental considerations are injected into equitable utilization by internalizing the often competing values of development and conservation in the definition of the principle. Other principles of the Convention include the obligation not to cause significant harm (Article 7), the general obligation to cooperate (Article 8), and the duty of notification concerning planned measures with possible adverse effects (Article 12). Article V of the Bellagio Draft Treaty charges the international Commission assigned to implement the treaty with "the creation and maintenance of a comprehensive and unified database" that collects and catalogues information pertaining to transboundary groundwater, and is made available in the languages of the Parties (International Transboudary Resources Center, 1989). The Seoul Rules also dealt with protection of groundwater and urged the riparian states to consider the integrated management of their international groundwater, including conjunctive use with surface waters (Salman, 2007). There is confusion over the relationship between the principle of equitable utilization and the obligation not to cause harm.

Throughout history governments have found innovative and cooperative solutions to transboundary water management tensions, even in the most difficult political environments and conflicts (UNDP, 2006). Conflict among the Arab countries and Israel on sharing Jordan River in 1955 has urged third party (USA) to introduce plan for developing the region irrespective of the political issues and constrain the plan in economic context (Haddaden M., 2004). This plan has suggested unbiased Engineering Council for monitoring and execution of the development plan and commitment. This council consists of professional engineers selected by concerned parties from list prepared by the Secretary General of the United Nation. It is expected from the selected engineers to work as professionals and not as representative for the parties that have selected them. The members of this council should not be from the citizens or beneficiaries from the shared parties. There is international obligation of not to cause harm for water resources even during wars.

6. CONCLUSION

Groundwater supplies in the environs of Egypt-Palestine border are under severe stress due to severe exploitation and extensive air strikes and bombing. The specific hydrogeological characteristics of the Eastern Mediterranean Aquifer have facilitated the migration of pollution across borders. The water management institutions in both sides have failed to protect groundwater and have not the capacity and motivation to raise the issue. There is confusion over the obligation of not to cause harm for water resources and enforcement. It is necessary to have third party that can stop Israeli invasion and enable local inhabitants to have their groundwater environment clean. The potential mechanisms for addressing the transboundary groundwater issues along the border zone include: emphasize cooperation, setting independent groundwater management association, applying principle of polluter pay, enabling local inhabitants to sue parties causing harm to their water environment irrespective of their government help. It is necessary to run jointly funded research to assess transboundary aquifer problems, spread education and outreach and establishing aquifer management association.

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Anthropogenic change of transboundary Syrdaria River regime

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ABSTRACT

Syrdarya River is one of greatest transboundary rivers in Central Asia. The river was intensively affected by economic activity in several last decades. Change of the river regime in time along the river are shown in the paper.

Key words: Central Asia, Syrdaria River, water runoff, anthropogenic influence.

Syrdarja River is one of the largest and most important water arteries in former Soviet Central Asia. It runs along territories of four new states – Kyrgizstan, Uzbekistan, Tajikistan, and Kazakhstan and supplies by water a large part of population of the region. In particular it flows along the well known Fergana valley which is the most populated area in Central Asia.

Area of the river watershed coming out the Fergana valley is equal to 142,000 km2. Total area of glaciers in the river basin was 2550 km2 in the middle of 50th of last century and occupied 1.8 % of the watershed area. Glacierization was reduced as much as 25-30 % to present day (Glazirin, 2009) and covered approximately 1.3 % of the watershed area.

Several large reservoirs were constructed on the river and its tributaries for rational control of its runoff before destruction of Soviet Union. Their total volume reached 40 km3 (Resources…, 1969). The regime of the reservoirs and water offtake to numerous irrigational channels were controlled by centralized direction. It allowed to distribute water optimally in time and over the territory. This system was collapsed and every state have used water for its own purpose only and did not takes into account interest of neighbors. The situation causes already serious economic losses and political conflicts.

Regular hydrologic observations at the river were organized in the begin of the past century. However long time data turned out being unusable for standard normal statistical processing because of essential anthropogenic runoff modification. Cross statistical analysis was applied for restoration of the natural runoff on some gouging stations. It was succeeded to restore characteristics of the natural runoff. Long-term change of calculated "natural" annual water discharges of Syrdarya River at Bekabad gouging station, located at coming out of the river from Fergana valley, is shown in figure 1 (Chub, 2000).

One can see that the natural runoff did not change systematically for the period. No significant trends were found. The runoff varied around average value 830 m^3/s only. It can be explained by the fact that annual precipitation was the same and just increased a little bit for the period (Spectorman & Nikulina, 2002). It should be noted that the considerable glaciation shrinkage did not result in run-off loss. The measured run-off is shown in figure 1 too. No explanation required.

It is clear that the river regime is subjected more and more anthropogenic influence downstream. We tried to estimate the distortion of the Syrdarya River natural run-off by economic activity, as well as track modification of this process at time and along the river. Data of the long-term measurements on several hydrologic gouging stations were analyzed. The stations are located along the river at distances from 2173 km (Kal' station) to 181 km (Kazalinsk station) from its flowing into Aral Sea.

Run-off change along the river is shown in figure 2 for 4 selected years: in 1942 before big reservoirs construction; in 1962 in the start of Golodnaya Stepp area agricultural developing; in 1991 on the eve of USSR collapse; and present day situation in 2008. The run-off is shown in percent from its value at Kal' gouging station. Is it distinctly seen how the share of water decreased reaching lower course of the river. This fact and reduction of Amudrya River run-off due to economic activity are a reason of Aral Sea tragedy.

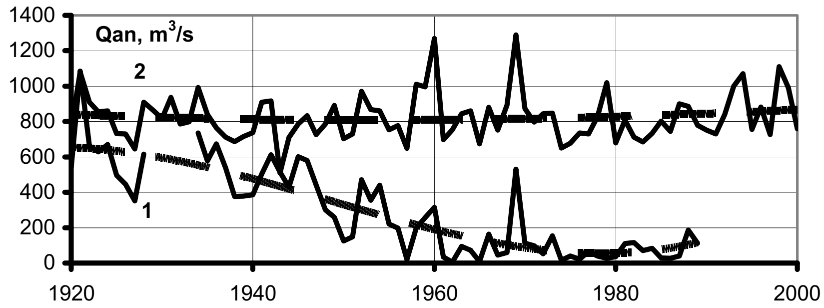

Fig.1. Long-term change of annual ran-off (Qan) of Syrdarya River at Bekabad gouging station. 1 - measured run-off; 2 - calculated natural run-off.

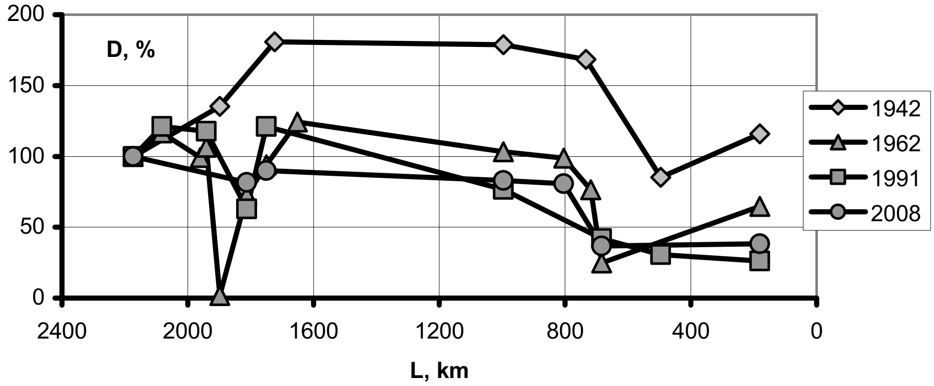

Fig. 2. Dependence of ratio (D) of annual ran-off at gouging stattions located at distance (L) from the Aral Sea on annual run-off at Kal' station .

Annual distribution of the run-off was intensively subjected too and changed drastically. The annual run-off distribution at Kal' station and Kazalinsk station in shown in figure 3. One can see that the run-off annual distribution is completely distorted even at the upper station by an above located Toktogul reservoir located at Naryn River.

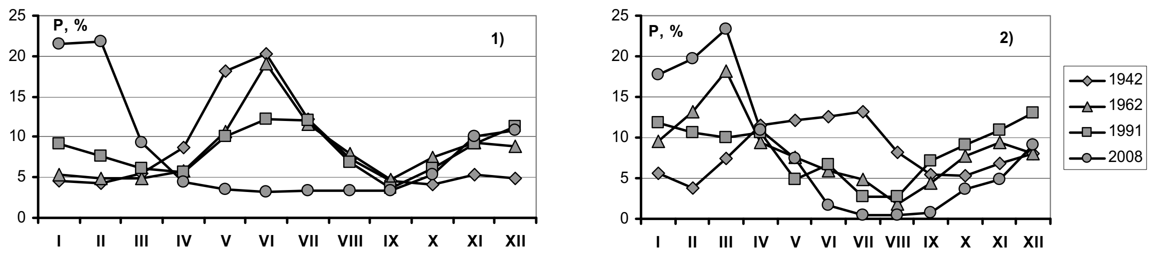

Fig. 3. Annual distribution of run-off at the Kal' station and Kazalinsk station in four years. P is share of monthly run-off in annual one.

Now minimal run-off takes place in summer time whereas in former time maximal run-off took place at this time. In lower course of the river annual run-off distribution was heavily distorted also. The share of the summer run-offr gradually approaches to zero.

The results permit to evaluate the anthropogenic influence to the transboundary Syrdaria River runoff and should help in planning of optimal management by water resources of the region.

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The Shared Resources in the North-Western Sahara Aquifer System (Algeria-Tunisia-Libya): The use of Environmental Isotopes (Algeria part)

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ABSTRACT

The North-Western Sahara Basin (NWSAS) comprises two main aquifers: the deep "Continental Intercalaire" (CI), and the "Complexe Terminal" (CT). With a surface area of approximately 1 000 000 km^2, the CI extends across three countries, Algeria,Tunisia and Libya (Fig. 1) and constitutes one of the largest groundwater systems in the world. This resource is generally considered as being "fossil", i.e. inherited from previous climatic conditions, more humid than at present, with a very limited modern recharge. This basin supplied an estimated volume of 2.2 billion m^3 fresh water for domestic water supply, agriculture and other industrial purposes. Groundwater withdrawals from the NWSAS increased from about 14 m^3/s in 1950 to 82m^3/s in 2000, resulting in decreases in the natural water flows.
Over the last two decades, isotopic investigations have been carried out (^{18}O, ^{14}C, ^{36}Cl) and rare gas (He, Ne, Ar, Kr, Xe) to assess the groundwater resource potential in the Sahara of Algeria, Tunisia and Libya. The compilation of isotopic data indicate that waters from CT and CI aquifers are characterised by depleted oxygen-18 and deuterium isotope contents as compared to that of the modern rainfall. This would suggest that the modern rainfall is not recharging these ground waters. Although some sources for active recharge cannot be neglected. Different studies have shown that the NWSAS is recharged by infiltration of surface runoff around the periphery of the domain, particularly around the Saharan Atlas, the Dahar, Tadmait and Tinrhert as well as in the Great Occidental basin during years of exceptional rainfall.
The main objective of the present study, is to gather all these data and to examine how they may be interpreted in terms of groundwater residence time, recharge rate, evaporation losses can help the water managers of the three involved countries to ***develop or refine*** appropriate models. *This should facilitate the implementation of a trans-boundary integrated management of the shared resources.*

Key words : Isotope, Shared, Water Resources, Fossil Water, Saharan Basin

1. INTRODUCTION

The North-Western Sahara Basin (figure 1) extends over much of Algeria (700.000 km2), Libya (250.000 km2) and Tunisia (80.000 km2) and is an arid region with rainfall ranging from 20 to 100 mm·yr-1. The majority of the 4 million people living in this basin depend on groundwater resources for its water needs. As groundwater abstraction increases, the need increases for more precise hydrologic data to help refine management decision tools/models on water use. As a consequence, the three countries sharing the system are endeavouring to improve the state of hydro-geologic knowledge for sustainable management of their shared groundwater resources. The purpose of this study is to document the current knowledge of the NWSAS based on recent results of isotopic investigations.

2. OBJECTIVES

The main objective of the current study is therefore, to gather essential and updated information on groundwater isotopic characteristics that would be usable by water managers of the three involved countries to *develop or refine* appropriate models. *This should facilitate the implementation of a trans-boundary integrated management of the shared resources.*

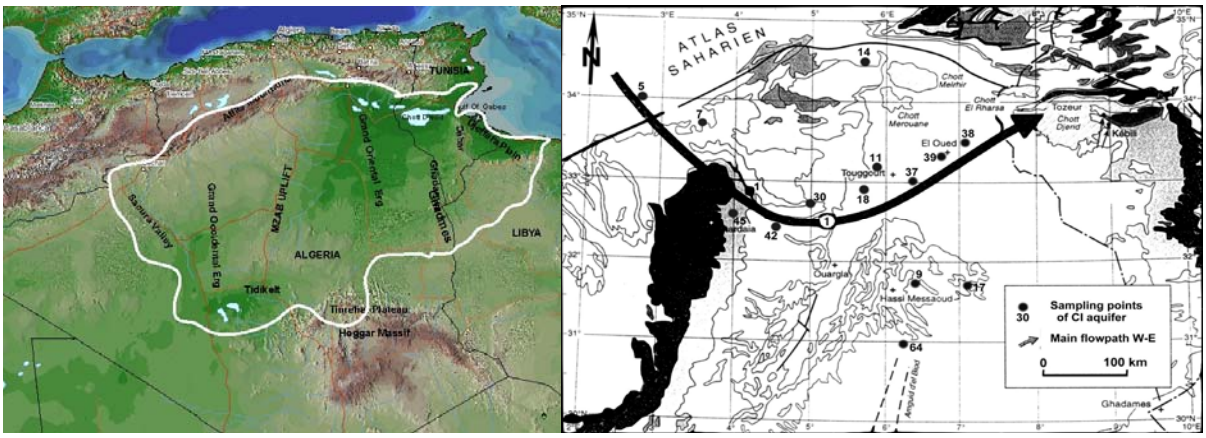

Fig.1. Map showing major basin features of the NWSAS and sampling points (Algeria part)

3.ISOTOPE RESULTS AND DISCUSSIONS

The isotopic data acquired so far from the aquifers show clear variations from one aquifer system to another reflecting differences in aquifer composition, recharge mechanisms, groundwater flow directions, groundwater age, groundwater mixing conditions, and hydraulic connections between aquifers.

3.1Stable isotopes results:

Comparison between the isotopic compositions of the aquifer systems with that of the present day rainfalls show major differences (Fig.2). Although some exceptions can be observed, the groundwaters in all the aquifer systems are generally isotopically depleted than the weighted mean isotopic composition of present day rainfall. In the Great Oriental Erg the groundwaters from the CI are the most depleted and the most isotopically homogenous, the values ranges between -5 and -9 ‰ (^{18}O) (Guendouz, 1985, Andrews, et al, 1985, Guendouz, et al,2003, Edmunds et al., 1997, 2003). The most depleted part represents the deepest and confined part of the aquifer (-7.9 and -9.0 ‰). The most enriched part of the aquifer water is limited to the recharge areas: Saharan Atlas, the Dahar mountains in Tunisia (-6 to -8.5) ‰.. However, high variability and generally enriched waters are common in the aquifers of the CI in the Occidental Erg, with ranges from -4.0‰ to -8.0‰ for ^{18}O and from -49.6‰ to -65.1 ‰ for ^{2}H. Waters of the CT aquifers have variable compositions, the majority of them plot below the GMWL following an evaporation slope. In some places, highly depleted waters from the CT are observed.

1.2 Carbon-14 activities

The carbon-14 activity shows two major trends (Guendouz, 1985, Andrews, et al, 1985, Guendouz et al, 2003, Edmunds et al.,1997, 2003). Up to 100 km from the supposed recharge zone in the Atlas Mountain detectable values were obtained (50 to 60 pmc). At distances greater than 100 km, the C-14 activity is nearly the detection limit until it reaches the Tunisian outlets where the C-14 activity reaches nearly zero.

CT aquifers generally contain variable C-14 activity though it is generally higher than that in the CI. The radiocarbon data indicate that a gradient in groundwater age exists in the main CI and CT aquifer system as one goes along the groundwater flow directions. Some tritium containing and relatively high carbon activity waters are observed in shallow unconfined aquifers and in groundwater bodies around the mountainous areas indicating the presence of modern recharge.

At the scale of the whole Sahara basin (North Africa) (Fig.3) shows that there is a depletion in heavy isotopes which is a function of age. The deep CI aquifer waters are old and depleted in ^{18}O, whereas the CT waters are younger and have more varied, but higher, δ^{18}O values. This same trend has already been observed in aquifers of the Kufra and Sirte basins in Libya. This indicates that the recharge coincides with the humid period of the late Pleistocene (20-40 ka) that has been demonstrated to have existed across the whole of northern Africa (Edmunds, W.M., Wright, E.P. (1979) Gibert 1990, Fontes and Gasse, 1991). (Gasse, F. Tehet, R. Durant, A., Gibert. E., & Fontes, J.CH., 1990)

3.1Chlorine-36 and Noble gases

Chlorine-36: Chlorine-36 contents in the CI aquifer, expressed as atomic ratio ($^{36}Cl/Cl$) and in atomic concentration (at.l^{-1}), vary respectively from 8_99x10^{-15} at.at^{-1} and from 0.90_3.53 x10^{8} at.

The meteoric, epigene and groundwaters production of ^{36}Cl is respectively*:* 116x10^{-15} at.at^{-1}, 116-133x10^{-15}, and from 8-99x10^{-15} at.at^{-1}. The calculated ^{36}Cl residence time, for the points situated on the main flowpath (fig.1), varies between (500 and 1Mka). This increase of residence time is observed up to about 500 km from the recharge zone. (Guendouz, A. and Michelot, J.L., 2006).

Noble gases: The recharge temperatures derived from noble gases (He, Ne, Ar, Kr, Xe) for the CI samples were generally lower than the samples collection temperatures and the present day air in the areas of recharge. Along the main flow direction west to east from the Atlas mountains, the recharge temperatures range, with no noticeable spatial evolution from 14-24 °C with an average of 16.9°C. This is some to 4-5°C cooler than the present mean annual temperature in the recharge area (20°C) (Guendouz et al, 1997).

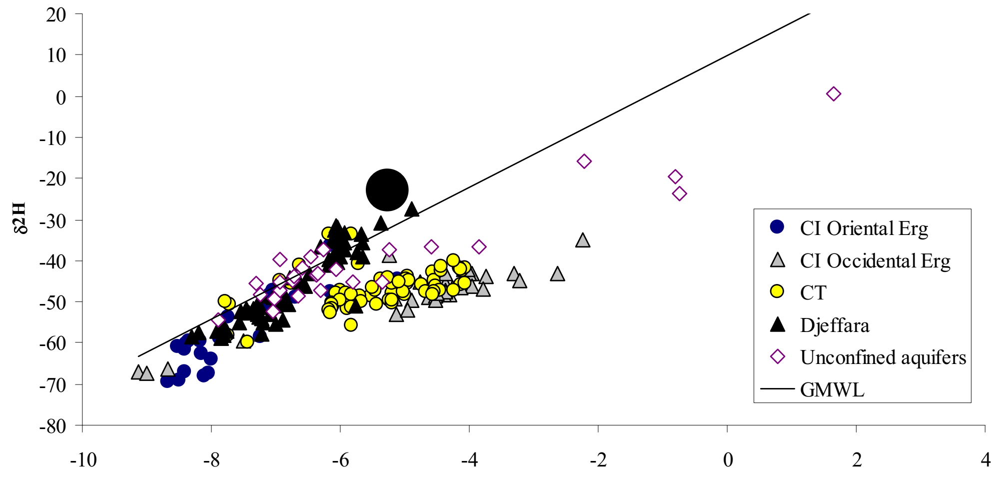

Fig.2. $\delta^{18}O$-δD plot of all water samples from the basin with respect to the GMWL and the weighted mean isotopic composition of rainfall (big circle).

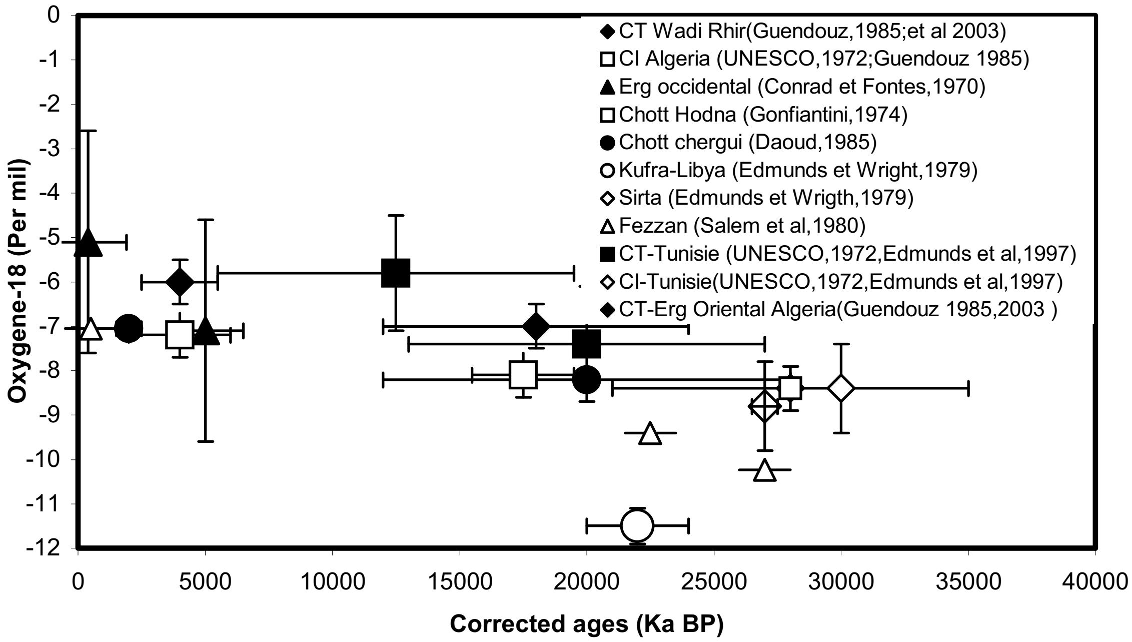

Fig.3. Plot of $\delta^{18}O$ against ^{14}C (pmc) of all groundwaters at the scale of the Saharan basin (North Africa)

4. CONCLUSION

The relationship between $\delta^{18}O$ and ^{14}C ages confirms the palaeoclimatic feature of the recharge which occurred during the humid periods of the late Pleistocene (20-40 ka) and the Holocene (0-4 ka) corresponding with what is known from past climatic records.

The estimated range of initial ratio $^{36}Cl/Cl$ was found very close to that observed for groundwater occurring elsewhere in the world. Moreover, radioactive decay accounts for the observed decrease of ^{36}Cl concentration along the main flowpath (W_E) from the Atlas mountains in Algeria to the Gulf of Gabes in the Mediterranean coast of Tunisia. This leads to age estimates up to 500 ka to more than 1 Ma.

The recharge temperatures derived from the noble gas contents in the CI were found to be 4-5°C cooler than the present mean annual air temperature. The relationship between recharge temperature and ^{14}C supports the hypothesis that these waters infiltrated during cooler, more humid climatic conditions.

The recharge temperatures derived for the CT samples, are consistent with the current annual mean ambient temperature prevailing in the recharge area of the Grand Erg Oriental, consistent with Holocene recharge. This is supported by the isotopic data, in particular the corrected radiocarbon ages (0-4ka) which imply relatively modern recharge

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Trans-Boundary Aquifers in the State of Punjab, India

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ABSTRACT

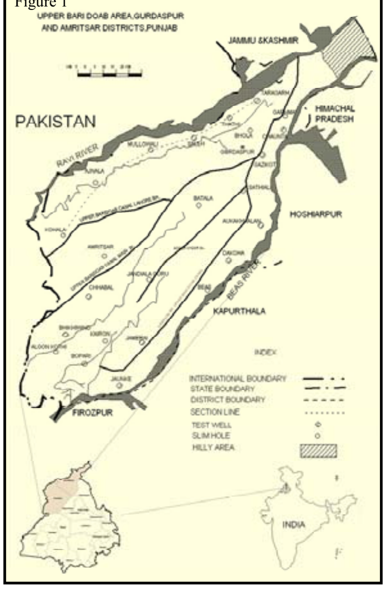
With growth of civilizations the insatiable demand for water resources has increased manifold. This huge stress on water resources due to increasing demands and declining water levels, growing vulnerability from floods and droughts, and eco-hydrological problems confront water resources management with challenges that need comprehensive strategies for providing water of adequate quantity and protecting mankind from adverse impacts. Sustainable solutions for trans-boundary water aquifer systems are therefore of high priority since nature does not draw its boundaries to coincide with the political boundaries. Punjab state is one of the most prosperous states of India with an agricultural based economy. The total water requirement of the state is 61.675 billion cubic meter (BCM). Against this, the water availability is only 17.54 BCM of surface water and 23.78 BCM of replenishable ground water resources. Punjab has a very long international boundary and the ground water aquifers are contiguous across the border too. Whereas the majority of the recharge areas lie in the hills of J&K and Punjab, the discharge areas extend to Pakistan too. It is thus felt that now is the time to study the trans-boundary aquifers of Punjab state in totality and on the basis of proper assessment of ground water contained down to a certain depth (say 1000 meters), decide the allocation of ground water usage by the neighbouring countries. The present paper outlines the above along with the hydrogeological set up of Punjab state with special emphasis on Upper Bari Doab area covering the districts of Amritsar, Gurdaspur and Taran Taran. Towards the end of the paper, a case study of trans-boundary aquifers across two states, Haryana and Uttar Pradesh, within India has also been detailed. The main aim of this was to study the effect of pumping of ground water through augmentation tubewells in Haryana on the Yamuna river flows and ground water resources of adjoining state of Uttar Pradesh. Similar situation may be present across global trans-boundary aquifers also. This study is a case in point to prove that study of trans-boundary aquifers is the need of the day.

Key words: *Eco-hydrological, Punjab, Haryana, Replenishable, Yamuna river flows*

1. INTRODUCTION

Ground water is a fugitive resource. Countries may legislate for water as a national asset, but the resource itself crosses political boundaries without a passport in the form of rivers, lakes and aquifers. Trans-boundary waters extend hydrological interdependence across national frontiers, linking users in different countries within a shared system. Managing that interdependence is one of the great human development challenges facing the international community.

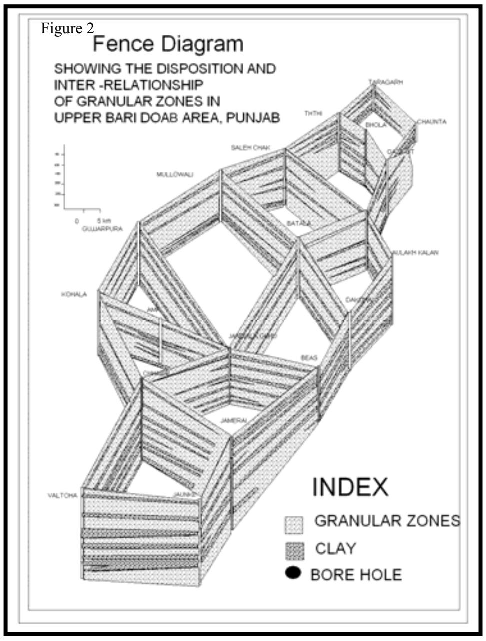
Figure 1



The key features of trans-boundary aquifers include a natural subsurface path of ground water flow, intersected by a national or international boundary, such that water transfers from one side of the boundary to the other. In many cases, the aquifer might receive the majority of its recharge on one side, and the majority of discharge would occur in another side. In Punjab state of India, a majority of the area is irrigated by groundwater. The tubewells in the state have grown from 26 thousand in the year 1965-66 to 1.23 million in the year 2006-07 and the ground water withdrawal is now 31.16 billion cubic meter (BCM) against total replenishable ground water resources of 23.78 BCM .

Punjab state is a vast tract of alluvial plain formed by mighty rivers, the Ravi, the Beas and the Satluj. The area discussed in this paper is locally called as “Upper Bari Doab” which is basically an inter-fluve area between the Beas and Ravi (Fig. 1). This area is underlain by aquifers that are laterally and vertically extensive containing good quality ground water. A lithological section drawn in a north-east: south-west direction parallel to the left bank of Ravi river, reveals the presence of 5 to 6 thick permeable granular zones down to a depth of 300-420 m below ground level. The first aquifer which forms the water table aquifer occurs up to 40-50m bgl and consists of sand with minor amount of gravel and *kankar*. The second and third aquifers consist mostly of sand, gravel and pebbles (Fig. 2 & 3).

Figure 2

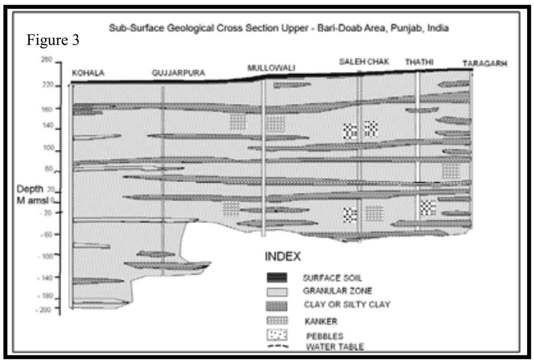


A study of the disposition of the water table elevation of the phreatic aquifer reveals the existence of a water divide running in Northeast – Southwest direction. Whereas water table contours are closely spaced in the extreme North eastern part indicating that ground water movement is fast, in other parts these are widely spaced which show that ground water movement is slow. Both the rivers i.e. Ravi and Beas are effluent in nature. Ground water, in general, follows the surface topography and is flowing towards west and south-west towards the Ravi that forms the border with Pakistan. The major withdrawal of ground water in this area is through the phreatic aquifer that is being recharged locally through rainfall and other sources like canal seepage, return flow from applied irrigation etc. The 2nd and 3rd aquifers have by and large not been tapped so far and their recharge area lies in the Shivaliks in the north and north-east apart from localized vertical leakage from overlying aquifers.

2. DISCUSSIONS

In the context of Punjab state, sharing its international boundary with Pakistan falling in the Indus basin, it is important that the disposition and design of the trans-boundary aquifers be studied in detail so as to assess the quantities of water that are flowing across the border. Based on the available data discussed in the preceding paragraphs, it is opined that the slope of the water table is towards west and south-west, which follows land surface slopes. Thus apart from any natural flows that regularly take place due to the difference in the head, any pumping activity that is taking place in downstream direction may impact the upstream aquifers. The need is to assess and quantify the flows as well as study the chemical quality of the water flowing across. It is also important to assess the long-term behaviour of these flows in case of increased pumping due to water shortages all over the region.

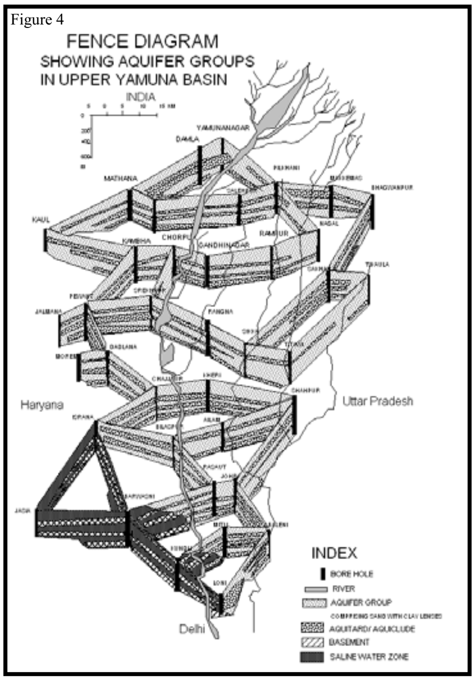
Figure 3



Central Ground Water Board has taken up study of trans-boundary aquifers within India where aquifers across the states of Haryana and Uttar Pradesh were studied during Upper Yamuna Project in the 1980s. A composite fence diagram (Fig. 4) across the state boundaries had also been prepared. The main aim of the project was to study the effect that pumping of ground water through augmentation tubewells located near the river Yamuna in Haryana might be having on the Yamuna river flows and ground water resources of Uttar Pradesh. The project used a multidisciplinary approach and was successful in predicting that:

- Ground water draft through augmentation tubewells have local effects in declining the water table but it appears that the ground water gets recouped by ground water flow to a major extent. Present quantum of ground water draft is having little injurious effect on the unconfined aquifer.
- Further augmentation draft may be permitted in the area without affecting the river regeneration but that draft must be from deeper aquifers. The allocation of the augmentation draft must be further down the present augmentation canal project. Such a scheme, however, may create local depressions.
- Continuance of the augmentation draft in future may generate decline in water table adjacent to river in U.P. area as well without appreciably declining river regeneration.
- Any large-scale ground water development upstream of the present location of augmentation canal project may affect the river regeneration.

Figure 4



From the experience gained in the above case it can be surmised that technique, methodology and experience is already available to study the trans-boundary aquifers, whether national or international. It is anticipated that similar conditions do exist in the trans-boundary aquifers lying across various countries including India and Pakistan. It is recommended that such studies on trans-boundary aquifers be taken up across the borders where the aquifers are likely to be in continuity so as to obtain a holistic view of the ground water regime in the area. This will go a long way in planning and management of the ground water resources of countries that have common borders especially in view of the predictions that water resources are likely to become scarce with the impending climate change.

The authors duly acknowledge several reports of Central Ground Water Board and state governments for writing this paper apart from own field experiences in area falling in the states of Punjab, Haryana and Uttar Pradesh. The views expressed in the study are authors' own and do not necessarily reflect the views of Government of India.

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Management of Transboundary Aquifers of Kuwait:
A Cooperative Approach

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Abstract

In the arid environment of Kuwait where there is no surface water, usable groundwater resource is limited, and the country mainly depends on the seawater desalination for its freshwater need, judicious management of the available groundwater resource is imperative for the well-being of the country. It is important to recognize in this context that the Dammam Limestone Formation and Kuwait Group, the two aquifers exploited in Kuwait, are 'transboundary' in nature (i.e., they extend beyond the international boundary of the country) and are present in the other adjacent countries of the Arabian Peninsula. Kuwait is making every effort to manage these aquifers sustainably and protect them from environmental pollution. However, with the increasing demand for water that has led to the over exploitation of the groundwater resources in all the 'aquifer states' that share these aquifers, development of a cooperative groundwater management plan will be beneficial for all the stakeholders concerned. Advantage of the newly adopted draft 'Law of Transboundary Aquifers' by the General Assembly of the United Nations that emphasizes on such cooperation for the greater benefits of all concerned, may be taken to formulate and execute such a plan in not too distant a future.

Key Words: Dammam Limestone Formation, Kuwait Group, Groundwater, Arabian Peninsula

1. INTRODUCTION

1.1. Background

As with any semi-arid to arid country, usable water is a very precious commodity in Kuwait. The freshwater need of the country is almost entirely met by the seawater desalination. The country has, however, some brackish groundwater resource that is exploited mainly for agricultural and industrial use. The aquifers that host this brackish groundwater are transboundary (located within the jurisdiction of more than one state) in nature. The cooperative management of this resource by the 'aquifer states' is vital for its sustainable exploitation, preservation and protection.

1.2. Hydrogeology of Transboundary Aquifers in Kuwait

In Kuwait, usable (total dissolved solids contents ≤ 5000 mg/l) groundwater is exploited from clastic sediments of Kuwait Group aquifer and the unconformably underlying dolomitic limestone of the Dammam Limestone Formation aquifer. Most of the recharge to these aquifers takes place from the lateral flow of groundwater down the natural hydraulic gradient toward the east and the northeast from recharge sites in the highlands of Saudi Arabia lying to the west and the southwest of the country, where these and other underlying formations extend and are exposed to the surface (Fig. 1). Thus the aquifer system of Kuwait is transboundary in nature with the major recharge zone located in Saudi Arabia and the discharge zone extending along the coastal parts of Kuwait and the lower parts of the Shatt El-Arab valley in Iraq.

2. CURRENT STATUS OF GROUNDWATER RESOURCE MANAGEMENT IN KUWAIT

In view of the ever increasing demand for water in Kuwait with increase in population and the living standard, pressure on the usable groundwater resources in Kuwait is increasing with time. In order to preserve this precious resource for the future generation, Kuwait is currently making every effort to manage the exploitation of the aquifers sustainably. Extensive hydrogeological studies and numerical modeling have shown that the aquifers that extend from Saudi Arabia to Kuwait are interlinked vertically. Lateral recharge from Saudi Arabia through these aquifers has been estimated to be in the rage of 180,000 – 185,000 m^3/d (Mukhopadhyay et al., 1994). However, the current production (in excess of 450,000 m^3/d) from these aquifers far outstrips the recharge and the aquifers are being effectively mined, causing a large drawdown in and around the brackish water fields of central and southern Kuwait. The freshwater lenses (total dissolved solids contents ≤ 2000 mg/l) underlying the surface depressions of Raudhatain and Umm Al-Aish areas in North Kuwait, though minor in volume, are strategic in nature due to the absence of any other natural occurrence of freshwater in Kuwait. Optimum utilization of this resource is also getting priority attention in this context (Hadi et al., 2006).

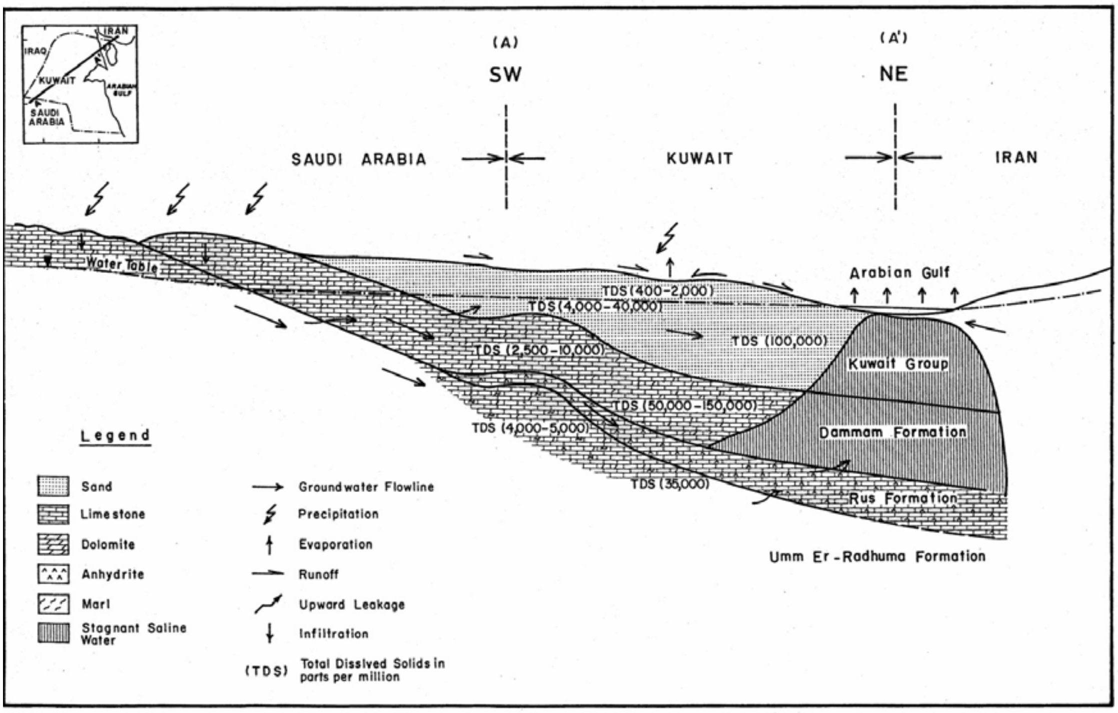

Fig. 1. Generalized hydrogeologic cross-section across Arabian Peninsula, depicting the recharge and the discharge zones.

The protection of the groundwater resources in Kuwait from the environmental pollution is another important consideration for Kuwait. A conceptual design for the monitoring network across the country has been developed as an early warning system for the detection of the contamination of the aquifers from various sources and recommendations have been put forward for the adoption of policies and procedures that will protect the groundwater resources of Kuwait from both intentional and unintentional deterioration in quality through environmental pollution.

3. FUTURE NEED OF GROUNDWATER MANAGEMENT IN KUWAIT

3.1. Co-operative Management

Though Kuwait is making every effort to manage and protect its groundwater resources in a sustainable manner, in view of the 'transboundary' nature of the aquifers, the exploitation intensity and distribution of the exploitation centers in the up-gradient areas will have significant effects on the lateral inflow volume and the potentiometry of the aquifer system in the State of Kuwait. This, in turn, should affect their exploitability in Kuwait. Furthermore, any environmental pollution taking place at the upstream side of the aquifer system will have the potential for affecting the water quality in the downstream side in Kuwait. In view of the above, a comprehensive and cooperative hydrogeological evaluation of the aquifer system covering these neighboring countries is called for to assess the long-term sustainability of these aquifers in the region as regards to the quantity and quality of the water produced from them.

3.2. Relevance to the 'Law of Transboundary Aquifers'

It is heartening to note that the General Assembly of the United Nations (UN) being "*convinced* of the need to ensure the development, utilization, conservation, management and protection of groundwater resources in the context of the promotion of the optimal and sustainable development of water resources for present and future generations" and "*affirming* the importance of international cooperation and good neighborliness in this field", in its resolution 63/124 dated 11th December, 2008, has adopted the draft "Law of Transboundary Aquifers". At present, Kuwait has no formal understanding with any of the neighboring countries on the exploitation of its transboundary aquifers. It is, however, realized that such agreements on the sustainable management of the aquifers will be of mutual interest and the proposed draft of the 'Law of Transboundary Aquifers' can provide a framework for such formal agreements. Kuwait will make all efforts to arrive at such bilateral and / or regional agreements with the 'aquifer states' as detailed in the articles of the draft law.

4. CONCLUSIONS

Usable (both fresh and brackish) groundwater resource of Kuwait is limited and over exploited. In view of the 'transboundary' nature of the aquifers of Kuwait and their exploitation in the neighboring states, joint formulation of an optimum management scheme for these aquifers by all the 'aquifer states' is pre-requisite for their sustainability in the long term and protection from environmental and natural degradation in their quality. The recent adoption of the draft 'Law of Transboundary Aquifers' by the General Assembly of the UN is a timely step in this direction. It is hoped that the law will soon be finalized after taking into considerations the view points of all the stakeholders concerned. Kuwait is looking forward to take advantage of this law in reaching mutual understanding with its neighboring states to initiate cooperative study of its 'transboundary' aquifers that should ultimately lead to the adoption of a mutually beneficial management plan for these aquifers by all the states sharing them one way or the other.

Acknowledgements

Thanks are due to the management of the Kuwait Institute for |Scientific Research for permission to present the poster.

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Artesianism state of Intercalary Continental drillings in Guerrara region (Southeast of Algeria)

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ABSTRACT

In the Sahara, the groundwater represents the water main resource for all economic activity in the region. In order to satisfy this request which does not cease increasing, the habitants of the Algerian South often use groundwater systems: the Terminal Complex and Intercalary Continental. This later is a transboundary aquifer shared by the three Maghreb countries: Algeria, Tunisia and Libya. Water is contained in formations dates from the Albian until the base of Barremian. The aquifer consists of detrital formations: sands, sandstone, clays with a dolomitic passage attributed to Aptian, reaching a thickness of more than 500m. In Guerrara, 29 artesian drillings exploit the aquifer at approximately 950m depth with a yield which can reach 100l/s. The groundwater is surmounted by impermeable layer of Cenomanian and evaporitic Senonian constituting its roof. This study shows temporal evolution of yield. The results confirm that the flows are in fall and consequently the artesianism.

Key words: Sahara, Intercalary Continental, drawdown, overexploitation, artesianism

1. INTRODUCTION

The availability of water is all the more important when it is about an arid region characterized by its climate always not very rainy, and sometimes very dry.

Guerrerra belongs to the central northern Sahara, it is located at 120Km in the North-East of Ghardaïa (Fig.1) between the latitude 32°30' - 33°30' N and longitude 4°25' - 4°35' E. It covers an area of 2600km^2.

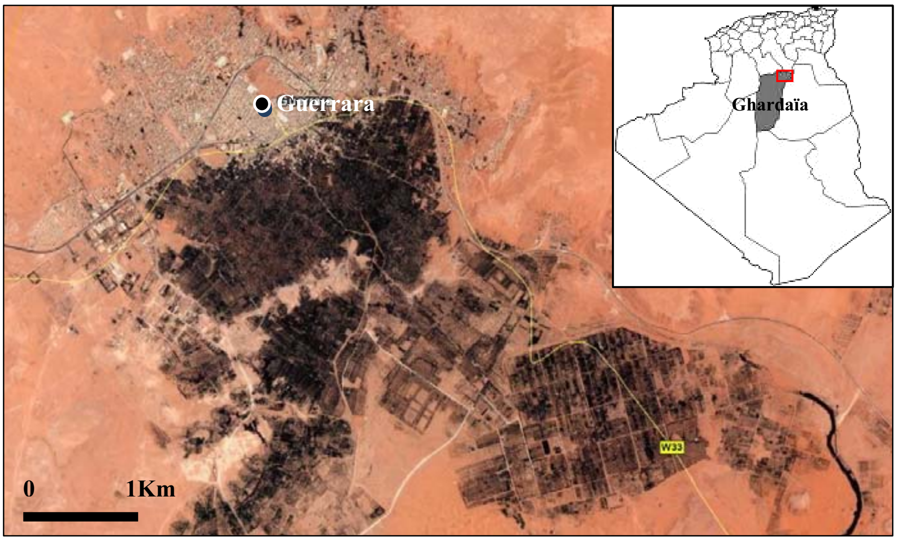

Fig1. Geographic situation of study area

The groundwater of Intercalary Continental is the main water resource in the region. It is contained in detrital formations: sand, sandstone and clay, of more than 500m thickness and located at an important depth of 650m. The transmissivities of CI admit for average 10.20^{-3}m^2

.

The exploitation of the groundwater does not cease increasing by the multiplication of drillings carried out during this last decade which has resulted in a significant drawdown of water level.

2. OBJECTIVES

In Ghardaïa, important quantities of water are mobilized from the Intercalary Continental with total volume of 214 million m^3 (A.N.R.H Ghardaïa 2005).

This paper illustrates the artesianism state of the aquifer during time by studying yield drillings evolution.

3. RESULTS AND DISCUSSIONS

The water needs of the study area have known a great growth in recent years. To satisfy this request the local authorities solicit more and more the CI resource what means new drillings.

In Ghardaia, the number of water points which was 288 in 1999, passed to 292 in 2002 to reach 345 drillings in 2005 (A.N.R.H Ouargla 2007).

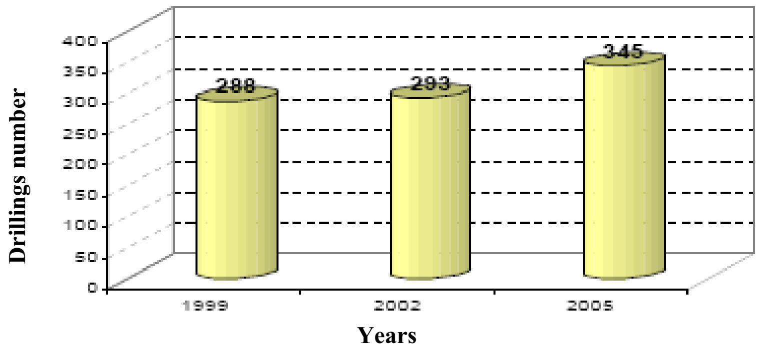

Fig 2.Drillings number evolution at Ghardaïa

In the region of Guerrara, the number of drillings was 22 in 1999 to reach 29 drillings in 2010.

During the period 1999 – 2005, the exploitation observation (Fig.3) shows a fast increase in the volume of withdrawals from the CI, passing from 179.3 10^6 m^3/y either 5.65m^3/s in 1999 to 213.96 10^6 m^3 per annum or 6.78m^3/s in 2005.

This volume augmentation is explained by agricultural programs development and the population needs of the drinking water supply.

In Guerrara city, the drillings count is 29 including 20 operating wells, with an average yield of 80 l/s. The amount withdrawn is 32.8 hm^3/year specially used for irrigation, household and industrial activities (A.N.R.H Ouargla, 2007).

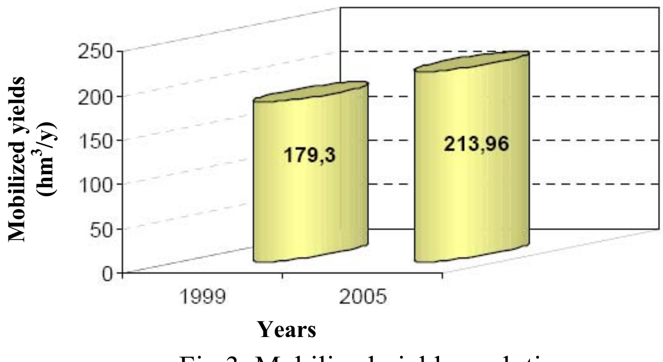

Fig 3. Mobilized yields evolution

The increased and irrational use of the water resource had already as a consequence a reduction in the artesianism in some sectors of Ghardaïa and possibly a substantial drawdown in the pumping areas.

The yield evolution of three drillings in the CI at Guerrara (Fig.4), shows a fall exceeding 50% of the initial yield. This tendency is likely to put an end to the artesianism within 10 years. Moreover, this loss has already been noted in some wells, it is the case of Tikamamine, Ain Bounoua, Ain Daci, Sidi Abdelkader, S'hane, and Foussaa drillings in which the exploitation became by pumping.

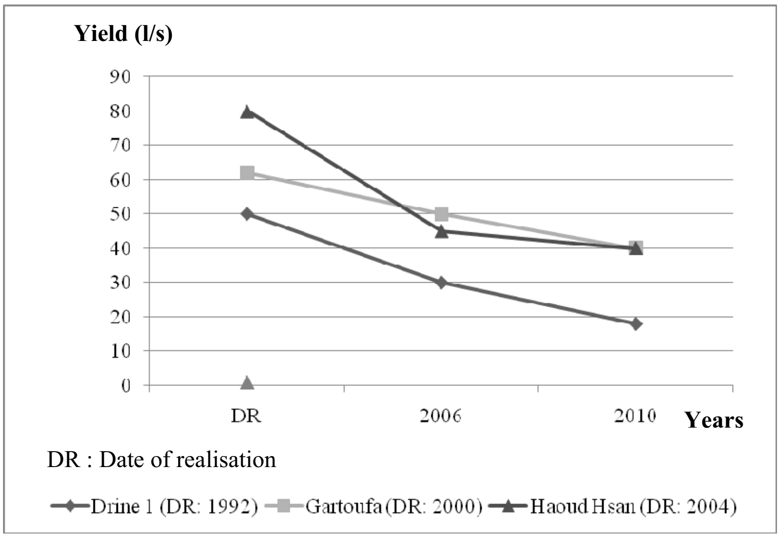

Fig 4. Drillings yield evolution at Guerrara

4. CONCLUSION

Guerrara located at the Western limit of low Sahara basin knows a disappearance of the artesianism on the level of some drillings whose ma!!jority is localised in the West of the area. The actual position of the exploitation of Intercalary continental will in the near future have a negative impact on the water reserve of the aquifer, on the one hand, and on the environment on the other hand.

Face to a water demand which does not cease increasing and with a slightly renewable reserve, it is necessary to act quickly by a better management.

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The Challenge of Transboundary Aquifer Resources Management in the Azerbaijan Republic -multidisciplinary and multifunctional approaches

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ABSTRACT

Successful management of the shared water resources of the Kura-Araz Rivers Basin is critical to the social, economic, and ecological prosperity for all countries of the region. The practical and just solution of this problem requires a multidisciplinary approach that encompasses various expertise and disciplines. And find a way of solving this problem is very important, especially, for Azerbaijan where about 70% of the surface water is transboundary resources and the aquifers systems generally do not follow political boundaries.

Key words: transboundary aquifer; water resources management.

1. INTRODUCTION

Azerbaijan(86,600 km²)is situated within the Alpine fold belt and includes mountain regions of the Greater and the Lesser Caucasus, the Kura inter-mountain depression and part of the Caspian Sea. Azerbaijan has common borders with Armenia, Georgia, Iran, Russia and Turkey; and maritime boundary with Iran, Kazakhstan, Russia and Turkmenistan. Of the available annual average fresh water quantity of 367 billion m³, 70% are the waters of Transboundary Rivers of Kura, Araz, Ganykh, Saumur, and Astarachai. Most of all groundwater are also in transboundary aquifers (Fig. 1).

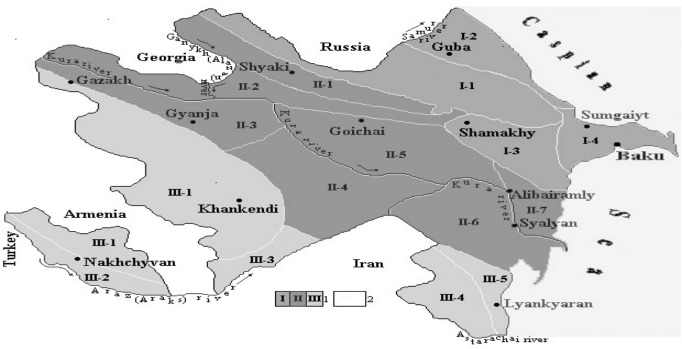

Fig.1:

Scheme of Azerbaijan hydrogeologic zoning

1. Hydrogeological regions; 2. Boundary of hydrogeological regions; I - Greater Caucasian hydrogeological basin: I-1 - Greater Caucasian mountain - fold region; I-2 - Gusar region; I-3 - Gobustan region and the abjacent part of the Near-Caspian lowland; I-4 - Absheron region. II - Kura depression hydrogeological basin: II-1 - Alazan-Agrichai region; II-2 - Adjinour-Jeiranchel region; II-3 - Gyanja-Gazakh region; II-4 - Mil-Garabakh region; II-5 - Shirvan region; II-6 - Mugan-Saliyan region; II-7 - South- Eastern Shirvan region. III - Lesser Caucasian hydrogeological basin: III-1 - Lesser Caucasian mountain - fold region; III-2 - Nakhchyvan region; III-3 - Jabrail region; III-4 - Mountain- Talysh region; III-5 - Lyankyaran region

2. BACKGROUND INFORMATION

The research results show that in the territories of Turkey and Iran environmental conditions of Kura and Araz Rivers are relatively better. The Kura River in the Georgian Varsiya - Akhalkalaki region and Araz beginning from Gumru region of Armenia to Azerbaijan territory are polluted. The annual amount of polluted waters coming from Armenia into Araz River is about 2.6 km^3 and from Georgian territory into Kura River is about 4.2 km^3. In the current situation, the groundwater (GW) plays an important role in all fields of endeavor providing Azerbaijan Republic with sustainable development (2).

Within the geologic-structural features of the region, several GW basins can be recognized: the Greater Caucasus basin, the Kura basin, and the Lesser Caucasus basin. Within these basins, sixteen sub-regions (corresponding to field survey of fresh GW - aquifers) are identified based on the nature of the hydrogeological setting (1). From the 16 identified fields of fresh GW resources, eleven of them are Transboundary Aquifer (TA). Practically about 90% of the fresh GW of the Republic falls in the category of TA and potentially it can produce over 12 million cubic meters (m^3) per day (Fig. 1).

3. PRESENT CONDITION

It may seem that the problem associated with TA is relatively new for Azerbaijan. There existed in the USSR internal boundaries between republics. Even then due to contamination and the lack of plans for regional use of TA, their share use was a great concern for Azerbaijan. Today the framework is an Inter-State problem and it is much more difficult to solve. Worldwide experience in the resolution of TA problems (3) demonstrate that the solution has many aspects (scientific, legal, socio-economic, institutional, environmental).

3.1 Scientific aspects

Just since the first years of the last century, hydrogeologic investigations in Azerbaijan have been conducted regularly. The first purposeful investigations are associated with the search for sources of water supply of the Grate Baku area. From 1939 to 1948 a network of wells to conduct monitoring of groundwater's regime in Azerbaijan was established. More intensive study of hydrogeological conditions started from 1945 to 1990. During that period data on the GW regime, balance and resources were systematized. The last 10-20 years especial attention has been paid to studies as it relates to contamination of GW (1, 2).

3.2 Legal aspects

The legal base adopted in the republic is meets principal legal codes of developed countries. As far as regulations are concerned there are no obstacles for the promulgation and protection of WR both inside the country and TWR. The " Water code of Azerbaijan" and the law "About Interiors of the Earth" approved by special session of legislators of Azerbaijan on December 26, 1997 and April 27, 1998 respectively lay down the principles for any negotiation on the subject matter of TWR. Unlike Armenia and Georgia, the supreme legislative body of Azerbaijan ratified all International conventions associated with the subject matter.

3.3 Socio-economic aspects

To emphasize the importance of WR of the TA in the socio-economic development of Azerbaijan it should be mentioned that about 50% of water supply of Baku city and the other two biggest cities in the republic (Gyanja and Sumgayit) is provided by the GW of the TA and about 70% of these waters are used for agricultural needs and industry.

3.4 Institutional aspects

At present and during the transition of Azerbaijan to a market economy there is an adaptation of the management structure of the WR in the leading countries of the world. The legislation has already fixed that the use of the WR is a prerogative of the local authorities, though control on the right use is in the competence of the Committee on Melioration and Water Resources. At the same time, after some reorganization, all the functions of former committees on geology and hydrometeorology had been passed to the re-established Ministry of Natural Conservation. It is quite natural that in this period when the authorities are not powerful enough the actual management of the WR in the republic is carried out by the above mentioned ministries. Thus this problem is still urgent and it needs a competent solution.

3.5. Environmental aspects

Environmental protection and maintenance of the TA ecology is another urgent problem in the republic as it reaches the inter-state level. The urgency of the problem may be illustrated by the example of the Alazan-Agrichai TA of Azerbaijan and Georgia. More than a million people of both countries live within the region. Intensive contamination of the environment since the time the territory was part of the USSR has resulted in serious pollution of the WR. Water sample form the ground and surficial sources in the territory of Georgia and Azerbaijan contain nitrates, heavy metals and some radioactive elements in amounts that exceed acceptable existing standards.

CONCLUSIONS

The element which units all countries is the understanding that to achieve success it is necessary to study all aspects of the TWR problem well. In this connection for Azerbaijan (in our opinion for other States of region as well) it is important together with the use of its own resources to seek joining numerous programs in the framework of UNESCO, UNECE, UNDP, WMO, etc. On the one hand, it will help to use the rich world experience of highly qualified experts and on the other hand it will result in a complete transparency of results. In this case (one can confirm confidently) such organizations like UNO, OSCE and others can perform as arbiters. By all means this will lead to the conclusion of a multilateral agreement between all countries of the region.

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Characteristics of climatic indicators and their influences on rainfall and temperature in the Murray-Darling Basin

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ABSTRACT

The association between climatic indices which are calculated on a monthly basis, including the El Niño Southern Oscillation (ENSO), and monthly rainfall and temperature in the Murray Darling Basin during the period 1960 to 2009 is investigated. The indices considered are El Niño 1+2, Niño 3, Niño 4, and Niño 3.4, Dipole Mode Index (DMI), North and Southern Atlantic Oscillation, Global tropics, Southern Annular Mode (SAM), Southern Oscillation Index (SOI), and Pacific Decadal Oscillation (PDO). A regression model with periodic functions is used to allow for seasonal variation, and the residuals are examined for evidence of non-stationarity over the study period. Generalized least squares is used to allow for the effect of autocorrelation when estimating the standard error of the regression parameters. Any estimated trend is removed from the residuals, which are then analyzed as a multivariate time series to highlight the dependence structure between indices. Correlograms suggested that the residuals of fitted ARMA (3,0,3) have significantly small autocorrelations, which is consistent with a realizations of white noise and cross-correlograms functions verify multivariate time series that cross correlogram of white noise approximately zero for all none zero lag by pre whitening method, which appears to be stationary process. A factor analysis model is also fitted, and possible interpretations of latent factors will be suggested.
Keywords: cross-correlogram, ENSO, generalized least squares,

1. **INTRODUCTION**

This poster paper proposes that the strong spatial and temporal variations of climate in the region of study are caused by the influences of synoptic systems. It is rational to examine relationships between climate indices and their influence on rainfall and temperature sequences in the Murray Darling Basin (MDB). Many studies have identified the relationship between Australian rainfall and the El Niño Southern Oscillation (ENSO) (Drosdowsky, 1993; McBride and Nicholls, 1983). Furthermore, changes in the Sea Surface Temperatures (SST) affect Australian rainfall (Zhang et al., 1997). The SST anomalous warming and cooling phases in the Pacific Ocean termed the Inter decade Pacific Oscillation (IPO) influences the ENSO phenomenon in Australia (Franks, 2002). Mantua et al. (1997) identified a multi-decadal persistence in the north Pacific sea surface temperatures, termed the Pacific Decadal Oscillation (PDO) The PDO index has been used in place of the IPO, as stronger relationships were found when using this index (Franks, 2002). The climatic variability in the Southern Hemisphere (SH) extra-tropics is measured by the Southern Annular Mode (SAM) that explains the greatest percentage of the variability. One objective of this paper is to present a regression based analysis to ascertain climatic indices, and to investigate their influence on rainfall and temperature sequences in the MDB.

2. AIMS

The recent variability of SST data has seen the development of indices based on more direct measures of temperature itself. The SST gradients have been indicating some uncertainty also to where exactly the ENSO process should be measured. More recently, another ENSO monitor called the multivariate ENSO index (MEI) has been developed (Wolter and Timlin, 1998). In this research several climatic indices are considered, for example, four climatic indices from the Pacific Ocean and three climatic indices from the Atlantic Ocean, Indian Ocean, Southern Annular Mode (SAM), SOI and PDO.

3. DATA

The rainfall and temperature data used in this research were obtained from the Australian Bureau of Meteorology (BOM, 2008). They were extracted from a 0.25° × 0.25° grid (BOM, 2008) for monthly rainfall and temperature from January 1957–December 2007. Sea-level pressure anomalies were derived from records over the Australian continent bounded by 110-160°E and 10-45°S over the period from 1957 to 2007 for each season and other pressure anomalies (e.g. monthly PDO, SOI) values were collected from the National Climate Centre of the Australian Bureau of Meteorology over the period 1957-2007. The weather station locations were selected because they recorded both rainfall and temperature data and had the highest BOM quality designation for both data series. The MEI in the Pacific Ocean, Atlantic Ocean, and Indian Ocean are defined in Table 1. The SST anomalies were derived from data available from Climate Prediction Centre (CPC) of the National Weather Service over the period 1950 to 2008. For the Dipole Mode Index (DMI) in the Indian Ocean, the SST anomalies were collected from the Japan Agency for Marine Earth Science and Technology (JAMSTEC) as derived by Kaplan et al. (1998) over the period from 1950 to 2008. The SAM data were collected from the Natural Environment Research Council, based on the British Antarctic Survey pressure anomalies derived by Marshall (2003) over the period 1957 to 2008. To facilitate time series analysis, the missing values were replaced by series' means, using SPSS version 17.

4. METHODS

There is a clear seasonal variation for at least some of the indices and in order to assess evidence of a trend, regression models are fitted with three periodic functions to allow for seasonal variation and linear and quadratic terms to allow for any trend. The general formula is given by.

$$Y_t = \beta_0 + \beta_1 C_1 + \beta_2 S_1 + \beta_3 C_2 + \beta_4 S_2 + \beta_5 C_3 + \beta_6 S_3 + \beta_7 (t - \bar{t}) + \beta_8 (t - \bar{t})^2 + \varepsilon_t \text{..eq.(1)}$$

Where t runs from 1 up to 608 and average t is 304.5, Y_t is climatic indicators and
$C_1 = \cos(2\pi t/12)$, $S_1 = \sin(2\pi t/12)$, $C_2 = \cos(2 \times 2\pi t/12)$, $S_2 = \sin(2 \times 2\pi t/12)$,
$C_3 = \cos(3 \times 2\pi t/12)$, $S_3 = \sin(3 \times 2\pi t/12)$,

An example of the fitted model is that for Nino1+2 shown below

$$\text{Nino } 1+2 = 23.12 + 0.0915\ C_1 + 2.8675\ S_1 - 0.2841\ C_2 + 0.09531\ S_2 - 0.0118\ C_3 - 0.0943\ S_3 + 0.00022\ (t - \bar{t}) - 0.0000018\ (t - \bar{t})^2$$

5. ANALYSIS AND DISCUSSION

5.1. DESEASONALIZED ASSESSMENT OF TREND

The result of fitting the regression model (equation 1) to the 11 climatic indices is summarized in Table 2. This is referred to as the deseasonalized – detrended time series.

Table 2: Assessment of climatic indicators

ENSO indices	NINO1.2	NINO3	NINO4	NINO3.4	NATL	SATL	TROP	DMI	PDO	SOI	SAM
Intercept	23.120	25.800	28.370	26.940	26.560	24.800	27.580	-0.004	0.218	-1.337	-0.122
Natural series Standard dev.	2.318	1.273	0.673	0.967	0.933	1.499	0.553	0.334	1.034	10.238	1.812
Deseasonalized Standard dev.	1.092	0.895	0.631	0.862	0.361	0.349	0.269	0.331	0.984	10.144	1.781
Co eff linear t	0.00022	0.00041	0.00070	0.00025	0.00058	0.00087	0.00091	0.00003	0.00157	-0.00724	0.00176
Est Standard error	0.00025	0.00021	0.00015	0.00020	0.00008	0.00008	0.00006	0.00008	0.00023	0.00236	0.00041
P-values	0.383	0.0484*	0.000***	0.2180	0.000***	0.000***	0.000***	0.679	0.000***	0.002**	0.000***
Co eff quadratic t	-0.0000019	0.0000005	0.0000036	0.0000023	0.0000051	-0.0000006	0.0000017	0.0000002	-0.0000047	0.0000064	0.0000001
Est Standard error	0.0000016	0.0000013	0.0000009	0.0000013	0.0000005	0.0000005	0.0000004	0.0000005	0.0000014	0.0000150	0.0000026
P-values	0.253	0.720	0.000***	0.068	0.000***	0.237	0.000***	0.723	0.001***	0.672	0.982
AR(1) coeff of residuals	0.902	0.922	0.937	0.936	0.88	0.849	0.936	0.736	0.807	0.636	0.208

*coefficients are statistically significant at the 5% level
* *coefficients are statistically significant at the 1% level
* * * coefficients are statistically significant at the 0.1% level

5.2. PREWHITENING WITH ARMA MODEL AND CROSS CORRELATIONS

In this section, we investigate the cross correlation between climatic indicators after removing trend and seasonal variation and allowing for correlation structure. This process is known as pre-whitening. In principle, the pre-whitened climatic indicator series are realisations of independent random variation and can therefore, be cross-correlated at one lag only

5.2.1. CORRELOGRAM AND CROSS CORRELATIONS

The pre-whitened series are considered as residuals of an independent sequence (discrete white noise). If we have two white noise sequences then by definition, the auto correlation function is 0 at all lags after than lag 0 when it is 1. The cross correlation between the two sequences can only be non-zero at a single value of lag k and if the white noise sequences are uncorrelated, the cross correlation is 0 at all lags. Therefore, for the pre-whitened time series, which we consider as realisations of white noise, we look for a single statistically significant cross correlation and note its lag. The cross correlations are shown in the Figure 3 and the maximum absolute values are presented in Table 4. In no case is there any evidence of one series leading or lagging another as the maximum cross correlations all occur at lag 0.

Table 3: Maximum absolute values of cross correlations

	NINO1.2	NINO3	NINO4	NINO3.4	NATL	SATL	TROP	DMI	PDO	SOI	SAM
NINO1.2	1.000										
NINO3	0.395 (0)	1.00									
NINO4	0.031(0)	0.201 (0)	1.00								
NINO3.4	0.088 (0)	0.766 (0)	0.510 (0)	1.00							
NATL	-0.024 (0)	0.003 (0)	0.049 (0)	0.025 (0)	1.00						
SATL	0.010 (0)	0.103 (0)	0.075 (0)	0.082 (0)	0.036 (0)	1.00					
TROP	0.365 (0)	0.673 (0)	0.532 (0)	0.673 (0)	0.127 (0)	0.301(0)	1.00				
DMI	0.098 (0)	0.71 (0)	-0.032 (0)	0.030 (0)	0.055 (0)	0.059 (0)	0.060 (0)	1.00			
PDO	0.092 (0)	0.040 (0)	-0.058 (0)	0.014 (0)	0.115 (0)	0.010 (0)	0.039 (0)	0.040 (0)	1.00		
SOI	-0.078 (0)	-0.035 (0)	-0.098 (0)	-0.084 (0)	-0.106 (0)	-0.003 (0)	-0.091 (0)	-0.081 (0)	-0.021 (0)	1.00	
SAM	-0.019 (0)	-0.027 (0)	-0.026 (0)	-0.043 (0)	-0.002 (0)	-0.079 (0)	-0.094 (0)	0.084 (0)	-0.021 (0)	-0.043 (0)	1.00

5.3. REGRESSION MODEL FOR RAINFALL AND TEMPERATURE SERIES

A regression model was fitted to determine whether the climatic indices and their interaction effects are significantly influencing the rainfall and temperature patterns in the MDB. A linear and quadratic term (mean adjusted) and a sinusoid of period one year were included in the regression model.

Table 4: Regression model fitted by individual CI for rainfall and temperature.

Rainfall model	Adelaide Airport		Broken hill		Canberra Airport		Hume dam		lake Victoria		Loxton		Melbourne Airport		Mildura Airport		Murray bridge		Sydney obs. Hill	
	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}
Nino1+2	23.990	0.264	29.220	0.004	37.52	0.044	39.680	0.117	21.520	0.038	18.190	0.041	29.580	0.034	22.910	0.033	22.69	0.089	91.51	0.033
Nino3	24.000	0.264	28.970	0.020	37.22	0.060	39.390	0.130	21.510	0.038	18.140	0.046	29.470	0.041	22.940	0.031	22.69	0.089	91.40	0.035
Nino4	23.990	0.264	28.590	0.046	37.17	0.062	39.390	0.130	21.420	0.046	18.070	0.053	29.370	0.048	23.190	0.010	22.67	0.091	91.30	0.037
Nino34	23.990	0.264	28.680	0.040	37.13	0.064	39.280	0.135	21.470	0.042	18.090	0.051	29.400	0.046	23.050	0.021	22.69	0.089	91.34	0.037
N-Atl	24.020	0.262	29.240	0.002	37.65	0.038	39.990	0.104	21.590	0.031	18.200	0.040	29.580	0.034	23.080	0.018	22.69	0.089	91.49	0.034
S-Atl	24.010	0.263	29.250	0.002	37.66	0.037	39.960	0.105	21.500	0.039	18.110	0.049	29.500	0.039	23.060	0.020	22.64	0.093	91.14	0.041
G. tropi	24.030	0.262	29.030	0.016	37.51	0.045	39.680	0.117	21.560	0.034	18.170	0.043	29.630	0.031	22.950	0.029	22.69	0.089	91.49	0.033
DMI	23.780	0.277	29.240	0.002	37.28	0.056	39.320	0.133	21.480	0.041	18.090	0.051	29.540	0.037	23.190	0.009	22.6	0.096	91.50	0.033
PDO	24.030	0.261	29.150	0.008	37.65	0.037	39.990	0.103	21.550	0.035	18.200	0.040	29.620	0.032	23.260	0.004	22.65	0.092	91.40	0.036
SOI	23.730	0.280	28.400	0.059	36.49	0.096	38.500	0.169	21.040	0.080	17.830	0.079	29.440	0.043	22.730	0.049	22.67	0.090	90.94	0.045
SAM	24.010	0.263	29.040	0.016	37.31	0.055	39.970	0.104	21.470	0.041	18.180	0.042	29.400	0.046	23.130	0.015	22.65	0.092	90.36	0.057
Temp model	Adelaide Airport		Broken hill		Canberra Airport		Hume dam		lake Victoria		Loxton		Melbourne Airport		Mildura Airport		Murray bridge		Sydney obs. Hill	
	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}
Nino1+2	2.581	0.879	4.809	0.131	2.315	0.904	1.629	0.940	3.430	0.552	1.484	0.933	2.634	0.893	1.531	0.937	1.893	0.828	91.510	0.033
Nino3	2.557	0.881	5.165	-0.002	2.288	0.907	1.643	0.939	3.427	0.553	1.491	0.932	2.627	0.894	1.541	0.936	1.891	0.829	91.400	0.035
Nino4	2.569	0.880	5.113	0.018	2.313	0.905	1.654	0.938	3.430	0.552	1.492	0.932	2.666	0.891	1.544	0.936	1.885	0.830	91.300	0.037
Nino34	2.560	0.881	5.106	0.020	2.296	0.906	1.651	0.938	3.427	0.553	1.492	0.932	2.647	0.892	1.544	0.936	1.888	0.829	91.340	0.037
N-Atl	2.531	0.884	4.894	0.100	2.347	0.902	1.645	0.939	3.425	0.554	1.487	0.932	2.670	0.891	1.540	0.936	1.883	0.830	91.490	0.034
S-Atl	2.550	0.882	4.884	0.104	2.349	0.902	1.655	0.938	3.429	0.552	1.492	0.932	2.685	0.889	1.544	0.936	1.885	0.830	91.140	0.041
G. tropi	2.473	0.889	5.137	0.008	2.317	0.904	1.654	0.938	3.430	0.552	1.488	0.932	2.663	0.891	1.543	0.936	1.867	0.833	91.490	0.033
DMI	2.538	0.883	5.160	0.000	2.319	0.904	1.627	0.940	3.430	0.552	1.473	0.934	2.648	0.892	1.527	0.937	1.887	0.829	91.500	0.033
PDO	2.581	0.879	5.141	0.007	2.352	0.901	1.655	0.938	3.422	0.554	1.492	0.932	2.680	0.890	1.544	0.936	1.888	0.829	91.400	0.036
SOI	2.578	0.879	5.166	-0.003	2.297	0.906	1.648	0.939	3.419	0.555	1.490	0.932	2.645	0.893	1.537	0.936	1.893	0.828	90.940	0.045
SAM	2.581	0.879	5.165	-0.002	2.310	0.905	1.654	0.938	3.425	0.554	1.483	0.933	2.663	0.891	1.537	0.936	1.893	0.828	90.360	0.057

From Table 4, the strongest influence of climatic indices on rainfall and temperature patterns will yield a minimum standard deviation (SD) and maximum adjusted R^2 in Table 5. This study suggested that the SOI is significantly the largest influence on rainfall and temperature patterns in the MDB and is well fitted according to the R^2 values from the regression model.

6. CONCLUSION

Statistical techniques were applied to assess the influences of climatic indices on rainfall and temperature patterns in the MDB areas and eastern Australia. This research provided evidence of seasonality. A deterministic trend and seasonal change in climatic indices series was highlighted by the various use regression models. Strategies were superimposed to detect the trend of influence of climatic indices on the SST and SLP in the Pacific and Atlantic Ocean. This study provided evidence of an increasing trend of influence in the Atlantic Ocean. Moreover, these indices are not significant influential on Australian rainfall and temperature patterns. The analytical evidence has shown that Australian rainfall and temperature subject to SOI and PDO influences. Furthermore, the consistent influence of SOI with PDO and their interaction effects was highly significant on Australian rainfall and temperature.

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Typologies of groundwaters in basins shared between Ethiopia-Kenya, Ethiopia-Sudan and Ethiopia-Djibouti and their trans-boundary implications

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The implementation of laws relating to transboundary aquifers necessitates field knowledge so that the laws can be coincident with reality on the ground. The definition of 'shared aquifer' is more complex than the mere physically-shared body of groundwater flowing from country A to country B. The border between Ethiopia and Kenya is characterized by low-volume groundwater storage and low transboundary flows. However, groundwater has visible environmental, social and economic functions. The characteristics of groundwater flow and storage in aquifers shared between Ethiopia and Kenya are different from those used in setting the foundation of the international legal framework on shared aquifers. By describing the characteristics of the groundwaters that are shared between Ethiopia and Kenya, this work demonstrates that the international legal framework is inadequate when applied in this region. The main inadequacies are: a) international law does not specify the minimum volume of transboundary flow in an aquifer for it to qualify to be treated under the law, and b) the physical aspects of water get more emphasis than the functions of groundwater. A more adequate international legal framework would be one that considers specific types of groundwater and local needs.

Prominent geologic and geomorphic features of the Ethiopia and Kenya border and bordering regions are domal uplifting centered over Ethiopia and Kenya, rift valley traversing the Ethiopian and Kenya domes, and accompanied volcanism and sedimentation. These prominent tectono-geomorphic features are responsible for the regional drainage pattern. The border between Ethiopia and Kenya is approximately located at the intersection (foot) of the Ethiopian and Kenyan domes. This makes the border region generally a site of drainage convergence from the Kenyan and Ethiopian highlands.

The hydrography of the basins is a direct reflection of the geology and structures and is characterized by complex networks of primary and captured drainages. Though localized in the great East African Rift, which is otherwise the site of volcanism and tectonism, the major parts of the region straddling Ethiopia and Kenya are underlain by Precambrian metamorphic rocks, Mesozoic sediments, Tertiary volcanics, and thick Miocene to Quaternary sediments.

In the shared basins of Ethiopia and Kenya the basement rocks are characterized by the lowest storage potential. Unlike many parts of central Africa where the basement rocks are overlain by up to a few tens of meters of thick regolith (Chilton and Foster 1995) the basement aquifers of southern Ethiopia and northern Kenya are characterized by only thin (in the order of 2 to 3 m) regolith thereby hampering groundwater storage.

While the rift structures are favorable for regional groundwater flows, the fact that the shared borders of Ethiopia and Kenya are located at the foot of two regional highlands favors surface-water discharge near the common borders. The low storage and hydraulic conductivity properties of the aquifers of the region limit the volume of transboundary flows across the Ethiopia-Kenya border.

The term 'transboundary groundwater' commonly implies to a body of groundwater intersected by a political border with potential threat of dispute over a shared resource and this kind of definition is inadequate to describe situations in southern Africa (Cobbing et al. 2008). This definition is inadequate at the Ethiopia-Kenya border as well. Approximately 80% of the Ethiopia-Kenya border is underlain by low-yielding aquifers and low cross-border groundwater flows, but water demand for socio-economic functions is high. The concept of transboundary groundwater must necessarily include aquifers where little cross-border flow occurs, but where cross-border cooperation will help to ensure sustainable socio-economic cooperation in the utilization of shared aquifer resources. From the information on groundwater flow and the aquifers investigated under the current study, the existing list of types of transboundary aquifers can be updated:

1. 'Ideal ' systems, under which the international law of transboundary aquifers or the international law of water courses and the definition of transboundary aquifer can readily be applied (eg. models of Eckstein and Eckstein (2005) or types of system described by Barberis (1986))
2. System under which the common definition of the transboundary aquifer cannot be readily applied because the flux of groundwater is low or 'insignificant' and the resource use is minimal, such as the basement aquifers of southern Africa (Cobbing et al. 2008)
3. Other systems, such as where an aquifer is shared by more than two states, or where states share more than one aquifer contained in one basin and the role of the states varies depending on which aquifer they are dealing with, or where there is no accurate boundary demarcation of the aquifer (Scheumann and Alker, 2009)
4. System under which the definition of transboundary aquifer or the applicability of the law of transboundary aquifers is vague because the flux and storage of groundwater is 'insignificant' but groundwater is the sole source of water supply for socio-economic activity. This is the typical case of the Ethiopia-Kenya shared groundwater resource.

International law which considers groundwater as a mere physical entity may fall short of serving the purpose of bringing about better management and protection of the scarce groundwater resources in the region. Therefore management of shared aquifers and groundwater resources should consider all socio-economic issues rather than considering the groundwater as a mere physical entity. A concerted effort may be needed to investigate and map the linkage between groundwater and cross-cutting issues such as environment, climate change, ecosystems, and socio-economics in the region. Encouraging cross-border socio-economic interaction, enhancing the roles of cross-border boundary commissions and water management committees, or establishing grass-roots institutions, give a better management outcome than the mere ratification of the draft law alone.

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Proposal Methodology for Establishing Limit Distances from Country Boundaries for the Management of Transboundary Aquifer Systems

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1- INTRODUCTION

Most countries have laws and legal rules, in national, regional and local ambit to regulate the water use. For transboundary surface water resources there are several agreements, however, related to groundwater management the international legal tools are very few, almost none. The reasons for that are related to several aspects that influence in getting accordance among countries. Probably the main cause or the root cause is the lack of reliable and systematized information related to the TAS. The amount of information necessary to do a TAS management is large, diversified, expensive and takes time to get them. In general, in most of the countries, they don´t exist, or are not systematized.

When dealing with TAS with large areas, an integrated management aiming the minimization of possible negative consequence from water use among countries is very difficult. This problem is directly related with the incertitude if an intervention made in a country could have a negative consequence in other country, and if this occurs, how long it will take to happen. As the velocity of groundwater flow, in most of the cases, is slow, the time for an intervention made in a point of the TAS could cause a possible effect in another distant point could be very long, taking hundreds or thousands years. For all the facts, it is necessary the search for minimum management mechanisms for having understanding instruments about TAS in areas where a water use could have repercussion in neighbor country.

It is well known that aquifer management is more efficient the smaller its area is. In this aspect, some countries have agreement about establishing a strip of land, in both sides of the political frontiers among them, in which, due to the size of its area, is possible to have sufficient available information to establish a minimum management understanding. However, this strip is established, in general, in an empiric way, with low technical consistency.

This article suggests a methodology for estimating the wide of this strip of land incorporating most of physical, demographical, environmental, social and institutional aspects of TAS in order to determinate the water supply and demand, as well as facilitates its governability and management.

2- METHODOLOGY

The first step of this methodology is the estimation of the most distant point from the border line, in which, any physical intervention on the aquifer could cause a negative consequence on the other side of the frontier, in a reasonable time lag. The proceedings for estimating this distance is following.

Identification of the lithology (rock types) that constitute the TAS and estimation of the respective hydraulic conductivity medium rate. These information are, generally, available in the literature. As an example, is presented bellow a table with general data about this issue.

Lithology	Hydraulic Conductivity (cm/s)	Total Porosity n (%)
Gravel	$1 - 10^{-2}$	25-50
Sand well sorted	$10^{-1} - 10^{-3}$	20-35
Sandstone	$3 \times 10^{-8} - 6x\ 10^{-4}$	5-30
Limestone	$10^{-7} - 6x\ 10^{-4}$	0-20
Granite	$8 \times 10^{-7} - 3x\ 10^{-2}$	0-1
Basalt	$2 \times 10^{-9} - 4x\ 10^{-5}$	3-35
Fracturated crystalline rock	8 x 10-7 - 3x 10^{-2}	0-10

Table1 – Examples of Hydraulic Conductivity and Total Porosity (1)

The definition of hydraulic conductivity rate for this methodology must consider the following conditions: a) If there is doubt about the lithology or the occurrence of rocks of different origins and characteristics in the frontier region, must be selected, for precaution, the one that presents the higher hydraulic conductivity rate that will be denominated TAS' Critical Conductivity Rate (CCR); b) The value to be considered in the calculus will always be the one which is the superior theoretical limit. For instance: if we take the values from table, the CCR to the sandstone would be $6x10^{-4}$ cm/s.

Management Time (MT). The estimative of a management time for a TAS must consider, among other factors, a suitable planning time horizon in which the countries can plan and have management governability. For instance, a 1000-years planning time could be not reasonable, considering the imponderability originated from this kind of forecast.

The Physical and Technical Strip of Land (PTS). The estimative of the distance from the farthest point where an action developed in one country could cause a negative impact in another country, in a reasonable time leg, is calculated by multiplying CCR for MT. Considering the lithologycal variability and technical difficulties in the acquirement of reliable conductivity data in all frontier extension, must be considered for this methodology that the water flux between countries will be predominantly linear, continuous and horizontal. This consideration will allow that the external line of the PTS will be uniform and parallel to the frontier line (Fig. 1).

Frontier Management Stripe (FMS). One of the major problems to have an aquifer water management is the availability of reliable georeferenced data directly related with the TAS area. These information with demographic, economical, social, environmental data, in most cases do not exist in a systematized way. On the other hand, the great majority of countries have most part of these information presented in its national census. These data are collected, in general, from the smallest administrative country unity (SAU), considering its respective political division (state, province, municipality, district, etc) to the national level and they are aggregated according different formats and subjects.

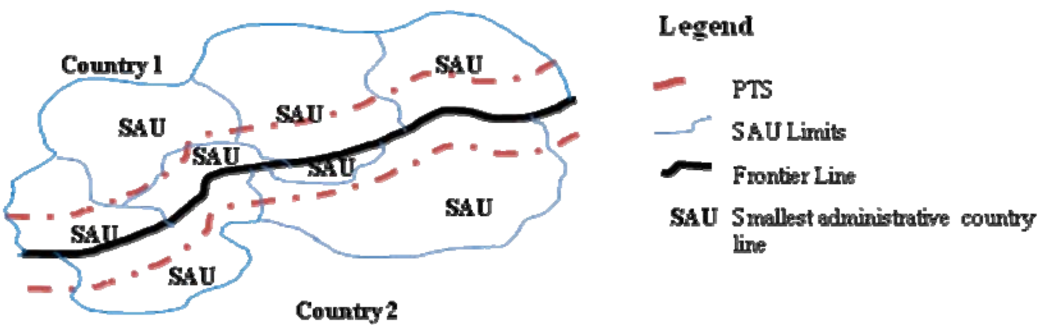

Figure 1 Physical/Technical Strip of Land (PTS)

In order to adequate the aquifer management conditions with information about the needs of water for supply and demand (for all purposes, including environmental ones) in its area, these data must be well known and be available. Considering that once the PTS is established, the countries will have TAS technical physical information in that strip of land, it necessary to know how the water use could reflect in the local environment (anthropic or not). To do that is necessary to compatibilized and systematized these information with socio-economic-environmental ones.

As PTS is parallel to the border line, and also, in general, crosses areas of the SAUs, becoming hard to get systematized data census information to these specific aquifer areas located inside these unity territories. This methodology suggests the establishment of a FMS, in order to facilitate this association. In this sense, FMS is defined as the strip of land, besides de frontier line, which area is composed by the total area of the SAUs, which territory is included part or completely in the FTS. The external line of the FMS is composed by the junctions of the farthest SAU territory limits from the border line (Fig. 2).

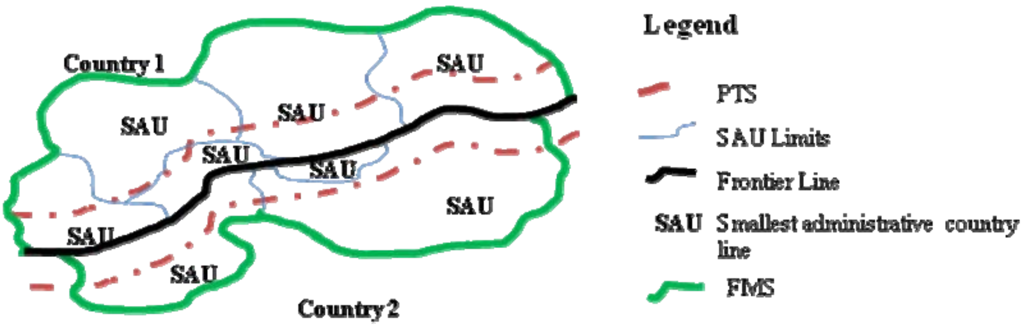

Figure 2 - Frontier Management Stripe (FMS)

3 - CONCLUSION

The purpose of this methodology is having socio-economical-environmental systematized data for a strategic strip of land, where transboundary groundwater management is necessary and relevant. Taking into consideration that the FMS already have available systematized census data the acquirement of information, must be easier and less expensive. In this way, the establishment of this strip of land can facilitate countries to agree about legal mechanisms to the FMS area, where an action in water use really could cause an impact in the neighbor country, allowing the establishing of minimum and effective management mechanisms that will contribute to the protection and management of TAS.

Acknowledgements

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Effects of land use change on surface water regime
(Case study Orumieh Lake of Iran)

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ABSTRACT

Land use change from rangeland and forest to agriculture and orchard areas which affected water regime, are widely occurred in many parts of Iran.
The above mentioned problem has happened in Orumieh Lake basin for an area of 1146 km2 which is located in northwest of Iran. The recent land use map was resulted through satellite images of 1990, 1998 and 2006 as well as field observations and the previous period map was performed by using the aerial photographs of 1955 (which is considered as the oldest documents). In this period 14% of rangeland is changed into dry farming and 7% of irrigated farming is converted to orchard.
The results show that due to land use change in this area, the mean annual discharge has not changed but maximum daily discharge increased and minimum daily discharge reduced.

Key words: Land use change; water regime; dry farming; daily discharge; Orumieh Lake; Iran

1. INTRODUCTION

There are complex processes such as climatic variables and environment parameters that convert rainfall to runoff. Historical researches proved the effects of forest on water regime. The effects of suburban development have been characterized in several studies; increased flood frequencies in areas with impervious surfaces werereported in the late 1960s and early 1970s (Leopold, 1968; Seaburn, 1969; Anderson, 1970). More recent studies have focused on the effects of engineered aspects of catchments, (e.g. detention basins, riparian buffers and septic systems) on runoff volume and water quality (Robertson et al., 1991; Griffin, 1995; Chin and Gregory, 2001; Booth et al., 2002).

Land use change can have significant effects on rainfall-runoff processes. For example, research indicated that deforestation can amplify flood risk (e.g. Laurance, 2007; Bradshaw et al., 2007) through decreasing infiltration capacity, transpiration and interception (Clark, 1987). Urbanization decreases the infiltration capacity and transpiration as well through the removal of vegetation and the creation of impervious surfaces (e.g. Dow and DeWalle, 2000; DeWalle et al., 2000). In the Eururalis project (Verburg et al., 2006), four land use change scenarios for Europe were developed, which are based on the story lines described by the SRES scenario families.

In this paper we are going to prove the effects of land use change on water regime in Orumieh Lake of Iran.

2. METHODOLOGY

2.1. Study area

Orumieh lake located in northwest of Iran Barandoozchai basin, with an area of 114565 ha is one of the main rivers and situated between 44:45 E to 45:13 E and 37:06 N to 37:28 N. The climate of study area is mostly semi-arid. Based on river branches the basin divided to 7 sub-basins. Fig.1(a) shows the location of sub-basins on satellite ASTER image.

2.2. Methods

The satellite ASTER 2006 was used for preparation of new period of land use and its results was checked by field observations. The aerial photographs and topography maps in 1956 were used to determination of old period land use map and the results were completed by native's knowledge.

Babarood gauging station is located in the outlet. Its data from 1953 up to now was utilized to determination of changing river regime. To compare the trend of annual discharge with annual rainfall first of all they became dimensionless using dividing to their average. The trend of peak discharge compared with maximum daily precipitation after dimensionless them.

3. RESULTS

Use of land use maps for present and previous period various land use area measured (table 1)

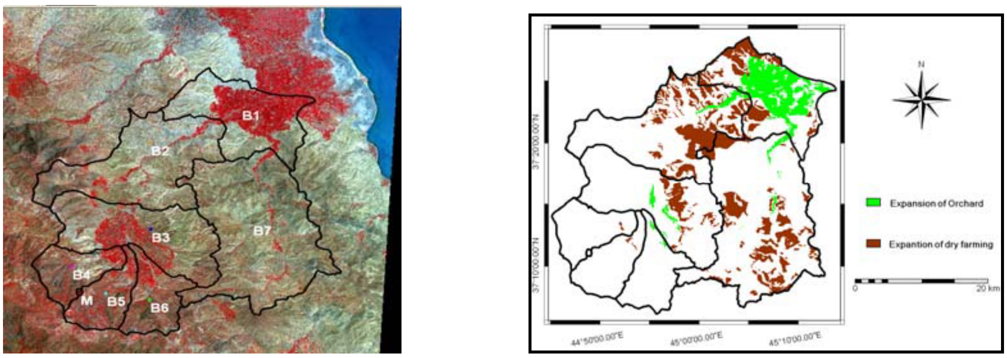
Table 1: Area of land use at present (new) and previous (old) period (ha)

sub-basin	B1		B2		B3		B4		B5		B6		B7	
land use	new	old	new	old	new	old	new	old	new	old	new	old	new	old
Rangeland	3990	6845	12513	18183	11561	13202	6314	6365	6035	6025	6153	5986	24927	30935
Irrigated arming	85	6090	3390	3669	5263	5796	725	717	782	693	1307	1692	1112	1575
Dry farming	4804	1951	6649	1296	1843	151	55	-	118	229	47	-	6716	902
Orchard	7000	1176	623	26	409	-	-	16	-	-	130	-	617	6
Urban	257	74	101	17	156	30	5	1	16	4	55	11	67	20
Others	101	101	172	257	330	383	23	23	33	33	82	85	-	1
Sum	16237	16237	23448	23448	19562	19562	7122	7122	6984	6984	7774	7774	33439	33439

Comparison of the columns in table 1 shows the land use change in this region (table 2). In this table negative and positive shows the reduction and increase of land use change respectively. Fig. 1(b) shows the expansion of dry farming and orchards during 1955 to 2006.

Table 2 : Percent of land use change during periods

sub-basin / land use	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**sum**
Rangeland	-18	-24	-8	-1	0	2	-18	-14
Irrigated	-37	-1	-3	0	1	-5	-1	-7
Dry farm	18	23	9	1	-2	1	17	14
Orchard	36	3	2	0	0	2	2	7
Urban	1	0	1	0	0	1	0	0
Others	0	0	0	0	0	0	0	0
Sum	0	1	1	0	-1	1	0	0



(a) (b)

Figure 1 : a) Aster satellite image of area b) Map of expansion of Orchard and dry farming

Wet and dry periods using 5 year moving average of discharge data were determined. (Dry periods: 1953 to 1967 and 1980 to 1988 and wet periods: 1968 to 1979 and 1985 to 2000). Inasmuch as the rainfall data started from 1970 the parameter indexes calculated only for wet periods (Table 3).

Table 3 : Comparison of Barandoozchai River statistical characteristics before and after land use change in wet period

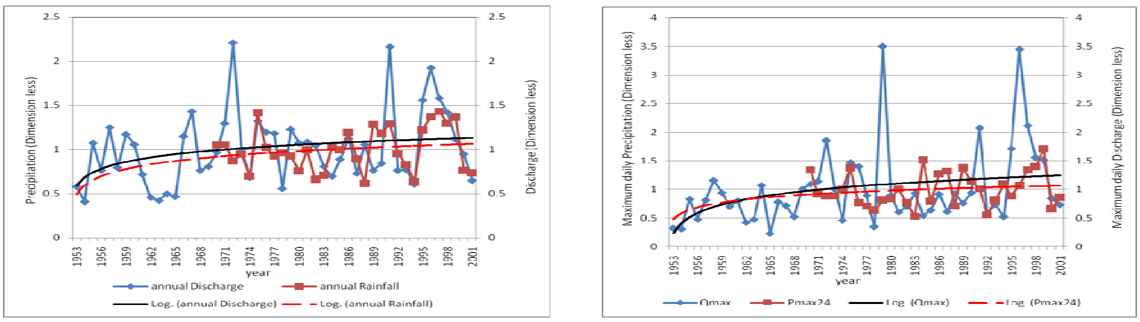
Parameter	wet period	Discharge		
		Mean	Max Daily	Min daily
max	68-79	19.35	215.28	0.61
	85-00	18.98	212.2	0.22
min	68-79	4.9	21.34	0
	85-00	5.27	32	0
mean	68-79	9.67	75.24	0.18
	85-00	9.76	74.63	0.02
Sd	68-79	3.77	51.6	0.25
	85-00	4.06	47.69	0.05
Cv	68-79	39.01	68.58	143
	85-00	41.61	63.9	335

3.1. Mean Annual Discharge Trend

Mean annual discharge has a rising trend of course the annual rainfall has to consider. Both parameters divided by their mean to ignore their dimensions (Fig 2(a)).

3.2. Maximum daily Discharge (Qmax24)Trend

To analysis the change in Qmax24 trend, it compared with maximum daily precipitation (Pmax24) (both dimensionless). (Fig 2(b))



(a) (b)

Figure 2: Comparison of Discharge and Precipitation. a) Annual b) Maximum daily

3.3. Minimum daily Discharge (Qmin24) Trend

Fig 3 shows the minimum daily discharge and Trend line.

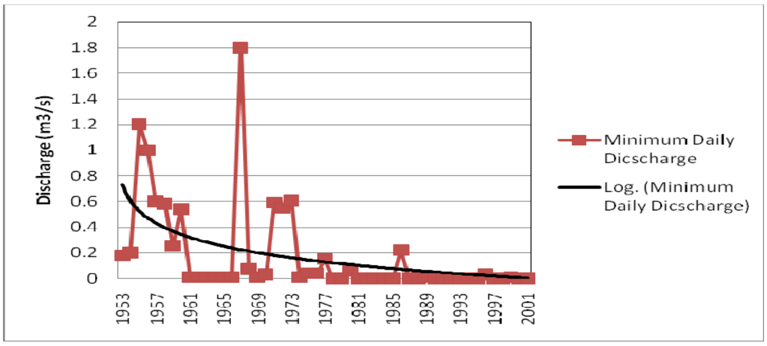


Figure 3 : Minimum daily discharge and Trend line

4. CONCLUSION

Previous and present land use map show that the range land area is reduced from 87500 ha to 71500 ha and change to dry farming. In this region due to high slop land is tiled downward which increase runoff rate and decrease infiltration.

Comparison of the results show that this rate of land use change could not have a significant change on mean annual discharge (same trend gradient) but maximum daily discharge is being increased and minimum daily discharge is being decreased. The continuous of this approach may cause to decry of ground water level, increase water salinity of Orumieh Lake and its land surround.

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Transboundary aquifer within the mining areas
– the case study of the Upper Silesian Coal Basin

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ABSTRACT

The crucial problems for the Debowiec formation aquifer, situated on the borderland of Poland and Czech Republic: mitigation of hydrogeological hazards and water inflows into coal mine workings situated below, restraining the mining drainage responsible for depletion of the non-renewable groundwater resources, estimation of CO2 sequestration potential of the aquifer are discussed in the paper. However the first steps, taken by the research groups from Polish and Czech Universities, in cooperation with mining companies were undertaken, these issues require comprehensive solutions in the spheres of mine safety legislation and improvement of information exchange.

Key words: The Upper Silesian Coal Basin, coal mining, CO_2 geosequestration, mine flooding hazard

1. INTRODUCTION

The Upper Silesian Coal Basin (USCB) – one of the major European Coal Basins - is situated on the borderland of Poland and Czech Republic, within the range of Carpathian foredeep structures. The base overburden units of coal-bearing Carboniferous complex are formed by Tertiary coarse-grained sediments of Lower Badenian (LB). These sediments (so called the Dębowiec formation) fill deep depressions in paleorelief, and they form confined geohydrodynamic structure of the area of 635 sq km (Fig. 1). Groundwater of marine origin contain high amounts of Br^- and I^- enabling their possible utilization in balneology. The groundwater volume is estimated at about $3{,}8 \cdot 10^9$ m^3.

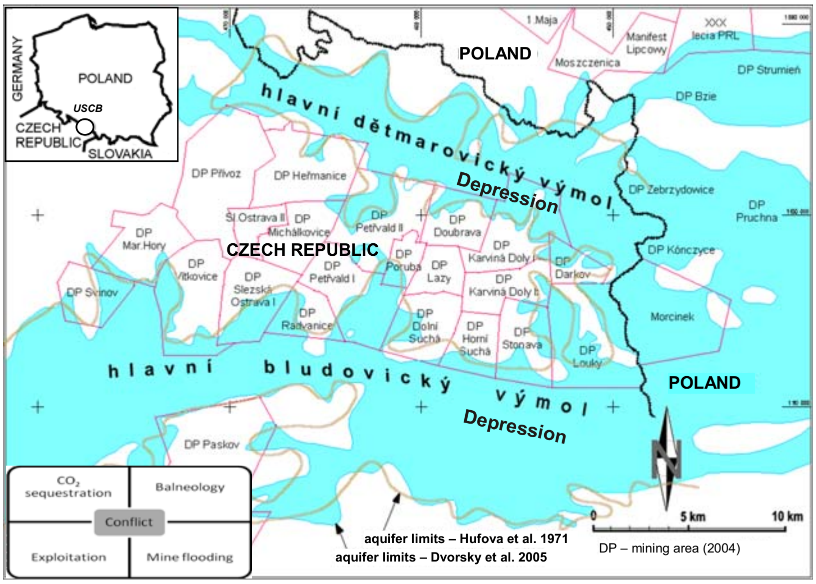

Fig. 1. Situation of the USCB, and the idea of local transboundary aquifer issues.

2. LOCAL TRANSBOUNDARY AQUIFER ISSUES

The crucial issues for the LB aquifer management are: mitigation of hydrogeological hazards and water inflows into coal mine workings situated below, restraining the mining drainage responsible for depletion of the groundwater resources, estimation of CO_2 sequestration potential (amounts of CO_2

than can be stored in the aquifer). The starting point of recent sustainable groundwater management of the aquifer was the database building. The records contain the data: description and XYZ coordinates of sampling points, origin of waters, technical information on sampling and analyses, properties of water and concentrations of major and trace components, water level changes. Thy include also the samples of inflows from water-bearing faults, hazardous to mine workings. The database enabled the definition of hydrochemical zoning, mathematical modeling of groundwater flow – in order to predict the flooding hazard to existing coal mines, and geochemical modeling of CO_2 sequestration capacity.

2.1. Exploitation and mine flooding

This aquifer has been a source of hydrogeological hazards connected with water inrushes and increased water inflows into coal mine workings situated underneath. Accidents of penetration and migration of gases (CH_4 and CO_2) from the Detritus aquifer into underground mines occurred frequently in the Czech part of the Upper Silesian Coal Basin. Moreover flooding (closure) of a coal mine in the Polish (the "Morcinek" mine) increased the inflow and the risk of mining activity in the adjacent Czech colliery - the ČSM. The figure 2 depicts mine water drainage changes, including the forecast elaborated basing on hydrodynamic model of the area (Dvorsky et al., 2007).

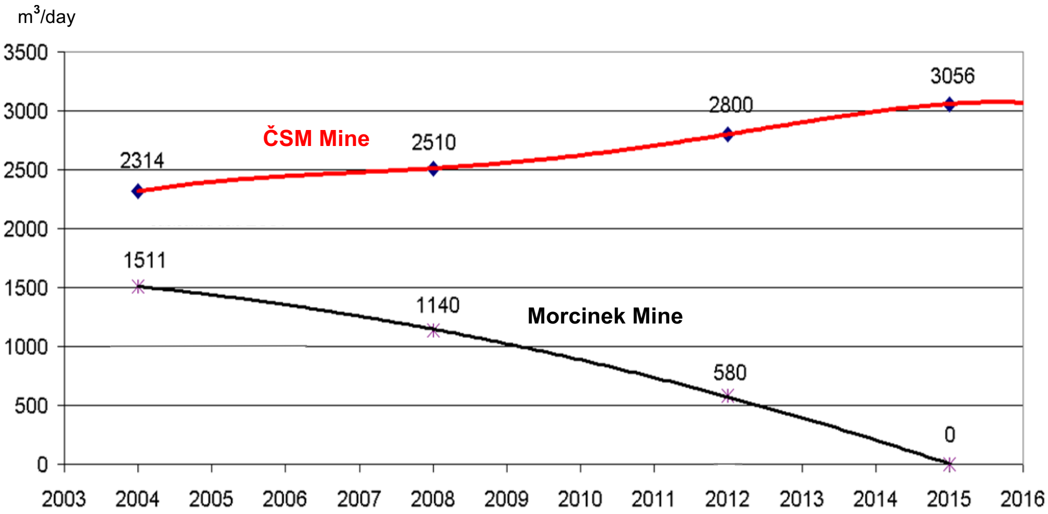

Fig. 2. Mine water drainage changes due to the Morcinek Mine closure.

2.2. Balneology

Mining drainage, caused locally partial depletion of the non-renewable groundwater resources within the aquifer and decreased the possibility of utilisation of the groundwater in balneotherapy. The most of recent studies present opinions about domination of mining activity and drainage as the factors of forming the groundwater flow within the USCB. The disturbances in hydrogeological regime and freshening of waters are caused just by mining activity. According to Różkowski (1995), mining exploitation causes the stress relief, resulting in the increase of rocks permeability, leading consequently to hydraulic contacts between waters of different types. Deep exploitation and intensive drainage lead to widening and deepening (to 450 - 650m and maximum to 850m below the ground surface) of recharge zones. Also in the Czech part of the USCB, the stratification of waters has changed, and the present chemical composition of waters from Badenian is not corresponding with the analyses made 10 years before. The phenomena are explained with the impact of mining. Despite the negative changes, waters from Badenian, considered as fossil connate ones, of mineralisation ranging from 28 to 60 g/l, contain J^- and Br^- at the levels making possible their balnaeotherapeutic application in the Ostrava-Karvina Region (Grmela 1997). The conflict between preservation of groundwater resources, and industrialisation of this part of the USCB was particularly sharp in case of medicinal waters. The Spas of Kokoszyce and Jastrzębie Zdrój, existing here in the past, lost their medicinal water due to the mining drainage impact. Waters of the Goczałkowice Spa were threatened by the activity of a nearby coal mine. In consequence new exploitation wells had to be drilled there.

2.3. CO_2 geosequestration

Perspective localities for CO_2 sequestration in Poland comprise also the saline aquifers of Tertiary and of Carboniferous productive formation of the Upper Silesian Coal Basin (USCB), on the borderland of Poland and Czech Republic. Hydrochemical modeling was carried out for the purpose of the assessment of amounts of CO_2 than can be stored in the geological space of the LB aquifer. Numerous information was applied, regarding the petrophysical and mineralogical characteristics of the formation, pore water composition, pressure and temperature values, and kinetic reaction rate constants. The effective porosity of rocks representing the Dębowiec Formation ranges from 9,08 to 24,13. The trapping capacity was calculated basing on the balance of the CO_2 contained in the carbonate minerals (mainly dawsonite) precipitating and dissoluting in the modeling period of 20 000 years. For the aquifer rocks it reaches nearly 1,9 $kgCO_2/m^3$, and for cap rocks - 1,42 $kgCO_2/m^3$. The quantity of gas trapped in the form of solution, assessed basing on modeled chemical constitution of pore water, equals for the aquifer to 1,0 $kgCO_2/m^3$, and for the cap rocks - 1,42 $kgCO_2/m^3$. Western part of the LB aquifer is suitable to play a role of specific natural analogue for the case of the USCB, helping to understand the impact of slow flux of CO_2 on such a hydrogeological environment. One-dimensional advective-dispersive-reactive transport model was applied to reconstruct the processes of forming groundwater chemistry in effect of primary pore fluid dilution by infiltrating precipitation waters, accompanied by: geogenic CO_2 inflow, ion exchange and dissolution of carbonates and/or aluminosilicates. It was found that the transformations of primary groundwater chemistry could be presented in stages according to the water type changes: Cl-Na - HCO_3-Na-Mg, connected with the flow of water through the pore space (Labus, 2009).

3. SUMMARY AND CONCLUSIONS

Set of the issues listed above, requires comprehensive solutions in the spheres of mine safety legislation, preservation of valuable groundwater resources, hydrogeological modelling of mine flooding effects and forecasting the risk assessment of CO_2 storage. The first steps, taken by the research groups from the Silesian University of Technology in Gliwice (Poland) and Technical University of Ostrava (Czech Republic) in cooperation with mining companies included:
- Database building – to gather the information on hydrogeological environment of mining areas,
- Identification of hydrogeochemical phenomena in the mining environment
- Mathematical modelling of groundwater dynamics changes due to mining drainage and flooding
- CO_2 squestration impact modelling and experimental testing.

The effects obtained so far, and the atmosphere of transboundary collaboration give an encouraging outlook for the next activities.

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ISARM and the Role of UNESCO-IUGS-IGCP Project 523 – GROWNET
(Ground Water Network for Best Practices in Ground Water Management in Low- Income Countries)

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ABSTRACT

Key words: IGCP Project GROWNET, Aquifer Management on Both Sides of Boundary

1. BOTTOM LINE FOR ISARM

Internationally Shared Aquifer Resource Management or ISARM deals with equitable management of a trans-boundary aquifer. The bottom line in ISARM is that *"ISARM is easier for an aquifer which is well-managed on either sides of the international boundary."* In other words, when an aquifer is mis-managed on either side or both sides of an international boundary, its equitable, trans-boundary, joint management becomes more difficult.

The management of Trans-Boundary (T-B) aquifers is important because, while the trans-boundary flows of surface water in international rivers are estimated at 42,800 Cubic Kilometres per year, the storage in trans-boundary aquifers is estimated at 234,000,000 Cubic Kilometres. However, it should be remembered that the actual volume of T-B flow could be much smaller depending upon hydraulic conductivity (K), cross-sectional areas of flow (A) and the Hydraulic Gradient. But even a small quantity of polluted ground water flowing from one side to the other is capable of spoiling a good aquifer on the other side. Luckily, in some cases the boundary follows a mountain ridge forming a ground water divide (Limaye S.D. 2010) or runs along a river representing a ground water trough or ridge, depending upon the effluent or influent nature of the river, so that the cross-boundary flow is not significant.

The main objective of ISARM is to promote a joint, multidisciplinary management for sustainable use of ground water in a shared aquifer and to find amicable solutions to problems resulting from "Actions" taken by Stakeholders on one side of the boundary, which have an impact on the interests of Stakeholders on the other side of the boundary. Typically, such actions are Over-exploitation and / or Pollution of the shared aquifer. Negotiations under ISARM have to be conducted in the spirit of PCCP (moving from Potential Conflict towards Co-operation Potential) exploring the opportunities for Synergies.

2. UNESCO-IUGS-IGCP PROJECT No. 523 - GROWNET

UNESCO-IUGS-IGCP PROJECT GROWNET (Ground Water Network for Best Practices in Ground Water Management in Low-Income Countries) aims at global dissemination of 'best practices' in ground water management so that the negotiators / planners of ISARM know how to promote synergy and rectify the impact of over-exploitation or pollution in a shared aquifer. (Limaye, S.D. & Reedman, A.J. 2005)

In "GROWNET" project, the Scale of trans-boundary management of an aquifer includes an aquifer shared by two nations, two states, two villages or even by two adjoining farmers. GROWNET recognizes that aquifer management through 'best practices' is more difficult at international level because at the international level, a few additional factors or aspects given below have to be considered:

1) Technical Aspects.
These include aquifer characteristics, its recharge & discharge zones; effects of over-exploitation on one side of the boundary, sea-water intrusion, land subsidence, pollution and the possibility of recharge augmentation in the intake area.
2) Benefit: Cost Ratio.
B: C ratio of ground water use for Agriculture is important because irrigational use is mostly a consumptive use. Cost of pumping from a deep aquifer could often affect the ratio. Other stakeholders may claim to put ground water to a more productive use. One country may have cheaper tariffs for electrical energy than the other.
3) Political Factors: Inter-Governmental relations and mechanism of implementation of ground water legislations, if any, in both countries affects the negotiations. The type of government such as democratically elected or military dictatorship also decides the speed of implementation of mutually agreed norms.
4) Degree of Economic Freedom: This is necessary for movement of funds, agricultural produce, industrial products, labour force, and other resources across the boundary, which is related to ground water usage for irrigation or industries.
5) Water Governance: Governance is related to rules in both the countries for allocation of pumping quota to farmers and industry; Control of industrial pollution; and Policies for Re-use, Recycling and Wastewater treatment by Industries.
6) Social Factors: Social factors include the percentage of population depending upon the aquifer resource and hence the importance attached by the Governments to the sustainability; possibility of equitable distribution of benefits arising out of ISARM in the society; creation of Trans-boundary Job Opportunities; flexibility of farmers towards changes in cropping patterns; and social acceptance for movement of trans-boundary labour in industrial or in farming sector.

The goal of GROWNET is to achieve a healthy state of aquifer management on either side or preferably both sides of the boundary and to empower the ISARM negotiators with good quality field-data so as to obtain more crop yields, more profit for farmers, more Jobs and higher Value addition to Industrial Products, **per cubic meter** of ground water pumped from the Shared Aquifer.

3. HYDROGEOLOGICAL FACTORS.

If the two countries are in good terms, politically & socially and also have (a) Technical capabilities, (b) Governance mechanism for monitoring pumping and (c) Development policies conducive for IWRM, then the negotiations regarding recharge augmentation, control on pumping of ground water, demand management, allocations for priority uses of ground water and related trade-offs, pollution control etc. could take place, in consultation with civil society organizations & professional associations, between multidisciplinary teams at various levels, such as between:

1. National Governments
2. State or Provincial Governments
3. Industrial Stakeholders / Federation of Industries and
4. Farmers' co-operatives.

Governments are responsible for developing tools and mechanisms for monitoring ground water quality and yields, and for anticipation, prevention and resolution of water conflicts.
The first step could be setting up of ISARM Commissions, with stakeholders' representation. It should be remembered that the negotiations could be quite complicated even in simple hydro-geological situations like:

1) Aquifer has recharge area in one country and discharge area in the other.
2) Phreatic or Shallow Confined aquifer in one country becomes deep confined aquifer in other.

3) Ground water with industrial, dairy or agricultural pollution from one country crossing the boundary into the other. And
4) Heavy pumping in one country causing seawater intrusion into the coastal region of the same aquifer in another country or is causing land subsidence.

GROWNET therefore advocates collection of baseline data as the starting point.

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The Features of Formation of Araks Basins Rivers Runoff (in Armenia) and Regularities of Spatial-Temporal Distribution

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ABSTRACT

The purpose of work is study, analyse and appreciate regularities of spatial and temporal distribution of Araks basin river runoff, with that end in view had collected and worked out the results of water measuring observations of points in 1926-2008.

In basin runoff distributed irregularly both temporal and spatial. In spring flood period by rivers passes 30-80% of annual runoff. Mainly in this period passes maximum outlet of water. Minimum outlet of water is being formed in summer and winter period.

As a rule, moisture increases by height because of precipitation increasing and evaporation decreasing, therefore increases runoffs height layer and river link between average balanced height of basin and runoffs layer height.

By the height are increase both annual value of runoff and height of runoff layer, runoff module. It has got close link between annual values of average balanced height of basin and height of runoff layer: vertical gradient is 86 mm.

Key words: Araks River Basin, regularities of spatial-temporal distribution, aaverage height of drainage basin, height of runoff layer

The rivers of Republic are tributaries of the big rivers of Southern Caucasia, Araks and Kura rivers. 76 % territory of Republic (22 556 km^2) belongs to Araks river basin. Araks blowing to east in his middle part twice comes in the boards of Armenia on 364th and 746t^{h} km distances, becomes near-boundary river between Armenia and Turkey (about 150 km) and between Armenia and Iran (42 km). In inside parts passes by Azerbaijan-Iran board, then in Azerbaijan territory on 1072 km joins with Kura, and after 241 km falls into the Caspian Sea.

In the most part of Araks basin speaded perforated and splintered newest volcanic rocks, which promote to atmospheric precipitation seepage and accumulation in the form of, underground waters. In the result of it increases underground nutrition of rivers and sometime even underground waters have prevailing significance. To rivers of basin is characterized melting snow, rainy and underground nutrition and that is why rivers have unstable regime (characterized big fluctuations of levels) and inside annual distributions features of runoff. In some places (Aragats, Geghama mountains, Zangezur) rivers feed on with snow also. The floods observe in spring (IV-VI) mainly, and the second comparly light flood in September-October. Minimum levels of rivers observe in summer and winter, when rivers have underground nutrition.

Araks river basin in the territory of Republic mainly covered with volcanic rocks, which promote to atmospheric precipitation resorption. It is result in underground nutrition increasing of basin as a rule have comparatively a large nature regulation.

In the Republic 20 % of surface-water flow is near-boundary rivers, Araks and Akhuryan, intermediate runoff.

Drainage basin square of Arks is 102 thousand km^2 (22,6 thousand km^2 is in Armenia). Before the approaching to the broad of Republic Araks, having 11 630 Araks km^2 catchments basin, already is full-flowing river and has original hydrological characteristic. The Araks is characterize with spring violent flood regime, which is peculiar to mountainous rivers. The Araks is an fuliginous river. It is being used for irrigation. Study of regularities Araks basin river runoffs spatiotemporal distribution has an important significance.

The purpose of work is study, analyse and appreciate regularities of spatial and temporal distribution of Araks basin river runoff, with that end in view had collected and worked out the results of water measuring observations of points in 1926-2008 (table 1).

Table 1

Araks basin rivers form measuring characteristics (Surface water resources of USSR, 1967, 195, 1979; Long-term data about regime and resources of surface water of Land, 1987)

River - point	Distance from, km		River slope, ‰		Period of expense observation	Main characteristics of catchments' basin			
	mouth	source	average from forest point /source	average balanced from forest point /source		square, km^2	average height, m	average slope, ‰	afforestation %
Akhuryan - Paghakn	186	0.04	5.0	5.0	1953 - 2008	220	2350	129	0
Akhuryan - Akhurik	117	69	18/8.1	15/7.7	1953 - 2008	1060	2100	-	0
Akhuryan - Haikadzor	84	102	5.6/6.0	3.1/5.9	1953 - 2008	8140	2010	-	2
Ashotsk - krasar	0.1	26	30	14	1959 - 99; 2004 - 09	197	2250	135	0
Karkachun – Gharibjanjan	2.5	53	38	31	1942 - 48;1950 - 2008	1020	2020	-	0
Sevjur – Taronik	31	7.0	22/0.9	14/0.9	1959 – 94; 2001 - 08	1560	1410	-	1
Sevjur – Ranchpar	4.9	33	19/0.7	12/0.7	1931 - 35, 45 - 47; 49 - 89; 1993 - 96; 2000 - 08	3540	1610	-	3
Qasakh - Vardenis	68	23	32/9.0	22/8.9	1965 - 2008	441	2300	157	3
Qasakh – Ashtarak	29	60	27/16	16/14	1966 - 2008	1020	2150	-	2
Hrazdan – Hrazdan	113	28	29/7.4	21/6.3	1965 - 97; 99 - 2008	697	2200	234	11
Marmarik - Aghavnadzor	8.0	29	37/27	22/16	1936- 40; 42 - 91; 2000 - 08	375	2350	338	13
Dzknaget – Tsovagyugh	1.0	21	34	30	1926 - 34; 1936 - 2008	85.0	2220	211	0
Masrik – Tsovak	4.4	44	27	16	1967 - 2008	673	2310	158	1
Argichi – V. Getashen	6.4	46	14	8.0	1926 - 2008	366	2470	144	0
Gavaraget – Noratus	7.5	18	29/3.8	24/3.7	1926 - 44; 46; 48 - 50; 52 - 92; 97 - 2008	467	2430	133	<1
Azat - Garni	31	9.0	61/69	55/55	1936 - 44; 45 - 94; 99 - 2008	326	2420	304	<1
Vedi – Urtsadzor	25	33	51	45	1969 - 94; 2001 - 2008	348	2060	366	30
Arpa - Jermuk	105	23	52	48	1957 - 2008	180	2790	188	6
Arpa - Areni	40	88	26	20	1981 - 2008	2040	2110	-	3
Meghriget – Meghri	6.0	30	89	77	1945 - 47; 49 - 2008	274	2200	464	25
Voghji – Kapan	44	39	55/74	45/59	1965 - 90; 1999 - 2008	643	2380	476	18
Vorotan – Gorhaik	142	36	31/31	27/27	1988 - 93; 2000 - 2008	268	2630	197	0
Gorisget - Goris	12	17	115	94	1967 - 91; 99 - 2008	84.5	2180	324	5

The river runoff forms mainly in mountainous regions, where atmosphere precipitation considerably is a lot that evapotranspiration. In low plan places rivers us a rule have not runoff augmentation: in some cases runoff is decreases even. The river runoff in go up zoning conditions depend on average height of basin mainly and submits to go up zoning influence (table 2).

As a rule, moisture increases by height because of precipitation increasing and evaporation decreasing, therefore increases runoffs height layer and river link between average balanced height of basin and runoffs layer height (figure 1).

Table 2

Main hydrological characteristics of average annual runoff of rivers, maximum runoff value and passing periods

River - point	Modul, l/sek. kM^2	Average height of runoff layer, mm	Annual runoff, m^3/sek	Maximum runoff		
				average value, m^3/sek	absolute value, m^3/sek	passing period day, month, year
Araks - Surmalu	3,68	116,2	81,1	561,4	1690	01.05.1969
Akhuryan - Paghakn	10,4	329,2	2,30	11,9	23,0	20.07.1978
Akhuryan - Akhurik	6,92	218,9	7,33	59,2	182	18.04.1968
Akhuryan - Haikadzor	3,63	114,6	29,3	162	529	28.04.1969
Ashotsk - krasar	17,7	564,8	3,53	18,7	118,0	31.05.1975
Karkachun – Gharibjanjan	1,02	32,1	1,04	9,48	79,4	27.03.1964
Sevjur – Taronik	9,40	296,3	14,6	30,0	74,5	02.04.1960
Sevjur – Ranchpar	6,93	218,5	24,5	71,6	152,0	07.03.2004
Qasakh - Vardenis	3,19	108,5	1,28	23,5	151,0	12.04.1972
Qasakh – Ashtarak	3,29	103,5	3,34	52,4	130,0	06.03.2004
Hrazdan – Hrazdan	11,0	347,2	7,83	66,3	144,0	29.04.1990
Marmarik - Aghavnadzor	12,4	390,9	4,77	40,4	86,7	03.05.1987
Dzknaget – Tsovagyugh	12,7	400,3	1,10	14,0	46,4	14.04.1948
Masrik – Tsovak	4,81	151,8	3,24	9,60	20,3	30.04.1969
Argichi – V. Getashen	15,1	475,2	5,53	59,5	244,0	07.05.1942
Gavaraget – Noratus	7,46	235,0	3,48	16,5	72,5	07.04.1928
Azat - Garni	14,6	460,6	4,78	32,9	83,9	09.05.1963
Vedi – Urtsadzor	4,53	143,2	1,56	15,2	53,8	11.09.1974
Arpa - Jermuk	29,4	924,8	5,29	49,3	91,0	17.05.1983
Arpa - Areni	6,60	209,0	12,3	108,9	199,0	18.04.1988
Meghriget – Meghri	10,3	331,0	2,85	17,9	87,5	12.04.1956
Voghji – Kapan	16,8	530,5	11,0	59,6	118,0	20.05.1976
Vorotan – Gorhaik	16,7	527,2	3,89	17,4	27,6	26.05.2007
Gorisget - Goris	6,66	207,8	0,45	5,64	46,4	18.06.1967

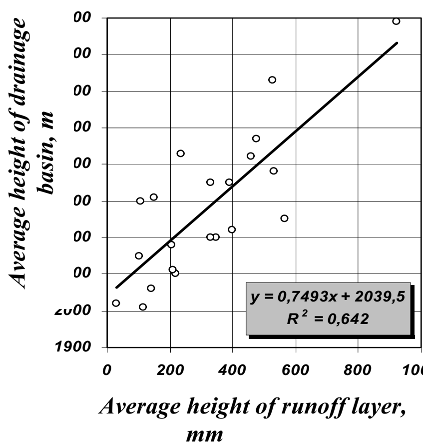

Fig. 1 Correlation link between height of runoff layer and average height of cat

The using of rivers waters with boundary countries takes place by principle of equality. The runoff of rivers basin distinguished by spatial maldistribution. It is clear, that runoff is changes from o (Ararat valley) to 900 mm (Geghama and Vardenis mountains zones).

For rivers stimulation as irrigation source is important within-year distribution by monhts and seasons. The rivers of basin are distinguished with spring flood, summer-autumn and winter low water-level phases. Spring floods are main phase of runoff in the Republic, in this period by rivers flows 30-80% of annual runoff (table 3). The rivers, which have undergraund nutrition, the runoff is 30-40% an average (for Gavarget – 32% of annual) (Hydrography of Armenian SSR. Academy of Sciences press of ASSR, 1981). Mainly surface nutrition having Dzknaget, Voghdji, Argichi rivers and from high mountains starting Mantash, Gegharot rivers and in other small rivers the runoff of spring flood is 70-80 % of annual runoff.

The majority of Republics rivers maximum outlet observes drawing the spring floods usually. Maximum water consumption observes usually in May, especially in the first part. The volume of maximum outlet is bigger per 2-4 than average volume of annual runoff, but for small rivers it is per 10-12.

The majority rivers of Araks basin have well-marked low water-level phase with summer-autumn and winter periods. During this phase rivers feed mainly with underground waters (in winter completely). In winter rivers have absolute underground nutrition. Minimum water expenses (0,51-1,26 m^3/sec) observes in winter mainly. For regularization a spring runoff are being constructed reservoir, its waters are being used for irrigation. The users of river basin water are agriculture, industry, city water-supply hydro-electric engineering. The Armenia has universal river basin management principle for water resources.

Table 3

Long-term monthly and season values of Araks rivers basin water measuring points runoff (m^3/sek)

River - point	*months*												*Part of season runoff in annual runoff, %*			
	I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*I-III*	*IV- VI*	*VII- IX*	*X -XII*
Araks - Surmalu	36,7	39,8	66,6	213,3	255,5	109,0	55,7	46,0	38,3	37,5	37,9	36,9	15	59	14	12
Akhuryan - Akhurik	5,85	5,89	7,32	16,2	11,6	6,30	5,63	6,87	5,57	5,48	5,60	5,66	22	39	21	19
Akhuryan - Haikadzor	11,5	12,5	17,5	51,4	59,6	43,8	38,6	38,8	28,3	20,5	16,7	11,9	12	44	30	14
Ashotsk - krasar	2,81	2,86	3,30	6,01	5,90	4,15	3,33	2,88	2,77	2,84	2,80	2,67	21	38	21	20
Karkachun – Gharibjanjan	0,76	0,82	1,20	1,78	2,00	1,32	0,66	0,61	0,71	0,94	0,89	0,79	22	41	16	21
Sevjur – Taronik	21,5	21,3	21,4	16,5	10,1	8,84	6,70	6,49	9,80	13,5	16,8	21,8	37	20	13	30
Sevjur – Ranchpar	28,3	27,7	28,4	32,3	26,8	21,2	16,4	15,1	19,1	22,9	26,0	29,4	29	27	17	27
Qasakh - Vardenis	0,47	0,50	1,17	4,26	3,66	1,89	0,74	0,49	0,56	0,55	0,56	0,51	14	64	12	11
Qasakh – Ashtarak	2,50	2,50	3,70	7,36	3,60	3,29	3,41	3,43	2,49	2,50	2,73	2,61	22	36	23	20
Hrazdan – Hrazdan	2,78	2,80	5,15	21,0	28,5	12,5	5,01	3,30	3,17	3,26	3,40	3,09	11	66	12	10
Marmarik - Aghavnadzor	1,17	1,18	2,26	12,0	20,2	9,81	3,44	1,64	1,30	1,42	1,47	1,30	8	73	11	7
Dzknaget – Tsovagyugh	0,19	0,23	0,68	4,24	4,29	1,57	0,50	0,28	0,26	0,32	0,37	0,23	8	77	8	7
Masrik – Tsovak	2,57	2,63	2,90	4,95	5,56	3,50	2,66	2,47	2,83	3,06	2,98	2,75	21	36	20	23
Argichi – V. Getashen	2,26	2,25	2,71	15,1	21,3	9,55	2,82	1,45	1,67	2,34	2,45	2,36	11	69	9	11
Gavaraget – Noratus	2,99	2,96	3,28	4,95	6,50	4,36	2,82	2,36	2,70	2,90	2,98	2,98	22	38	19	21
Azat - Garni	3,09	3,14	3,50	7,68	12,4	9,49	3,41	2,71	2,76	2,97	3,09	3,08	17	52	15	16
Vedi – Urtsadzor	0,66	0,75	1,22	4,24	6,77	2,30	0,56	0,30	0,28	0,43	0,61	0,61	14	71	6	9
Arpa - Areni	5,90	6,08	9,01	26,9	42,9	23,0	6,25	3,71	4,48	6,17	6,86	6,56	14	63	10	13
Meghriget – Meghri	0,90	0,95	1,87	5,42	7,30	7,96	4,32	1,50	0,87	0,99	1,11	0,99	11	61	20	9
Voghji – Kapan	2,62	2,88	5,08	16,6	33,1	32,9	17,6	7,01	4,16	4,02	3,54	2,93	8	62	22	8
Vorotan – Gorhaik	2,17	2,18	2,38	5,27	10,0	8,59	4,13	2,78	2,51	2,27	2,18	2,17	14	51	20	14
Gorisget - Goris	0,42	0,44	0,49	0,64	0,73	0,51	0,27	0,28	0,39	0,42	0,42	0,40	25	35	17	23

The universal management plan of water resources is organize water relation and suppose cooperation supplying in the country and between neighbour countries on intergovernmental level.

Thus, in basin runoff distributed irregularly both temporal and spatial.

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International research collaboration as a tool for water resource management in the Lake Chad Basin

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ABSTRACT

There is a large community of researchers in resource management in Africa, but they are currently partly disconnected, even in a single country. Most researchers engaged in the Lake Chad Basin are involved in studies motivated nationally or in their own institutions. Groundwater or streams do not stop at political borders. This means that investigation must also cross national borders. As a consequence and considering that no country or region is independent of the rest of the word, international research collaboration stands out as the major challenge in addressing excellence and sustainability of scientific activities in the future? A multi and interdisciplinary approach and international cooperation are absolutely essential for positive realization of the objectives of water resource management in the Lake Chad basin.
In 2002 the UNESCO project "Virtual laboratories for drying lakes in Africa, Middle East and Central Asia" was a joint effort to mobilizing researchers of the sub region promoting sustainable development of the Lake Chad basin.
CORUS and FSP-RIPIECSA have successfully supported joint research in the Lake Chad basin on climate and water resource.
IRD has initiated major's programmes as LMI (Laboratoire Mixte International) that offer opportunities to examine interactions between science, environment and society.
Despite the substantial body of research that exists on the Lake Chad basin, it remains inadequate to address the serious challenges facing the sub region. The sharing of experience and knowledge among researchers from South to South and from South to North can better be viewed to ensure knowledge transfer to where it is needed, and in the form in which it can be used.

Keywords: Lake Chad basin, International research collaboration, LMI (Laboratoire Mixte International), water resource management, transboundary aquifer

1. INTRODUCTION AND MOTIVATION

The Lake Chad Basin (Fig. 1), with ~2.5 M km^2, is the largest transboundary endoreic basin at a global scale (Burke, 1976). Whenever talking of the Lake Chad Basin, people generally refer to surface water; the Lake Chad itself. The Lake Chad is unique as its water remains fresh while being submitted to intense evaporation in the semiarid Sahel (E ~2000 mm/yr, rainfall of ~200 – 600 mm/yr). Between 1963 and 1976, Lake Chad had lost nearly 90% of its water volume. Its surface area had shrunk from 25,000 km² to less than 3000 km², and its water level had fallen by ~4 m. The Lake Chad Basin is also characterized by rainfall deficits, southwards shift of the isohyets (Ngounou Ngatcha *et al.*, 2005; Niel *et al.*, 2005), reduced runoff of the (Komadougou and Chari) rivers discharge into the Lake Chad (Olivry *et al.*, 1996).

Figure 1 The Lake Chad watershed

Population in the Lake Chad basin has grown rapidly for the last decades, at a rate of about +2.5% $year^{-1}$ and was estimated of ~35 M inhabitants in 2007 (World Bank, 2010). Regarding water uses (water supplies for drinking, industry and agriculture), demand in the Lake Chad Basin is satisfied mainly with groundwater. However, extraction rates are rarely measured and, therefore, it is impossible to estimate the level of use of the aquifers. The need to improve social conditions and reduce poverty for the inhabitants will lead to an increase in water supply and sanitation services. In addition, higher water demands are expected in the basin for economic activities such as tourism, intense cultivation within the lake (polders), fishing and herding. Questions remains on how pumping would affect groundwater reserves at the whole aquifer scale (500,000 km^2). As a consequence of the diverse and competing uses for water, the Chad basin faces a challenge for integrated water resources management.

Collaboration between scientists is a strong recommendation for improving research programs outcomes and formation. The LMI project is bound by strong links between researchers from different universities in Africa (Cameroon, Chad, Niger, Nigeria), Europe (Montpellier, Rouen and Aix-Marseille in France), Australia (University of « James Cook », Cairns), America (University of Texas, Jackson School of Geosciences, Austin), and other institutions of higher learning or research (IRD). The aim of this LMI is to bring together the global experience in an accessible and helpful compendium of optimal approaches, to support the practical and effective development of IWRM in the Lake Chad basin, to provide adequate formation to students and updated key information to stakeholders.

2. MAIN SCIENTIFIC ISSUES AND OUTCOMES

Most of the field-based scientific knowledge was gathered during the 1960-70s (Barber, 1965; PNUD/FAO, 1973). These results, conducted mainly using hydrological, geological and geochemical methods, helped to understand the basic functioning of the Lake Chad Basin. During the 1990s and 2000s, several PhD thesis of high quality were defended with various methods and approached developed, using complementary methods: unsaturated zone survey, surface water-groundwater modeling and remote sensing. Meanwhile, several key-questions remain fundamental for better predicting and managing surface water and groundwater resources.

- Understanding the role of climate (rainfall) variability and increasing water use on observed changes in water resources in the Lake Chad basin is the main goal of then LMI project. This question remains central for predicting changes in the Lake Chad Basin and managing water resources.

- Improving understanding and modelling of surface water – groundwater transfers. This question is central in every studies of large water bodies under tropical climates (eg., Okavongo basin, Inner Niger delta). Increase in knowledge in this domain requires improving lake level chronicles (using both on-ground and satellite surveys), long-term groundwater chronicles, better knowledge of groundwater use (pumping) and surface water use and management (dams).

- Understanding (eco-)hydrological functioning of large piezometric depressions. Natural piezometric depressions in the unconfined aquifer do exist all around the lake and their functioning remains challenging (eg., Dieng et al., 1990). Possible explanation includes role of deep rooting vegetation and low permeability of the aquifer. Understanding Piezometry of aquifers will help to quantify sustainable pumping in the unconfined aquifer.

- Understanding salt transfer from the lake to the aquifer. Groundwater below Lake Chad is salty and villages do struggle to find fresh lenses within the aquifer. Understanding variability in time and space of groundwater nearby Lake Chad will avoid villagers to use lake water, often non-drinkable due to Cholera and other bacteria. Understanding salt transfer will also help to better quantify infiltration of water from the Lake to the aquifer.

- Understanding impact of climate and land use/land cover change (LUCC) on sediment, solute, and water transfer to rivers and/or aquifers. Past and present records of sediments and fluxes will help to estimate sustainability of water resources and rural development at a regional scale (damming, pollution from irrigation to the aquifer used for drinking water). These records will also help in constraining the sensitive response of the LCB system to environmental changes.

3. STRATEGY ON TECHNICAL CAPACITY BUILDING AND POST-GRADUADE EDUCATION

Following the worldwide recognition of the paramount importance of the human resources capital for sustainable and long term development, the LMI will help in:

- increased capacities in analytical capacities, modelling, access to a tool to deal with spatial processes (GIS) and application of data. Capacities will be expanded using commercial educational licenses in groundwater modeling and SIG;

- hydrogeological and hydrogeophysical tools will be acquired for both educational and research purposes; this will include the recent technique of MRS that has proved to be efficient in the LCB.

Researchers involved in the LMI have various background and capacities in different research specialities (geochemistry, sedimentology, geophysics, hydrodynamics, remote sensing). Cross-participation in Master's courses will strengthen each of these formations, enrich examples from neighbor countries sharing common issues and help to foster co-operation among nations and regional or international programmes for education and training facilities, for appropriate learning technologies, for the exchange of information and experts in the field of hydrology and water resources. In addition, the LMI project will:

- increase the multidisciplinary aspects of the contents of the courses, introduce the teaching of hydrology into regular school curricula or reinforce the teaching of the basic hydrological sciences at university level;
- promote a series of advanced study seminars, short courses, workshops or tutorials on national, regional or international scale for specific themes involving users, planners, policy-makers, women, postdoctoral researchers, hydrology teachers… at all levels;

- gain experience with distance learning techniques and encourage their use for greater efficiency.

4. PERFORMANCE INDICATORS

There is an ongoing project to restore lake Chad to its maximum 25,000 km² surface are of the 1950s by transfer of water from the Oubangui river (Congo basin) to the Chari river (World Bank, 2010). The feasibility of this project is under study and would involve huge socio-economic changes at a regional scale. The LMI team, by collecting data and building trans-national expertise, will help decision makers to obtain full benefit from significant and relevant investment.

The LMI will also help to: 1) product datasets and strengthen database for regional scale hydrological studies, 2) improve South/South co-operation, co-operation with NGO's and co-operation between researchers and LCBC, 3) improve the quality of life of women by facilitating their access to water resources and their participation in training programmes, 4) improve community responses to climate change and land uses, 5) implement a regional working groups on water resources and environment, 6) reinforce teaching material on the specific hydrological problems on arid and semi-arid zones.

Water resource is a key component of development and there is an urgent and steady need in scientific expertise (Bassett, 2010). The execution of this ambitious project requires strong co-operation both intellectually and financially. The international component of the LMI project (9 Universities and Research Institute, 4 continents) will represent a proposition force that will help in developing high quality research, that aims to provide key quantitative analysis and perspective on the status of the water resources system and raising additional funds. The LMI team will work in close collaboration and cooperation with UN agencies, non-governmental organizations (NGOs), donor agencies, International networks of experts and co-operating intitutions (FRIEND, AMMA, IAH, IAHS, UNESCO, WMO, IGRAC, IAEA, ICSU,BAD, World Bank,).

The LMI Lake Chad is a major opportunity to develop joint studies and research programmes in order to strengthen the capacity for strategic and integrated water resources management in the Lake Chad basin and contibution to assist countries and LCBC in meeting the Millenium Development Goals (MDGs), and contributing to the UN International Decade for Action "Water for Life" (2005-15) and the UN Decade on Education for Sustainable Development (2005-15).

Acknowledgements

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Development of a hydrological trans-boundary model for the Lower Jordan Valley, Israel, Palestine, Jordan

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Keywords: hydrological model, groundwater recharge, JAMS, IWRM, SMART, linkage of model

1. INTRODUCTION

The groundwater resources of the Lower Jordan Valley and its tributaries in Israel, Palestine and Jordan are strongly limited by the semi-arid conditions. In addition, the extreme population growth intensifies the lack of available and high quality water resources in the region, where overexploitation of surface- and groundwater is usual. References are the intense drawdown of groundwater levels, the disappearance of springs and saltwater intrusions. To solve that complex issue a smart and integrated strategy to manage all available water resources (IWRM) will be developed. Such an IWRM is the aim of the multilateral SMART-project in the Lower Jordan Valley (www.iwrm-smart.org), where all water resources (groundwater, surface runoff, waste water) will be quanti- and qualitatively evaluated. One major topic of SMART is the generation of a trans-boundary numerical flow model in the scale of the Lower Jordan Valley. Different sub-projects on the local scale were necessary for the achievement of this goal. The study area of the here presented sub-project is one of the northernmost tributaries of the Lower Jordan Valley, the Wadi Al Arab (Jordan). The aim of the sub-project is to evaluate natural resources on catchment scale by combining hydrochemical and hydraulical methods to develop a high precision model. Concerning the quantification of the system, two separated models will be linked: a numerical finite element flow-model for the groundwater passage and a new developed hydrological model JAMS. The challenge of the investigation were the deployment of a conceptional groundwater model based on scarce data and adjustment of empirical equations and input parameters of JAMS onto the semiarid conditions. The results lead to a better understanding of the processes, which are important and necessary for the implementation in the trans-boundary model.

2. HYDROLOGICAL MODEL JAMS

The goal was to develop a tool for a highly accurate assessment of soil moisture balance and consequently of surface runoff and groundwater recharge. JAMS is a simplified hydrological model to calculate temporal aggregated and spatial distributed hydrological variables. Krause (2002) developed it for a humid climate zone, the challenges in the first phase of SMART were the adaption and parameterisation of JAMS onto the semiarid and arid conditions. That means basically adaptation in soil physics and vegetation conditions.

2.1 Procedure of JAMS

In JAMS the presentation and calculation of the hydrological procedures occur one-dimensional for any amount of points in space. The mentioned input data are spatially organized in hydrological response units (HRU), which lead to a spatially discriminated output. The HRU mesh builds a raster of defined scale, and therefore information of satellite images, aerial photographs and ground truth data the land covers in the catchment area of Wadi al Arab were classified. The model bases on different input parameters slope, aspect, altitude and soil type, which are determined and prepared by remote sensing techniques. The characteristics of the relief, the specific soil and the vegetation parameters define the later differentiation of the catchment into HRUs. All input parameters have to be intersected, which lead to spatially discriminated outputs (Figure 1). The resulting HRUs are the fundamental part of linkage of the hydrological and groundwater flow model.

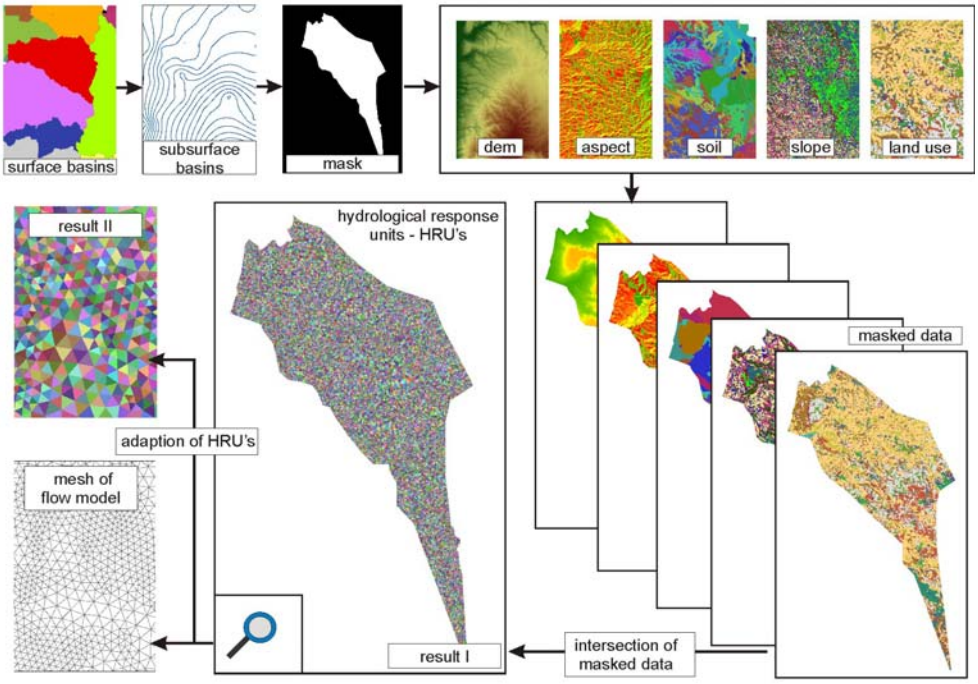

Fig.1: The intersections of the different input parameters of JAMS in combinations
with the mesh of an groundwater flow model lead to the development of the HRUs.

3. RESULTS

Using climatic background information of monthly values from January 1980 until December 2008 completed the JAMS–model of Wadi al Arab. The direct measured surface runoff (WIS, 2000-2005) in the Wadi course was used to calibrate the model (Figure 2). The figure indicates that the calculated runoff, simulated by JAMS fits well to the measured runoff.

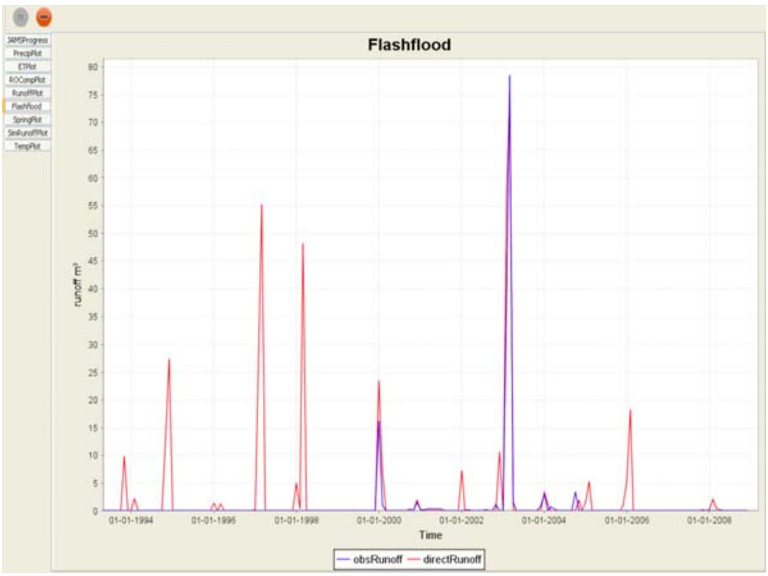

Fig.2: The result of the runoff calibration of the JAMS model of Wadi al Arab (blue observed, red simulated)

For additional validation of the model outputs, the data were compared to the groundwater (gw) recharge calculated by different methods (direct measured spring discharges, water table fluctuation and chloride mass balance methods). The simulated results of the model JAMS lead to the spatial and temporally distribution of groundwater recharge in the study area of Wadi al Arab (Figure 3).

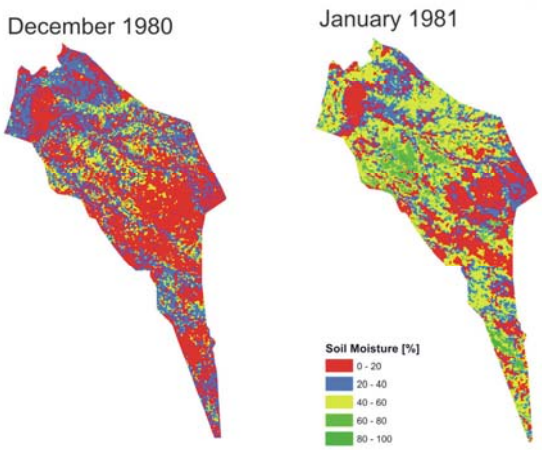

Fig.3: Spatial distribution of calculated soil moisture by JAMS in December 1980 and January 1981

Analysis of distribution of the gw recharge show, that the different input parameters of JAMS strongly control the simulated gw recharge. The Figure 4 show the minimum, maximum and mean values of gw recharge in comparison with the frequency of these parameters.

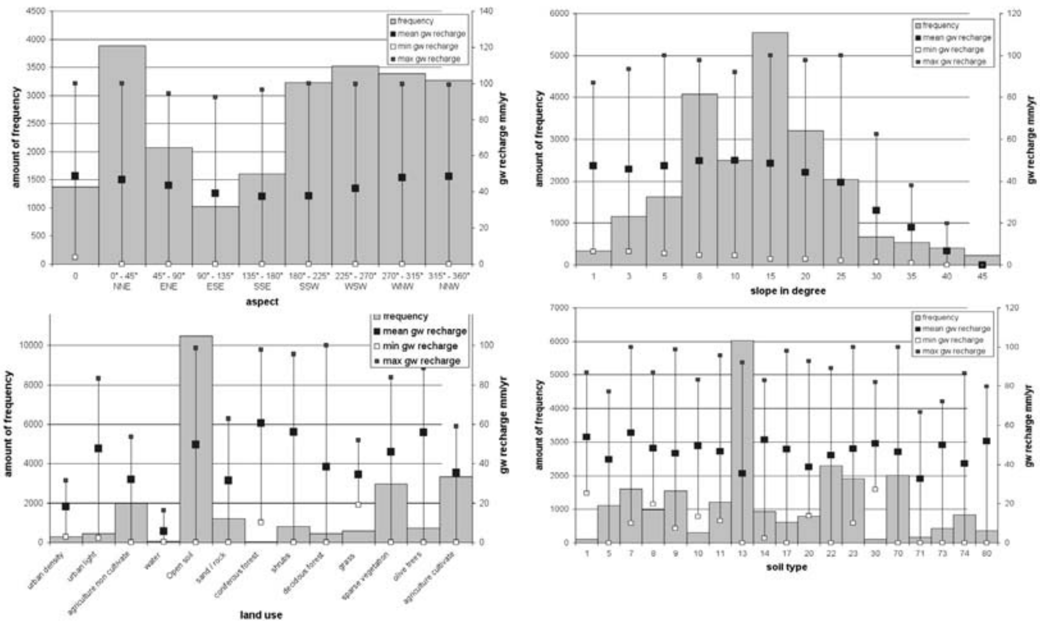

Fig.4: Analyzing of simulated gw recharge by JAMS in respect to the aspect, slope, land use and soil type

4. OUTLOOK

JAMS will linked with a groundwater flow model. The advantage is the direct comparability of the meshes of both models. The realization of linkage should be a mathematical interface between both models, which will allow a direct exchange of values.

In the second phase of SMART the hydrological model JAMS will be adapted and upscale onto the mesh of the trans-boundary model of the Lower Jordan Valley. The challenge for the development will be, that different transition zones from semiarid to arid climate conditions have to be combined in one model.

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Effect of paleo-recharge on large regional scale groundwater systems in arid and semi-arid regions

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ABSTRACT

The knowledge of the time to reach a new equilibrium after a hydraulic perturbation is crucial to model accurately the groundwater system. A hypothetical numerical model loosely based on the western margin of the Great Artesian Basin in Australia was used as a demonstration to estimate this time in large unconfined/confined aquifers. The time to reach a new steady state after a hydraulic perturbation, such as the cessation of the recharge in arid and semi-arid regions, is on the order of 50 ky. This time is longer than the present interglacial phase, i.e. 10ky since the last climate transition, and thus the hydrodynamic system is a transient one which is still responding to the paleo-perturbation due to recharge. Moreover, analytical solutions have been used to assess the time to reach a new equilibrium for several large aquifers in the world. The times obtained range between 0.4 and $5.8\text{x}10^{10}$ years. These values suggest that large regional scale aquifer systems are rarely expected to be in steady state with respect to their hydraulic behaviour.

Key words: Great Artesian Basin, Large aquifers, Time constant, Paleo-climate.

1. INTRODUCTION

To accurately model the regional groundwater systems, their current hydrodynamic state has to be determined. Changes in boundary conditions can result in transient groundwater behaviour. The time to reach a new equilibrium after a hydraulic perturbation is given by the time 3τ, where τ is the time constant and depends on the storativity, the transmissivity and the length of the aquifer. It is often assumed that prior to anthropogenic influences that the groundwater system was in steady state; i.e. it is in hydrodynamic equilibrium, because they adjust quite rapidly to any hydraulic perturbation. In this paper, we examine the time required to reach a new steady state after a hydraulic perturbation in large mixed aquifers, i.e., composed of an unconfined and a confined portion. Moreover, the time to reach a new equilibrium will be estimated for several large aquifers in the world.

2. TIME CONSTANT

The time constant is defined as the time required for a decaying exponential function to decrease by 63% of its initial value. In this study, we defined the steady state at 3τ, i.e. 5% of the initial perturbation remains. Analytical solutions exist to estimate the time constant. Domenico and Schwartz (1998) defined the time constant for a homogeneous and fully confined aquifer as:

$$\tau_c = \frac{S\,L_T^2}{T}$$ Equation 1

where τ_c is the time constant for a confined aquifer [T], S is the storativity [-], L_T is the aquifer length [L], T is the transmissivity [$L^2.T^{-1}$].

The time constant for a homogeneous and fully unconfined aquifer is (Reilly and Harbaugh, 2004):

$$\tau_u = \frac{S_y L_T^2}{T}$$ Equation 2

where in addition to Equation 1, τ_u is the time constant for a unconfined aquifer [T] and Sy is the specific yield [-].

These two relations will be used to provide a range a time constant to reach a new equilibrium for several large aquifers in the world.

3. CONCEPTUAL MODEL

To assess the effect of the modification of the recharge on the hydraulic heads in large aquifers a conceptual model loosely based on the western margin of the Great Artesian Basin (GAB) in Australia was used (Figure 1). The conceptual model is a mixed aquifer where the recharge occurs in the unconfined part and the discharge occurs at the end of the confined portion.

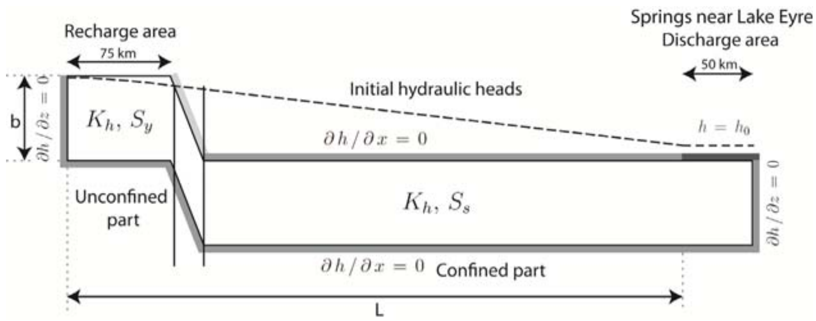

Figure 1: Two-dimensional cross section of the conceptual model, indicating the boundary conditions and the initial hydraulic heads assumed at the end of the Pleistocene.

A numerical model was used to represent the behaviour of this conceptual model to the cessation of the recharge at the transition Pleistocene-Holocene. The numerical code MODFLOW was used to model the groundwater flow. The initial conditions of the model are assumed to be those at the Pleistocene-Holocene transition. At the end of the Pleistocene, the groundwater system is assumed in steady state with a high water level in the unconfined part (Figure 1). At the beginning of the Holocene, the recharge is assumed to stop and a transient simulation was run until a new steady state was reached.

4. RESULTS AND DISCUSSION

4.1. Hydrodynamic state of the aquifer

The time to reach the new steady state for a large mixed aquifer was estimated from the evolution of the hydrodynamic state, represented by the evolution of the ratio of the discharge rate. A time of 55 ky was obtained. This result is not intended to represent the actual condition on the western part of the GAB. Nevertheless, it provides the evidence that this kind of aquifers may show a transient behaviour today, i.e. 3τ is bigger than the time since the last hydrodynamic perturbation which is the cessation of the recharge 10 ky ago. This result suggests that large mixed aquifers may not be in equilibrium with the modern climate and that a part of the modern hydraulic heads result from long-term behaviour inherited from wetter paleo-climate.

4.2. Theoretical time constants for several large aquifers in the world.

We calculated the time to reach a new equilibrium for several large aquifers in the world, which can be classified in three different groups. The confined aquifers group: the Hungarian Aquifer (HA-c), the North China Plain (NCA-c) and the Western Siberia Basin (WSB). The unconfined aquifers group: the Hungarian Aquifer (HA-u), the North China Plain (NCP-u) and the Ogallala Aquifer (OA). And the mixed aquifers group: the western and eastern part of the Great Artesian Basin (GAB-w and GAB-e, respectively), the Dogger and the Albian in the Paris Basin (PB-D and PB-A, respectively), the Nubian system Aquifer (NSA), the Guarani Aquifer (GA) and the Aquitain Basin (AB)

The time constants for the confined aquifers were calculated with Equation 1, and Equation 2 was used to assess those of the unconfined aquifers. For the mixed aquifers, the two end members (confined and unconfined behaviour) were used to assess a range of time constant, knowing that the confined equation will give an underestimation and the unconfined assumption will give an overestimation of the time constant for a mixed aquifer. The results of these calculations are presented on Figure 2. The 3τ values obtained range between 0.4 and 5.8×10^{10} y and for all the aquifers the upper limit is higher than 10 ky, i.e. time since the last climate transition. These results suggest that all these aquifers will present a long transient behaviour and thus they are probably not in equilibrium with their current boundary conditions. Thus the modern hydraulic heads in theses large aquifers are a complex mixture of both current and past conditions.

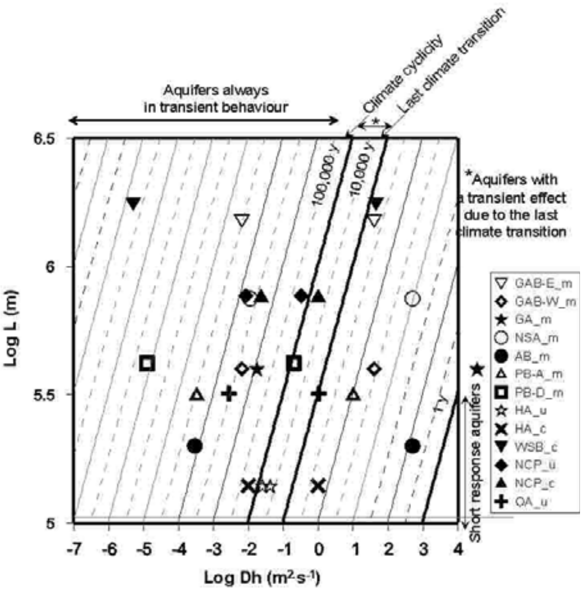

Figure 2: Time to reach a new equilibrium in year as a function of the hydraulic diffusivity ($m^2.s^{-1}$) and the aquifer length (m).

5. CONCLUSIONS

The time to reach a new steady state obtained in this study, although assessed on a theoretical conceptual model or from analytical solutions for homogeneous aquifers, are important and suggest that they are probably not in equilibrium with their present boundary conditions. The hydraulic heads observed in this kind of large aquifers are thus a complex mixture of both current and past conditions. And then, these aquifer systems may present long transient behaviour and thus the assumption of steady state prior to anthropogenic activities should not be used and transient models should be run.

Acknowledgements

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The North West Sahara Aquifer System:
the complex management of a strategic transboundary resource

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ABSTRACT

The North Western Sahara Aquifer System (NWSAS) is a very large aquifer system extending on a 1 million Km^2 surface, under the national territories of Algeria, Libya and Tunisia. Due to the lack of fresh surface water availability in these desert and semi-arid regions, its importance is today strategic for the above mentioned countries economic and social development, As a consequence of it, in the last decades, its exploitation has increased exponentially, causing serious hydrogeological problems and worries for the future. Supported by the scientific community, many national and international organizations, the Observatoire du Sahara Sud (OSS) above all, have recently raised the debate on the compatibility between the Algeria, Tunisia and Libya withdraws and the very little groundwater resource renewal rate. The apparent, but difficult, upcoming solution is a shared management of the whole aquifer system by the three involved countries. In this context, some results of a hydrogeological study carried on the tunisian NWSAS region are presented, focused on the actual exploitation state of the art definition and to estimate the different withdrawal scenarios consequences at medium-long period on the aquifer system at local and regional scale.

Key words: NWSAS, Tunisia, arid regions, artesianism, overexploitation.

1. INTRODUCTION

The most important water resource in the whole desert and semi-desert area of North Western Sahara is given by the North Western Sahara Aquifer System (NWSAS), a very large hydrogeological complex shared between three States: Algeria, Libya and Tunisia. The NWAS, from the geological point of view, is made by sedimentary formations the oldest of them date back to the Carboniferous-Permian period and it includes two main aquifers with different hydrogeological features, the Complexe Terminal (CT) and the Continental Intercalaire (CI) (Fig.1).

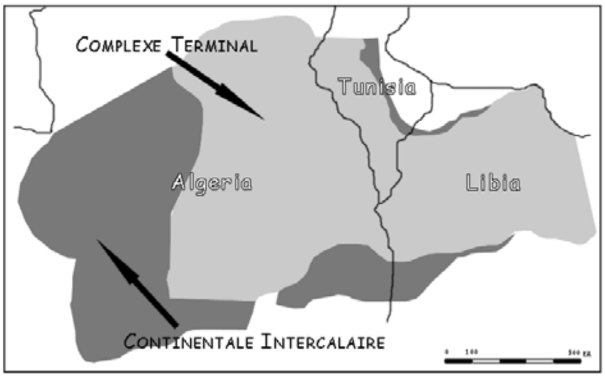

Fig.1 – NWSAS boundaries

Even though the NWSAS groundwater have been often considered as "fossil" to mean a meteoric water recharge absence, recent studies (Ould Baba, 2005) found that in some regions there is a direct alimentation by rainfall for a total recharge of about 10^9 m^3/y; nevertheless, the NWSAS hydrogeological features produce some very low filtration velocities justifying the average groundwater age of about 35.000-40.000 years. All these topics show the typically nature of a non renewable resource.

2. THE NWSAS EXPLOITATION

A recent census provided by the Observatoire du Sahara Sud (OSS) international organization in 2001 showed that about 8.800 withdrawal points affect the NWSAS with predominance in the agricultural sector: 3500 are fed by the Continental Intercalaire and 5300 by the Complexe Terminal (OSS, 2003).

From a geographical point of view, 6500 are in Algeria for about 42,1 m^3/s, 1200 in Tunisia for 17,2 m^3/s and 1100 in Libya for 10,8 m^3/s (Fig.2).

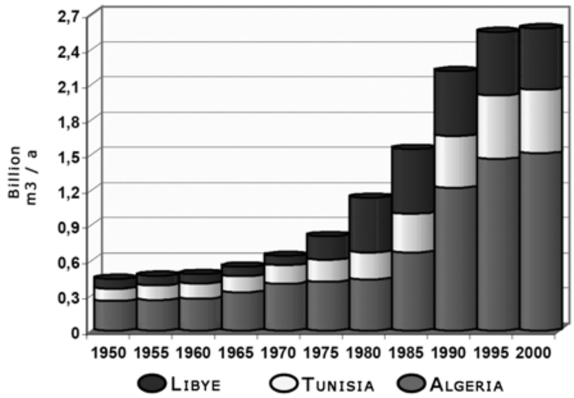

Fig.2 – NWSAS withdrawal evolution trend

The total withdraw from the NWSAS have been estimated in about 70,1 m^3/s, corresponding to 2,2 10^9 m^3/y, with a worrying increasing trend.

These values easily give a clear idea about the hydrogeological imbalance affecting the NWSAS with a consumption more than double with regard to the recharge: even if the total groundwater availability, estimated in about $30*10^{12}$ m^3 doesn't seem to be an obstacle to a massive exploitation for the human activities, many problems could raise due to the withdrawals spatial concentration in small areas and to the future planning of new and huge well fields and adduction works by Libya and Algeria. In fact, while this aquifer has remained substantially stable up to the 80's, in the last fifteen years, its strategic role has led to a very fast increase in its water consumption especially for major agricultural projects in the arid and semi arid areas in these Countries. As a consequence, some of its main hydrogeological features are quickly altering and many problems are rising, like aquifer pressure loss, water salinization, natural oases disappearance (OSS, 2003; Besbes et al., 2004; Zammouri et al., 2007; Sappa et al., 2008).

3. THE CASE STUDY

We have met this critical situation in the frame of the Hydraulic Commission works, set up by the Italian-Tunisian Cooperation in the aim of driving on the Project of rehabilitation and creation of date palms in Rjim Maatoug, in South Tunisia (Agoun et al., 2007).

The Rjim Maatoug artificial date palms oasis spread out on about 2500 ha on the arid region of the Tunisian Chotts; they are irrigated by 22 artesian wells exploiting the NWSAS, with artesian discharges changed in the years from the initial values of about 100-150 l/s in 90's to the actual 50-60 l/s. Data collected in some recent field campaign (Agoun et al., 2007; Sappa et al., 2008) show a worrying artesianism lowering trend related to the exploitation increasing in the whole Chotts region. In comparison with the initial predictions (DGRE, 1997), the drawdown is about 10 years early with an actual trend of more than 1 m/y (Fig. 3).

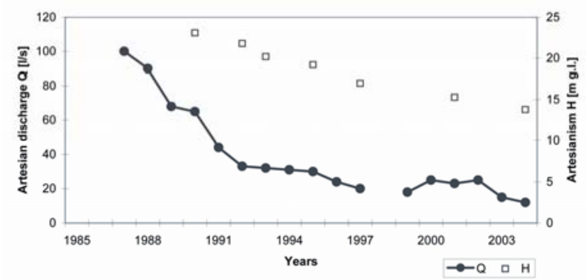

Fig.3 – NWSAS artesianism drawdown at Rjim Maatoug oasis

The numerical simulations made at regional and local scale lead to fix the definitive artesianism disappearance at 2020 horizon while at 2040 the piezometric level would reach the Chott's static level, causing a possible aquifer salinization phenomena trigger. Moreover, the actual aquifer hydrostatic pressure values are not adequate any more to grant the waterworks functioning, requiring the probable usage of electromechanical pumps, with serious consequences on the whole oasis production and the economic and social budget due to the obvious rise of the groundwater prices.

4. CONCLUSIONS

The experience made in Tunisian context allowed to define a worrying sketch about the local consequences of the lack of NWSAS exploitation shared management politics: the drawdown trend acceleration monitored at some oasis in the Tunisian Chott's region can't be only related to the local withdrawals at regional scale, but must be considered as a warning of a widespread situation about the NWSAS hydrogeological deficit. The studies results showed as the only management strategies carried out at national scale are not sufficient to grant the water resource availability for the future generations. International legislations, consumption data monitoring and cooperation among the involved countries, together with people awakening, seem to be the only effective ways to prevent some possible system collapse.

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New scientific information on the Southwest part of the Gondo plain (Burkina Faso)

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INTRODUCTION AND OBJECTIVES

The Gondo Plain lies between Mali and Burkina Faso. Its area is 36000 km², with 6000 km² in Burkina Faso and 30000 km² in Mali (figure 1). Since 2003, the Laboratory of Hydrogeology of the University of Ouagadougou has been carrying out two research projects on the Southwest Part of the Plain, where the piezometric levels are very low (50 to 60 m in Burkina Faso and more than 100 m in Mali), with two main purposes: first, to find water resources for drinking water supply of Ouahigouya town and second, to assess the exploitation possibility of the deep aquifer for rural water supply.

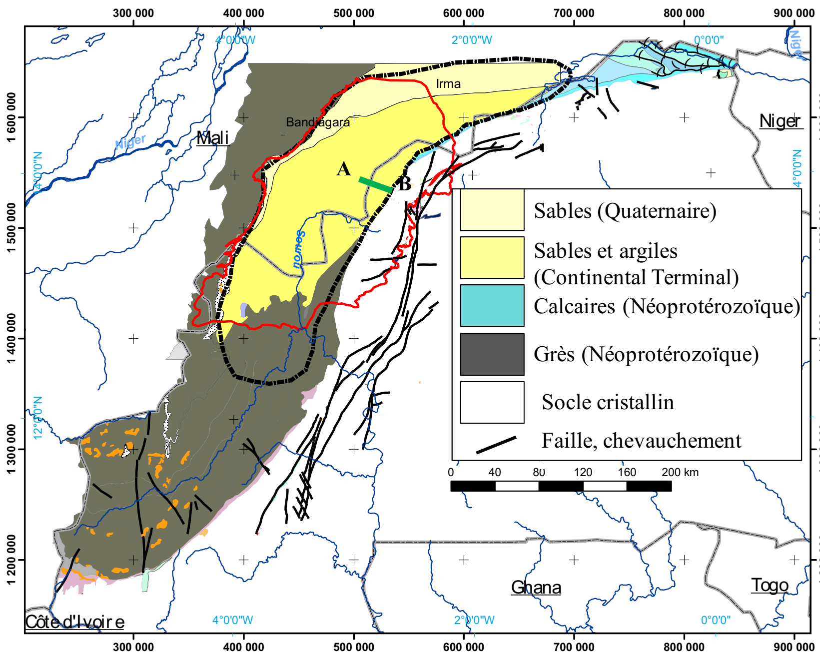


Figure 1 : Geological map of the Gondo plain and his border (Koussoubé Y. 2010)

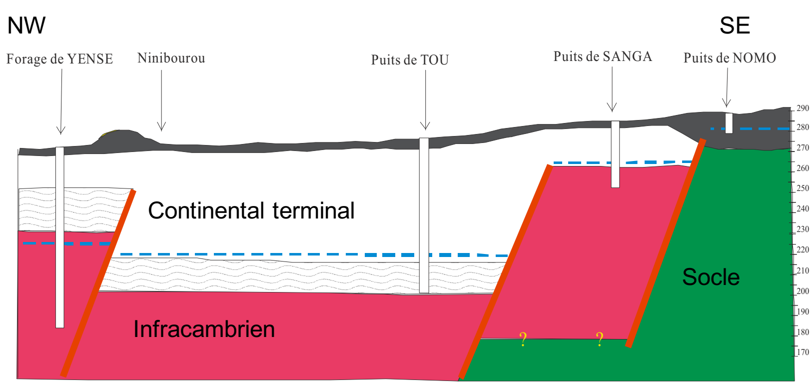


Figure 2 : Structural cross-section (see AB on figure 1) of the eastern border of the Gondo plain

METHODS AND RESULTS

The combination of remote sensing, geology, geophysics (electromagnetism and resistivity methods), and hydrochemistry and isotope chemistry allowed:
- to specify the geology and the tectonic of the East border of the basin (on both sides of the road from Ouahigouya to Mopti), figure 2;
- to identify and characterize the different aquifers and their relationships (figure 2, figure 3);
- to show through the implementation of 250 m deep trial water drillings that the water sheet of the lower Cambrian can be under pressure below the Continental Terminal and has its level 15 m over the near surface water sheet;
- to show that the water reservoir of the Dam of Sourou has contributed to modify the piezometric depression noticed in the plain (figure 4);
- to highlight karstic zones (which geometry should be studied) on both sides of the water reservoir of the Dam of Sourou;
- to show that water chemistry and isotope chemistry can be used to differentiate water sheets and to evaluate their recharge (figure 4).

These studies not only show the efficiency of the methods used here, but also have allowed to get new scientific information on the geology, the hydrogeology, the hydrochemistry and the water stocks of the Gondo Plain located in Burkina Faso.

Key words: Gondo Plain, aquifers, geophysics, trial water drilling, isotopic chemistry, piezometric depression

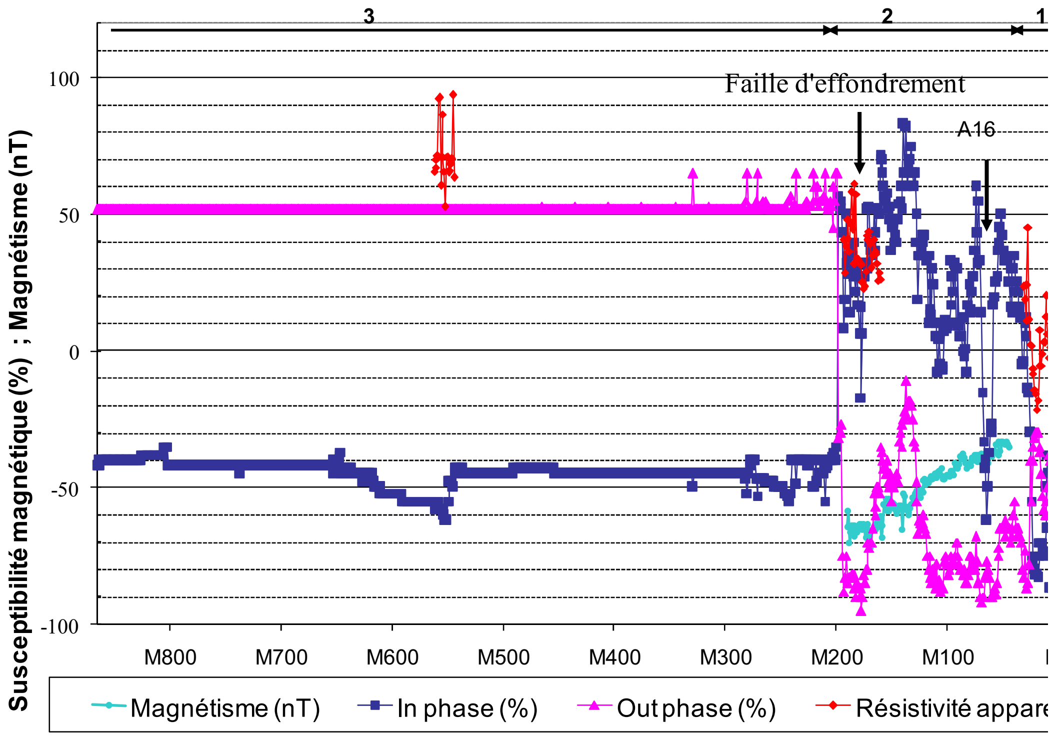
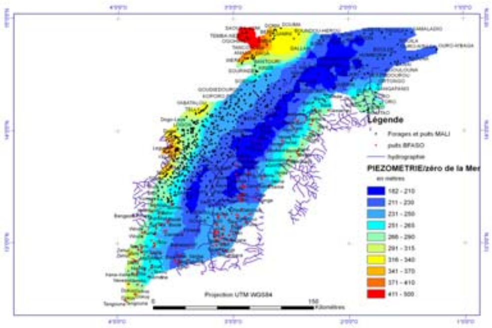
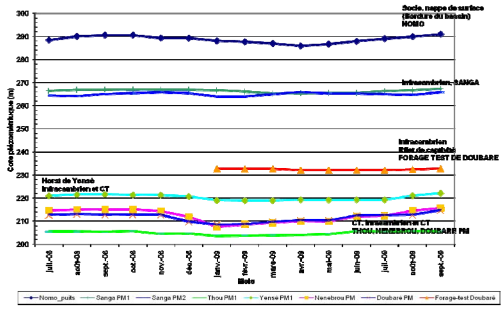
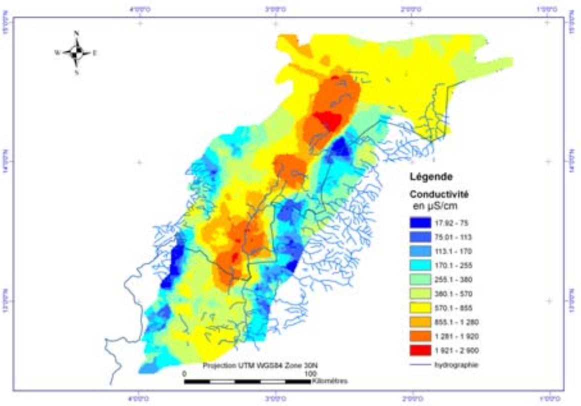


Figure 3 : Geophysical profiles across the crystalline basement (1) and the overlayed sediments (2 : Lower Cambrian , 3 : Continental Terminal)

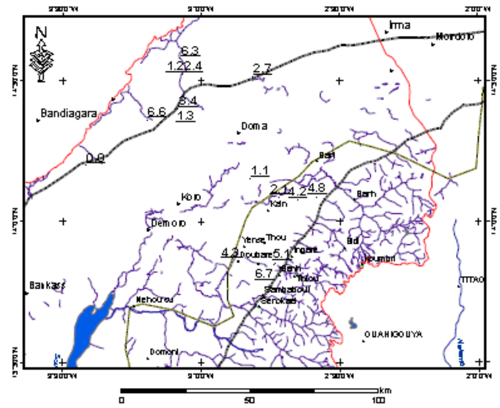




Piezometry



Electrical conductivity



Isotope (^{3}H) concentrations

Figure 4 : Different interpretative maps on Gondo plain (piezometric map and graphs, Electrical conductivity, isotope concentrations)

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Regional Features of Sustainable Use of Fresh Groundwater in Europe (on the Specific Example of Belarus)

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Abstract

Freshwater resources are one of the major constituents in successful development of economy of any part of the world. As a rule, surface waters provide for agriculture and industry. But since groundwaters server as a major source of drinking water, their quality and availability is of vital importance.
This article presents an analytical overview of distribution of fresh groundwater resources in Belarus, the dynamics of their usage and the influence of human activity on groundwater resources.
Spatial differentiation of freshwater resources within the borders of Belarus is reviewed. The dynamics of fresh groundwater abstraction and consumption during a prolonged period of time (24 years) is analyzed.
Also, described and classified are the main natural and anthropogenic factors influencing the quality and availability of fresh groundwater. Their mapping is done.
As a result, it was found out that the country possesses rather considerable resources of fresh groundwater sufficient for present and perspective water demands. However, the quality of groundwater does not always meet the norm.

Key words: natural fresh groundwater resources, water quality, drinking water, fresh water consumption, groundwater contamination

INTRODUCTION

The area under study – Belarus is situated in eastern Europe. The west of the country is characterized by the climate transitioning between maritime and continental. The climate in the central and eastern parts is continental. The territory of Belarus is situated in the sufficient precipitation area. The average annual precipitation is 700 mm, ranging from 600–650 mm in the southeast to 650–700 mm in the highest areas in the center of the country. The average annual evaporation varies from 550–575 mm in the south to 475 mm in the north of the country (Climate, 1996). Due to its climatic, geologic and geomorphological features, the territory of Belarus has favorable conditions for formation of freshwater resources, their wide distribution and reproduction.

OBJECTIVES

- To carry out a regional evaluation of provision of the territory of Belarus with freshwater resources and examine their differentiation.
- To analyze groundwater usage in national economy.
- To find and classify natural and anthropogenic factors influencing sustainable use of fresh groundwater and carry out its mapping.

The following methods were used to implement these objectives: comparative-geographic, cartographic and method of statistical analyses.

RESULTS AND DISCUSSION

Freshwater resources include surface and ground waters. Surface waters and groundwater aquifers have a hydraulic connection. This has to be taken into consideration when solving problems of sustainable use of fresh groundwater.

Freshwater resources of Belarus are generated in the boundaries of five main catchment areas. These are the Dnieper, the Pripyat, the Western Dvina, the Neman and the Western Bug. All the main rivers of these catchment areas are transboundary. The largest Belarus rivers rise in Russia or Ukraine, flow through Belarus territory and bear their water towards Ukraine and Latvia. The total annual average river runoff is evaluated at 57.9 km^3/year; 59% of it is related to internal water resources and 41% is received from neighboring territories. Its largest amount belongs to the Dnieper catchment area (11.3 km^3/year) and the smallest to the Western Bug catchment area (1.4 km^3/year).

The water-bearing strata containing fresh water used for water supply belong to Quaternary, Paleogene and Neogene, Cretaceous, upper Jurassic, upper Devonian and upper Proterozoic sediments. As a rule, exploited aquifers are shallow (50–200 m). They contain hydrocarbonate calcium as well as magnesium and calcium water with mineralization level between 20 mg/dm^3 up to 1.000 gm/dm^3 (Jasoveyev, M.G. *et. al*., 2005).

To supply urban Belarus with water, over 260 fresh groundwater fields were explored. Their recoverable storage is about 6.600.000 m^3/day. The majority of fresh groundwater fields (over 60%) are small fields with recoverable groundwater storage of 1.000–30.000 m^3/day. The natural fresh groundwater resources are evaluated at 15.9 km^3/year, while the prognosis water resources at 18.1 km^3/year. However, these resources are not evenly distributed among catchment areas. The total abstraction at 1.800.000 m^3/day for public water supply accounts for only 27.3% of recoverable groundwater storage (The state, 2001). The prognosis groundwater resources can be considered sufficient for actual and perspective water demands.

In Europe, about 18% of the total water abstraction comes from groundwater, its proportion varying from country to country. In Belarus, the water abstraction from natural sources had a 39% decrease during the 1985–2008. For the same period of time the portion of surface water in total water abstraction decreased from 60 to 44%, while groundwater abstraction has increased from 40 to 56%. Water consumption has a similar tendency to decrease, but it has different features depending on the consumption sector. In 2008, water consumption was estimated at 1410 mln. m^3, or 86% of total water abstraction. On average, the total water consumption is distributed as follows: 40.6% of it is used for household and drinking purposes, 30% for industry, 21.3% for fish farming and 8% for irrigation, watering and agricultural needs. Compared to 1985, the total water consumption decreased by 46.5%. From 1985 to 2008, there was a steady tendency to decease of water consumption in industry, agriculture and fish farming sectors. For household and drinking purposes only groundwaters are used. The average water usage for drinking purposes per capita is about 200–220 l/day. It is higher than in many European countries (120–150 l/day/per capita). In this sector, the water consumption increased by 41% from 1985 to 2002, but after that decreased by 28% during the 2002–2008 (Environment, 1999, Environment, 1997–2009). There appears to be several reasons that account for serious decrease of water consumption. Some of them are decline in industrial and agricultural activity in the first half of the 1990s, decrease in population, water savings due to recirculation and successive water supply, introduction of domestic water metering.

The quality and availability of fresh groundwater is affected by several factors, which can be classified as natural and anthropogenic (Fig. 1). Natural factors include natural increased/decreased concentration of chemical elements, salt-water intrusion, floods and swamping. A specific feature of groundwater in Belarus is naturally high concentrations of iron (>0.3 mg/dm^3), manganese (>0.1 mg/dm^3) and deficit of fluorine (<0.7 mg/dm^3). There is salt-water intrusion in some sectors of underground saline water discharge, belonging to tectonic fractures and salt tectonics at the Pripyat trough. This causes mineralization rate to increase to 4.000–6.000 mg/dm^3 and the chemical compound of groundwater to acquire a chlorine sodium component. Floods occur either in spring or after abundant rains. As a result, industrial waste, sewage and radionuclides enter the floodwater, causing contamination of soil, open water systems and groundwater (Jasoveyev, M.G. *et. al*., 2005).

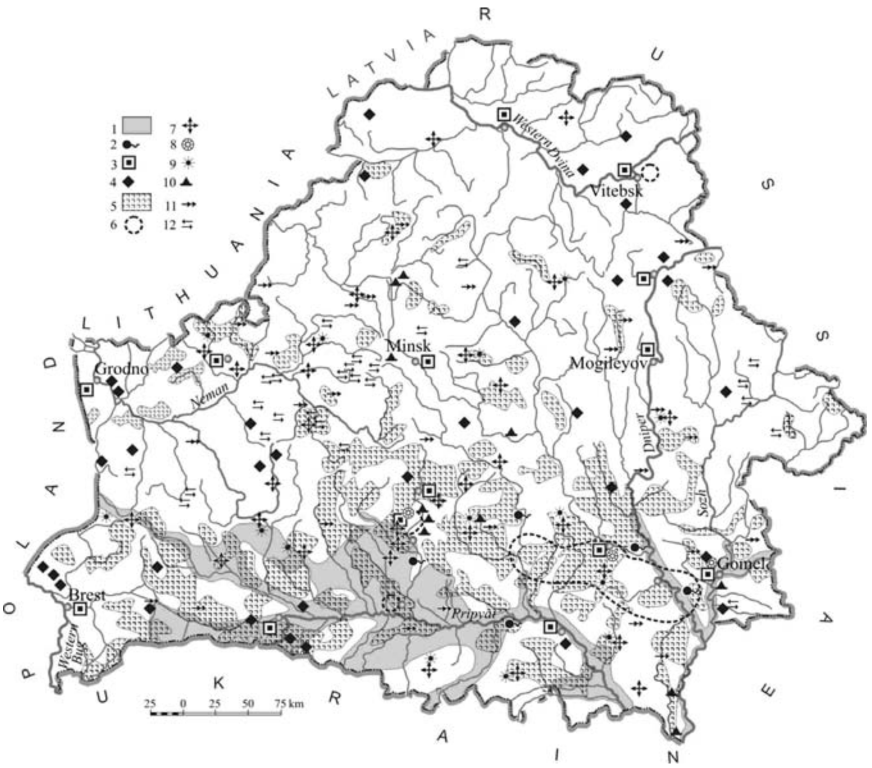

Figure 1 – Factors and processes effecting on quality and availability of fresh groundwater

Natural factors: 1 – Flood and waterlogging at hazardous spring flood, 2 – Salt water intrusion; Anthropogenic factors: 3 – Industry and household objects of intensive pollution, 4 – Large-scale agriculture objects, 5 – Areas of intensive land reclamation, 6 – Areas of mineral deposits prospect and exploration (oil, potash salt, building materials, dolomites), 7 – Deflation (on land reclamation, industry dumps, borrow pits), 8 – Karst (in industry dumps), 9 – Disintegration of organic (on land reclamation), 10 – Wetlands bordering on reservoirs, 11 – Suffusion (in separate borrow pits), 12 – Sheet erosion (on cultivated lands)

Anthropogenic stress has the deepest influence on the groundwater (3–6 m deep) and inter-stratum water-bearing complexes of Quaternary sediments. It leads to freshwater pollution by nitrates, chlorine, sulfates, pesticides, mineral oil products, heavy metals, etc., to developing processes of deflation, sheet erosion, suffusion, elevation of ground water level, wetlands, disintegration of organic substance, depletion of water and salt underground water intrusion.

CONCLUSIONS

Natural conditions of the territory of Belarus are favorable for formation of freshwater resources. Fresh surface and ground waters are unevenly distributed throughout the country, but they are sufficient for actual and perspective demands. The analysis of the dynamics of water abstraction in Belarus helped determine characteristic stages of water abstraction. There are several factors causing freshwater abstraction and consumption changes. To determine the role of each factor, one needs carry out additional analyses and specify the role of separate branches of national economy in the structure of freshwater consumption.

The quality of drinking water, as a rule, meets the standards. The only exception is when there is a naturally high concentration of some chemical elements in water. Anthropogenic stress causes a more serious problem to the regime of fresh groundwater.

There are practical and economic measures that could help achieve sustainable fresh groundwater usage. Some of them are improving ecological conditions in the protection zones of groundwater intake; limiting or restricting agricultural land use within the borders of cones of depression and riparian water protection zones; using superficial artesian waters for technical purposes in the areas of groundwater pollution and wetlands; monitoring regularly surface and ground waters within the borders of large-scale industry and agriculture, as well as solid municipal waste heaps.

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The Muskau Arch Geopark (Poland, Germany) – an opportunity of transboundary water environment protection and monitoring

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ABSTRACT

The Muskau Arch area is situated within the border zone between Poland and Germany. Presently the efforts to create the transboundary Muskau Arch Geopark (MAG) are being made. One of the important issues is the creation of a common surface- and groundwater monitoring system for the both parts of MAG, aimed at scientific research and protection of its unusual hydrosphere system.

Key words: Muskau Arch Geopark, anthropogenic lakeland, transboundary groundwater bodies

1. LOCALIZATION

The Muskau Arch area (Polish: Łuk Mużakowa; Germany: Muskauer Faltenbogen) is situated within the border zone between Poland and Germany (Fig.1). The region is localizated in a triangle, formed by Brandenburg and the Saxony (in Germany part) and the Lubuskie Voivodeship (in Poland part). The Muskau Arch represents a push moraine cut by deep erosion. This area was formed by the Southern Polish glacial lobe moving along the valley of the prehistoric Lusation Neisse and then the Mid-Polish glacier (stadial of the Warta river glaciation). The geological structure of the Muskau Arch is a horseshoe-shaped lobe which length is about 40 km and width is 25 km. The river Lusation Neisse forms the border between Germany and Poland – this structure is transboundary object.

Fig.1 Localization of the Muskau Arch

2. SURFACE WATER-ANTHROPOGENIC LAKELAND

The present, unique landscape has been influenced not only by the natural glaciotectonic structures that occur in its basement, but also by mining activities. Lignites of Miocene age has been mined here since the second part of XIX century for seventies of the XX c. The 1974 is the year when

the last mine - the "Babina", located in the Polish part was closed down. Elongated and usually narrow subsidence troughs were formed as the result of both open-cast and underground exploitation. After the end of mining they often had got filled with groundwater water and formed an artificial, so-called "lakeland" (Jędrczak, 1992), (Jachimko, 2007), (Kołodziejczyk, 2006), (Wróbel, 1997). In the Polish part, agglomeration of this unique lakes, consist of about 100 reservoirs, of age between 30 and over 100 years. They are situated in three groups: eastward from Łęknica town, near to Tuplice village and in the neighborhood of Trzebiel village. In the German part the reservoirs are located in main region – Lusatia, and their genesis, age and chemistry are almost identical to the Polish lakes. The reservoirs are featured by various colour of water (from turquoise, through navy blue, to reddish-brown) connected with their chemistry (Fig. 2,3). Their chemical composition significantly differs from the typical composition of surface waters. They are characterized by low pH (values between 2-4) and high concentrations of sulfates, Fe, Mn, etc. The surface and groundwater chemistry is fully controlled by the phenomenon of Acid Mine Drainage (AMD). The AMD is formed by a geo-chemical and microbial reactions that occur when sulfides, (especially pyrite - FeS_2) primarily "sealed" in rock massif, are exposed to air and water An overall net reaction for AMD formation is:
$4FeS_2 + 15O_2 + 14\,H_2O \rightarrow 4Fe(OH)_{3\downarrow} + 8H_2SO_4$ (Skousen *et al.,* 1998), (Akcil and Koldas, 2006).

Because of the unique natural values, the area of post-mining lakes within the MAG, should be protected by an uniform (transboundary) nature conservation law.

Fig. 2,3 Antropogenic lakeland.

3. GROUNDWATER BODIES

The Lusatian Neisse river cuts through the Muskau Arch and forms the border between Germany and Poland. Nevertheless, the groundwater bodies (GWB): the GWB unit number 67 ascertained within the Polish part of the region, and the "Lusatian Neisse" GWB in the German part, should be regarded as a one transboundary groundwater body.

4. IDEA OF TRANSBOUNDARY GEOPARK

The Polish part of the Muskau Arch has been identified as a National Geopark of Poland at 21st of October 2009. The German part of the area was recognized as the National Geopark of Germany at 1st of June 2007. The unique (in a global scale) hydrosphere system was one of the reason for commencing work in order to create a geopark in the Muskau Arch area. Presently the efforts to create transboundary Geopark are still being made. The Muskau Arch Geopark – situated on the borderland of this two countries – can give an opportunity of designing the representative, unified ground- and surface water monitoring and protection system. The idea of a transboundary park to place on the UNESCO list the both parts of Muskauer Arch (Polish and German).

Fig.4 Logo of the Geopark

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Transboundary Aquifers: Challenges and New Directions Ramsheh plain technical and social analysis

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ABSTRACT

Nowadays, in addition to the amount of surface and ground-water, its distribution and dispersion, ownership, political and geographical boundaries; utilization methods are among the head-on challenges.

Transboundary aquifers, located along the political borders, on one hand are concerned with subjects which directly have effects on their preservation and sustainability and on the other, deal with direct and indirect parameters which can affect utilization potentials and their effects on stake-holders.

Various complexities existing in transboundary aquifers between and/or among countries could be recognized inside the borders, e.g. between two adjacent provinces as well, which shows incremental sensitivity in the water industry.

In Iran, serious challenges are caused due to the change of water basin management into provincial management.

Ramsheh plain, located in the Isfahan province, is nourished by the Izadkhast river of the Fars province, especially, southern flank of Morvarid mountain. Gavkhoni wetland located in North–East, of the area is considered drainage of the plain.

Based on traditional water right, the Izadkhast river has been used by Ramsheh inhabitants for agriculture and recharging of the plain. In addition, its flow has turned water- mills which dates back to some 250 years.

In recent years, construction of Izadkhast dam in the Fars province for agricultural development has stopped the recharge of the Ramsheh aquifer causing transgression of high E.C. water into the aquifer.

This technical investigation on the Ramsheh aquifer is focused on mathematical models, dealt with social problems and their historical evolution is also accessed.

With the use of GMS model (Ground water modeling system) and based on geologic data and measurements of piezometers, the loss incurred by cutting off the water infiltrating into Ramsheh aquifer and its consequent effects on stake- holders, in terms of the Izadkhast dam construction, is evaluated.

Key words: Ramsheh- Esfandaran, aquifer, Gavkhuni wetland, Izadkhast dam

1. INTRODUCTION

The study area related to the present research called, Ramsheh- Esfandaran, in central Iran, is located some 160 Kms south-east of Isfahan, between longitude of 52˚ 41' to 52˚ 47' and latitude of 31˚,17' to 32˚,13'. The present study covers an area of 4768 Km^2, of which, 2408 Km^2 is plain and the rest elevated land. The average plain elevation is 1580 m above sea level, with annual precipitation of 97.8 mm.

The mentioned area has been a suitable sedimentation basin before Tertiary. It had been lifted along with Zagros folding and sedimentation in shallow sea commenced. With Zagros uplift, this area had been disconnected from sea, and for some era remaining a lake then dried up. Gavkhuni wet land is the remnant of the Gigantic Sea that existed before that time.

The most important and sole run-off source of water in the area is the Rahimi river, which flows off the western elevations of Izadkhast water-shed. This river runs down to Esfandaran sub-basin and eventually terminates in Gavkhuni wetland.

The Izadkhast highlands and its main water- basin, is located in the Fars-province, Due to its specific topography,and based on its past history, upstream stake holders have only been able to utilize water in the form of a narrow band along the Izadkhast valley with their limited agricultural lands extended along the river.The main agricultural lands and ancient riparian inhabitants of the Rahimi river, downstream of the water- basin, are settled in Ramsheh and Esfandaran, in the neighboring Isfahan province.In ancient times, most of the river flow (ranging between 4 to7 M.C.M annually) entered into Ramsheh – Esfandaran.

Furthermore, there existed an agreement in the form of a contract between upstream Izadkhast and downstream Ramsheh water users, which was in force for hundred of years. Thus the inhabitants of Izadkhast area had disclaimed their right to use water upstream and legal downstream users developed Hydro- structures with the aim of running their water mills and recharge water through recharging areas.

In recent years, the Fars Regional Water Board, having neglected the old agreements, implemented the construction of Izadkhast dam, thus preventing water flow to downstream Esfandaran-Ramsheh which naturally has caused water resources problems for downstream stake- holders and riparian rights.

In this research the social consequences and scientific aspects of upstream dam construction has been analysed and forwarded.

2- RAMSHEH-ESFANDARAN HYDROGEOLOGY (WATER RESOURCES)

In the study area of Ramsheh-Esfandaran, there exist 4 deep wells, 158 semi-deep wells and 26 Qanats.

Deep wells Maximum depth = 220m.
Deep wells average potential = 14 lit./second.
Semi deep wells average depth = 14 meters
Semi deep wells Maximum depth = 35 m.
Semi deep wells average potential = 4.7 lit./second.

3-WATER BUDGET (BALANCE)[1]

3-1-Aquifer charging volume: The average annual charge of the aquifer is around 496 million m^3 and the related factors are as the following:

- *Volume of precipitation over aquifer surface area*: Based on thiessen map, long term average precipitation (97.8 millimeters) and its surface area (665.9 Km^2), the volume of precipitation over the aquifer surface area equals 65 million m^3.
- *Volume of precipitation outside of aquifer surface area*: This area equals 4102.1 Km^2 with an average of 102 millimeters of precipitation, resulting in a volume of 418 million m^3 annually.
- *Returning Water Volume*: A volume of 6.75 million m^3 returns to aquifer annually, considering 25% out of 27 million m^3 water used as potable and industry.
- *Fluctuation in alluvial aquifer volume*: By drawing the plain Hydrographs for the recorded years and calculation of around 0.29 meter average annual drawdown of ground-water and regarding the average storing capacity of the aquifer (2/5%) 5 million m^3 is calculated for the annual utilization of the aquifer stored capacity.
- *Volume of water entering the aquifer from the neighboring basin unit*: Regarding the construction of Izadkhast dam and reduction of Cheshmehrizeh River flow (the only surface charge of the aquifer) the maximum expected charge from the neighboring basin unit is estimated 1 million m^3.

3-2-Aquifer discharge volume: The discharged water through pumping wells in the unit is around 14 million m^3 of which, 1 million belongs to the Fars province (Ab-e-shotor plain).The discharge water through Qanats and the existing spring is 10.5 and 2.5 million m^3 respectively.

[1] Balance volume presented in figure.1, refers to the first Dam impoundment on March.9. 1999 .

- *Volume of unit's outlet run-off*: This amount is calculated 38 million m^3.
- *Volume of unit's under-ground drain*: Regarding the piezometric maps, this amount is estimated 10 millions m^3.
- *Evapo –Transpiration*: Considering a share of 87% of the whole precipitation, the calculated volume of ET. is 421 million m^3.

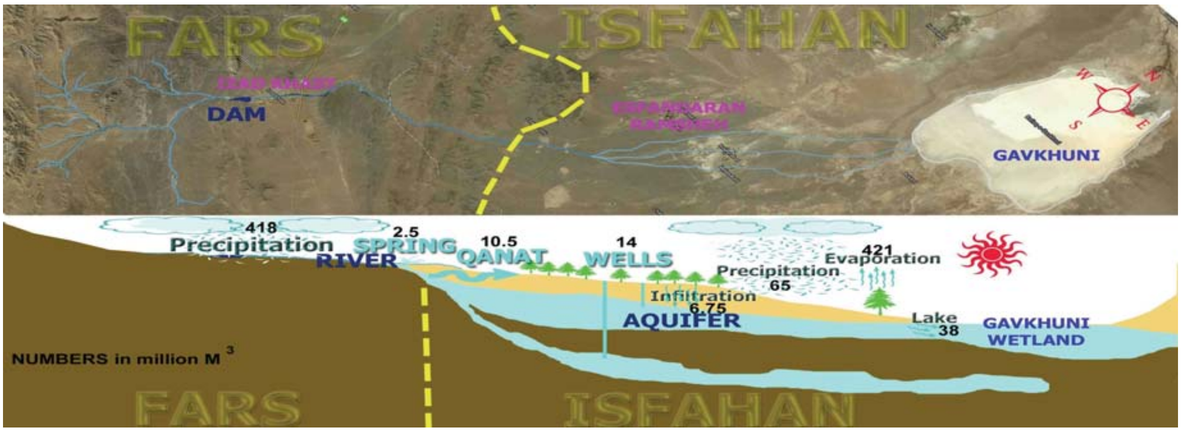

Figure.1: Plan and longitudinal profile of Izadkhast river in Fars & Isfahan Provinces

4-AQUIFER CHARACTERISTICS AFTER DAM CONSTRUCTION

A summary of aquifer Characteristics after Dam impoundment is presented in figure No.2. As noticed, Water table in aquifer has dropped about 1.7 meters which has resulted in a rise of salinity to more than 10000 µM/cm .This situation has endangered the agricultural produce and violated riparian rights, followed by severe reactions and consequences.

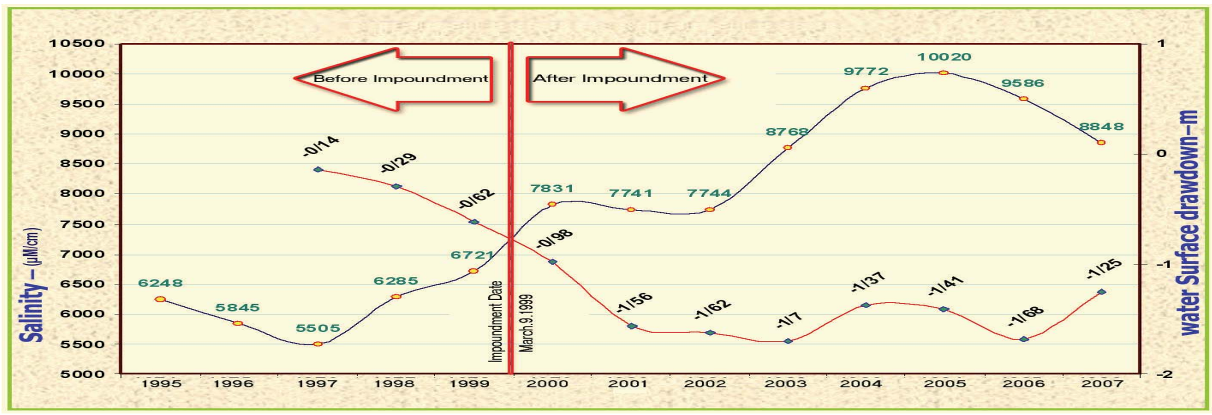

Figure.2: Graphs related to water-table drawdown & salinity in Ramsheh- Esfandaran aquifer

5-CONCLUSION

- Ignoring legal, riparian and stake holders rights, irreversible consequences may arise.
- Before execution of any new Hydro- structure, precise social studies and effects of the planned structures on the aquifer, should be given a high priority and attention.
- The Izadkhast dam construction has resulted in the severe draw-down of water- table and the sharp rise in salinity in terms of doubled E.C. which shows a crisis in the aquifer.

Climate and Land Use Change Impacts on Groundwater Quality in the Beninese Coastal Basin of the Transboundary Aquifer System Benin-Nigeria-Togo.

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ABSTRACT

The coastal basin of Benin covers 12377 km² of the transboundary aquifer system shared by Benin, Nigeria and Togo. Groundwater is the mean water supply source of a population approximately estimated by 4 million inhabitants. Population rapid growth with the rate of 4.5% induces extension of human settlements which interaction with climate variability affect groundwater quality. Statistical analyses were used to highlight observed climate change. Seasonal analysis of 40 shallow and deep wells, boreholes and spring water sampling and land use land cover (data provided by LANDSAT ETM7+, MSS, and SPOT imagery for 1973, 1995 and 2005) diachronic analysis helped to emphasise environmental change impacts on groundwater quality. Furthermore, binary diagram method was used to interpreted geochemical process of water mineralization. Water quality is also appreciated from the drinking water quality standards of WHO. This study shows that groundwater mineralization is dominated by calcium, sodium, bicarbonates, nitrogen and chloride depending on ions exchange process in the wet or dry period. Bacterial polluting agents were numerous (total coliforms, *Escherichia coli* (in dry period) and fecal streptococcus (in wet period)). On the whole, depth of aquifers, land use, unhealthiness around the water supply sources, induced recharge from inadequate sanitation facilities and sea water intrusion interaction with hydroclimatic change are the mean factors of the strong deterioration of groundwater. Groundwater quality assessment could contribute to plan transboundary aquifers management based on local hydrogeological basin scale.

Key words: sedimentary coastal basin, groundwater, global change, quality, management.

1. INTRODUCTION

Groundwater is a valuable natural resource providing a primary source of water for agriculture, domestic and industrial purposes in many countries (UNESCO, 2006). It is a major source of drinking water across the world (UN/WWAP, 2006; IPCC, 2007). According to Hiscock and Tanaka (2006), global climate change is expected to have negative effects on water resources as a result of increased variability in extreme events such as droughts and floods. On the other hand, land use and land cover (LULC) changes are one of the main human induced activities altering the groundwater system (Calder, 1993). As consequence on the coastal sedimentary basin of Benin, physicochemical and bacteriological compositions of groundwater change in time and space (Totin, 2010). The objective of this paper is to analyse groundwater quality sensitivity to climate and land use patterns change.

The coastal hydrogeological basin of Benin is a part of the Transboundary Coastal Sedimentary Aquifer System (n° 414) that stretches from south-western Nigeria across southern Benin into southern Togo. It lies between latitudes 06°15'N and 07°38'N and longitudes 01°30'E and 02°50'E, with approximately 12377 km². This basin is sub-divided into four aquifers with the high water reservoirs mean unconfined aquifer of Continental Terminal and confined aquifer of Upper Cretaceous and the minor reservoirs like Quaternary and Lower Palaeocene aquifers (Dray *et al.*, 1989; Boukari &

Alassane, 2007). Fortunately, they have a large part (35%) of the whole groundwater resources of Benin.

2. RESULTS

2.1. Climate and land use change in the coastal sedimentary basin of Benin

At the annual scale, climate variability is marked by alternation of wet and dry seasons, corresponding respectively to recharge and discharge periods. Long-term variability and trend of annual rainfall show rainfall decrease of 17% over 1951-2005 with the range of 9 to 30% (Totin, 2010). Furthermore, observed change of average temperature (in the change rate of IPCC (2007)) was from 26.7°C in 1950 to 28°C in 2005 with the rate of 1.8°C over 1951-2005. So, modification of climate patterns affects hydrological process and water quality depending also on land use change.

From 1973 to 2005, the mean LULC patterns changes were shown in Table 1.

Table 1 LULC patterns change in the coastal sedimentary basin of Benin from 1973 to 2005.

LULC categories	Forest/Savannah land	Wetland	Agriculture land	Human settlements	Watershed	Beach land
Area_1973 (%)	35.89	16.29	40.02	1.47	4.33	2.01
Area_1995 (%)	14.86	12.51	62.43	2.95	3.66	3.59
Area_2005 (%)	8.30	6.91	72.20	7.69	3.01	1.88
Balance_1995-1973	-58.6	-23.2	56.0	100.7	-15.4	79.1
Balance_2005-1995	-44.2	-44.8	15.7	161.2	-17.8	-47.5

So, changing LULC is dominated by regression of forest/savannah land, marshy land and progression of agriculture and constructed land. This land use modification particularly extended of human settlements and cultivated land causes more damage to groundwater quality.

2.2. Groundwater quality: physicochemical and bacteriological characteristics

Table 2 shows that, in spite of the high concentration of the major ions in groundwater in the dry season, measured values are generally below the WHO (2008) guidelines for drinking water.

Table 2 Statistical summary of the physicochemical parameters in groundwater (40 samples) from the coastal basin of Benin.

Parameter	Wet season					Dry season					WHO (2008) Standard
	Min	Max	Mean	Medium	Std Dev	Min	Max	Mean	Medium	Std Dev	
pH	3.9	8.6	5.9	5.8	1.1	3.7	8.6	6.0	5.9	1.2	25
Temp	27.7	30.5	29.2	29.1	0.8	26.5	31.7	29.5	29.4	1.0	6.5 - 8.5
EC	24.7	3630.0	511.9	177.3	847.7	22.0	1540.0	394.9	177.2	481.1	2000
TDS	24.0	1477.0	336.8	149.0	425.0	14.0	1001.0	218.9	91.0	306.3	1000
Ca^{2+}	1.5	83.2	18.6	9.3	22.4	1.2	145.6	27.1	14.6	34.8	400
Mg^{2+}	0.1	16.2	3.3	1.5	4.2	0.3	39.2	9.0	4.3	10.9	50
Na^{+}	0.6	132.0	23.5	6.1	35.3	0.1	178.3	32.2	13.7	50.1	200
K^{+}	0.8	32.7	7.3	3.7	8.9	0.0	73.1	9.9	3.8	17.1	12
Cl^{-}	0.0	301.5	19.6	2.9	66.6	0.0	423.8	55.8	9.9	112.5	250
SO_4^{2-}	0.0	81.3	4.8	0.2	18.1	0.0	162.9	11.6	1.2	36.5	250
HCO_3^{-}	0.0	190.0	53.4	26.0	57.0	2.2	240.0	54.9	26.0	65.4	-
NO_3^{-}	0.0	48.5	10.1	4.6	14.1	0.1	88.2	25.7	14.2	25.7	50

Temperature (Temp.) in °C; Electric conductivity (EC) in µS/cm; Concentration values of ions in mg l^{-1}

Median values (meq/l) of major ions shows that groundwater mineralization is successively dominated by cations Ca^{2+}, Na^{+}, and K^{+} in the wet season and Mg^{2+} in the dry season. Relative abundance of the anions is $HCO_3^- > NO_3^- > Cl^- > SO_4^{2-}$ in both the wet and dry periods. Chemical composition change of groundwater in various climatic contexts is related to ion exchange, rocks dissolution or weathering, seawater intrusion, human pollution, etc. So, the main sources of NO_3^- in drinking water are certainly agricultural contamination (just as for K^+) in the wet period and induced recharge (by wastewater) in the dry period. Kortatsi *et al.* (2007) explain that NO_3^-, Cl^- and SO_4^{2-} loading positively together reflect common anthropogenic origin, perhaps pollution from human induced activities such as inorganic fertilizer and pit latrines, animal droppings. In the coastal basin of Benin, the main sources of NO_3^- are agricultural contamination in the wet period and induced recharge (by wastewater) in dry period. According to Hounslow (1995) bicarbonate is formed when carbon dioxide and water react with various minerals. In the coastal sedimentary basin, abundance of HCO_3^- in groundwater is linked to carbonate rock dissolution Boukari (1998).

On the other hand, the seasonal concentrations of bacteria, presented in Table 3, are in most cases higher than the standards recommended by WHO (2008).

Table 3 Bacteriological patterns of the groundwater in the coastal basin of Benin.

Sampling sites	Total coliforms		*Escherichia coli*		Fecal streptococcus		Maximum Allowable Value
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	
Shallow and deep wells	160 – Innumerable	Innumerable	8 – 412	Innumerable	5 – 360	2 – 160	0 CFU/100ml
Boreholes	0 – 60	0 – 42	0	0 – 20	0 – 3	0	0 CFU/100ml
Spring	28	74	9	24	2	26	0 CFU/100ml

Results from seasonal water samples of 11 shallow and deep wells, 8 boreholes and 1 spring

Well water is more susceptible to bacteriological contamination than boreholes since the total coliforms were too numerous to count. The lower degree to which the boreholes are polluted can be explained by the depth of water table, the thickness of soil and geological layers (filters anti-pollutants) and their protected system. With regard to the sensitivity of the water supply sources to fecal contamination, it is clear that climate variability and land use affect groundwater quality.

3. CONCLUSIONS

Assessment of groundwater quality shows that the chemical elements concentrations are below WHO standards for drinking water while bacterial polluting agents exceed it both in rainy and dry seasons. Hydroclimatic change, depth of aquifers, land use and unearthliness around the water source are the mean factors of the strong bacteriological deterioration of groundwater. Therefore, in order to plan transboundary aquifers management, more attention should be paid to groundwater quality on the local hydrogeological basin like in Benin. So, studies from several sites in each country shared by the transboundary hydrogeological basin are needed to provide reasonable groundwater quality data for large scale use.

Acknowledgements

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Ecological Risks Assessment and Hydro Energy of the Kyrgyz Republic

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ABSTRACT (TIMES 9, BOLD AND CENTRED)

An assessment of made a calculation to produce electric power in Kyrgyz Republic energy system. Characteristic of basic lowland water reservoirs within Tien-Shan in Kyrgyz Republic. Investigation of water resources and water usage.
Adjusted data certify of that in spite of favorable forecast of increasing water resources due to climate changing seemingly Kyrgyz Republic fully provides the own water demand under realization of accelerative scenario, neighboring countries located on lowland in down streams will feel the water shortage in the foreseeable future.
Providing the economic-drinking needs of population will be becoming most priority to taking in account increasing the water demand of per head.

Key words: hydroelectric power plants, water use

INTRODUCTION

Kyrgyz Republic – independent state, located in northern-east part of Central Asia. The territory spreads from west to east 900 km, from north to south 410 km, area is 198,5 thousand km^2. Population is 5 million (Fig.1).

The history of the power system can be traced to 1934 when a 13.2 kV network was constructed in the mountain region.

Today, power engineering in the sovereign Kyrgyz Republic is comprised of major hydroelectric and thermal power stations, including the flagship Toktogul hydroelectric power plant.

There is a strong future for the development of hydroelectric power engineering in Kyrgyz Republic, as it represents the foundation for the development of ecologically clean power for the Republic.

This future includes a unique network comprised of the Kambarata and Upper-Naryn hydroelectric power-plants and series of small scale hydroelectric power plants.

CURRENT STATE OF HYDRO ENERGY SYSTEM

The current power generating capacity of Kyrgyz Republic is comprised of 20 electric power plants with a total installed capacity of 3.4 million kw; 5.8 thousand km of 110-500 kV systems and main electric power transmission lines; over 63 thousand km of 0.4-35 kV power distribution networks and 490 km of main district heating networks.

The annual power output of the power plants in the Republic is of the order of 12-14 billion kWh.

Unique overhead 500 kV (500 kV OTL) transmission lines are employed on the power system. The 500 kV overhead lines are used at altitudes of up to 3,500 m above sea level. The Kyrgyz power system is unique in domestic and international powerline engineering for its coverage of high mountain regions and advanced engineering designs employed in its 500 kV OTLs (special mountain supports; experimental wire and insulation suspension designs and spans).

The development of energy sector in the Republic will be based on the effective utilization of the extensive hydroelectric power generation capacity. A truly inexhaustible energy source exists in the mountain rivers of Kyrgyz Republic.

Kyrgyz Republic is third among Commonwealth of Independent States nations in terms of hydro-resources (after Russia and Tadjikistan). The rivers of the Republic have an extraordinary high concentration of potential power generation capacity per kilometer of river length. The specific power generation capacity of the Naryn river and its tributaries exceeds that of such major rivers as the Volga and Angara.

The hydroelectric potential of the Republic is 142.5 bin kWh/per year, of which only 9% has been developed. Current infrastructure makes it possible to utilize 72.9 bin kWh/per year, although only 48 billion kWh/per year are usable on a cost effective basis.

The Naryn River basin has potential resources of 56.9 bin kWh/per year. Twenty-two hydroelectric power plants producing on the order of 30 bin kWh/per year of electric power could be constructed on this river and its tributaries.

The comprehensive program for hydroelectric power resource development makes reference to the construction of hydroelectric power plants in the upper- and mid-river regions of the Naryn river for a total installed capacity of 5.85 billion kWh/per year.

The mountainous landscape facilitates the construction of reservoirs for hydroelectric power plants, while the deep, narrow canyons make damming highly efficient.

Recovery of capital investment on hydroelectric power plant construction is reached in periods ranging from 2 to 8 years.

High energy resources supply created favorable prerequisites for fast development of the energy complex of the Kyrgyz Republic which from the beginning of 80-ies became a large hydro power producer in the Central Asian region.

The Kyrgyz power system is one of few ones in the post soviet space which managed not only to preserve the electricity production level but also to support new capacities commissioning.

In a period of transition to the market economy, the power-engineering retained core productive capacities and qualified specialists. It also mobilized organizational and financial resources to meet new needs of our time.

A positive peculiarity of the Kyrgyz Energy System is the significant prevalence of hydro power plants in the capacities' balance in the presence of a large water-storage reservoir of Toktogul Hydro Power Plant with a- long-term regulation.

Potential hydroenergy resources of the Naryn river make 56,9 billion kWh. It is possible to build 22 new hydropower plants with electricity generation about 30 billion kWh on this river and its tributaries (pic.3).

The hydropower plants were build in downstream of the Naryn river - the one of the main tributaries of the Syrdaraya river on the south of the republic and they form coordinated hydroelectric system. Total capacity of power plants of the Kyrgyz energy system exceeds 3,6 million kWh including 2,9 million kWh or 82,2% belonging to hydropower plants.

The regulation of flow in river basin is carried out by the number of big water reservoirs: Toktogul, Kairakkum, Chardari, Andijan and Charvak designed for operation in irrigation mode for the Central-Asian republics.

JSC "Electric Power Plants" is a main producer of the electric and thermal energy in Kyrgyz Republic [1].Considering the impact of these processes on environment and regional population, we should note that Central Asia in the nature geographical relation presents itself as common territory. This unity provided with resources system and first of all two main – Syrdarya, Amurdarya. The very so water resources and their distribution in space and time are important defining factors both economy and ecology of this region.

During last tens years energies based on guided principles of using fresh water mentioned in chapter 18 of UNO agenda to 21 century in which says about quality protection and providing fresh water as well as integrated approaches to developing, managing and using water resources were focused on the following spheres:

- integrated developing and managing the water resources;
- assessment of the water resources;
- saving of the water resources, water quality and water ecosystem;
- water supply and sanitation;
- water and sustainable urban developing;
- water is necessary for sustainable producing food and rural developing;

- influencing of climate changing to the water resources.

Regional water resources are involved practically completely in economic using. Seasonal lack of water and water resource pollution keep back social-economic developing of Central Asia, according that the water resources often using with waste and prodigally.

Reserves of the regional water resources have been assessed for results of summation the reserves of surface and underground waters and subtraction of received results of water missing to produce hydro energy inter vegetation period correspond to average year of growth rate of hydro energy producing in maximal version i.e. 2,55 % annually. Volume of return water and influencing the climate changing under assessment of water resource reserves do not take in account.

CONCLUSION

Adjusted data certify of that in spite of favorable forecast of increasing water resources due to climate changing seemingly Kyrgyz Republic fully provides the own water demand under realization of accelerative scenario, neighboring countries located on lowland in down streams will feel the water shortage in the foreseeable future.

Providing the economic-drinking needs of population will be becoming most priority to taking in account increasing the water demand of per head.

- devote the deserved place to water saving policy on the targeted list of planned activity and measures;
- analyzing influencing to changing specific norm of water consumption per head on common country balance;
- include in program concrete sphere suggestions for water saving;
- include in capital investment to these measures into budget with preparation of state programs and projects;
- assessing the endowment of these measures to the economy of water resources;
- taking in account necessity of developing the organizing mechanisms water-economy agencies for realization of strategic measures to water supply;
- should be taking in account the questions linked with influencing to water consumption and water prize in agriculture and analyzing the influence to increasing tariffs in urban area [2].

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Water Balancing and Power Generation
Using Topographical Advantages
(Hidden Potentials between the Transboundary Aquifers)

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ABSTRACT

Great potentials are hidden across the Transboundary aquifer regions between the neighbouring countries. But these potentials are interlocked by boundary disputes .If any how we could open these interlocks of such disputes, tremendous potentials will be available at the disposal of mankind on the earth. In an ancient time boundaries are formed because of natural obstacles like high hill ranges, water barrier rivers & the coastal limits. The boundaries formed because of high hill ranges & the rivers flowing through it. There is a sudden & drastic changes in topography, like silt gradient of lands & tremendous changes in hydrodynamic current, which has high potential to satisfy man's need like water for drinking, water for irrigation, mainly for the generation of hydroelectric power ,which will become the prime & eco friendly source of electricity .Thus the down flow stream sprinkled the lower altitude region at the same time produced power will illuminated the higher altitude region.Beneficiaries will be neighbouring all.

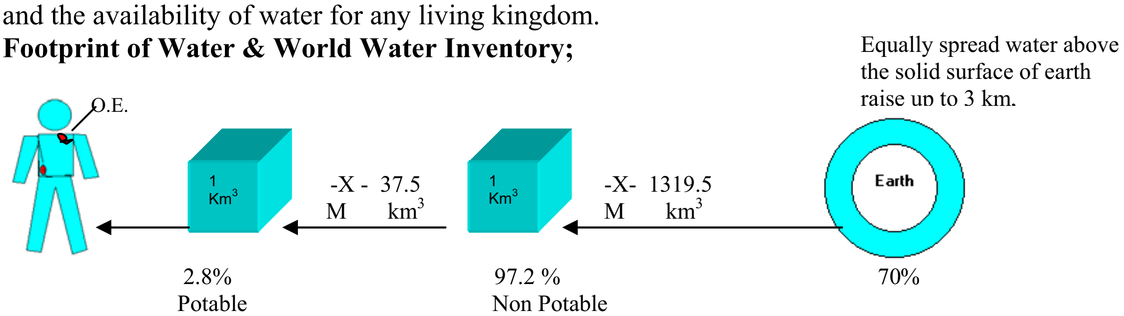
Every continent has a similar type of topographical landscape .To the extreme one end ,high ranges of mountains are there ,and next region is followed by silt gradient till nearby river basin, which is followed by low hill ranges & plateau then the slope of plains till the sea level. Thus surface area of continent spread at different altitudes. Nature distributes the potable (2.8 %)water in the form of precipitation. Water at particular height acquires certain fix quantity of potential energy because of it's altitude position **(PE =mgh)**.This potential can be use for the transportation of water from high hill ranges to the low hill ranges, crossing the lowest point of the river basins in between . Thus hill-to-hill transportation of water is possible throughout the continent through the conduit. Same water with the same quantity can be reused for the series of electrical power generation projects across the continents. This is just like a surface water current through conduit to balance the water scarcity zone & water rich zones.
One of the region in **Himalayan Transboundary aquifer location** is challengeable for giving the new directions for the use of transboundary aquifers.

Keywords.: Aquifer,potential,Interlock, dispute,water transport , Advantages& Reduction of global warming ,

1. INTRODUCTION

Water is one of the essentials of natural sources. We utilize it more than 95 % throughout life with respect to other essentials(O.E)..But water inventory shows only 2.8% water is potable with respect the total water present on the planet. These figures reveal the contrast between necessity and the availability of water for any living kingdom.

Footprint of Water & World Water Inventory;



So it is very important to know, how we get potable water and at what cost the nature is sacrificing for us, to provide the water at our doorstep. Just like the Atmosphere, Air ,climate, weather, Birds and Sea animals do not follow the rules of boundaries .In the same way precipitation and water-cycle have their own way across the continents. But as soon as precipitation touches the earth's surface it is distributed among the countries and the countries are divided by boundaries. Most probably boundaries are formed because of geophysical barriers and the obstacles like high hill ranges ,rivers ,coastal lines of the continent. Continents have nearly similar topography and water sheds structures. Water shed also does not follow the boundary rules but the barriers and obstacles between the thoughts of mankind produce artificial barriers which do not allow the use of this water of transboundary region ,which has very great potential to meet the drinking, irrigation and hydroelectric needs of the neighboring countries. Most of the transboundary aquifer regions are comparatively very small. But considering the height and altitude of water storage in the form of snow,& the silt gradient and the availability of water in all seasons. Such water possesses tremendous hidden potential energy(P.E.=mass x g x height).If anyhow we could transform this energy into electrical energy, and use it for water transportation across the continent crossing the river basin in between, by using the conduit, then no doubt transboundary aquifer will play a role of fulfillment of all above mentioned needs of mankind.

2. POTENTIAL CONTENT OF WATER BECAUSE OF ITS HEIGHT & ALTITUDE ;

As man understands only the language of money the calculations and figures given below will prove interesting for any economist.The water cycle completes after consuming millions of Kilo joules of energy of nature. For example the following figures reveal how many Kj energy is consumed during water cycle of one cubic kilometer quantity, from evaporation of sea water to precipitation on 8000 Meter altitude at 3000 Km distance away from the ocean .

Table No. 1

Vaporization	Precipitation	Transportation	Lifting
8.71×10^{7} Kw 25000 billion US D	8.71×10^{7} Kw 25000 billion USD	2.6×10^{7} Kw 5000 Billion USD	2.6×10^{7} Kw 5000 billion USD

Thus it is not difficult to understand that,How much quantity of energy is utilized by nature to complete a water cycle of one Km^3 quantity. These figures are only for 1 Km^3 .We can calculate for 37.5 M Km^3 (2.8 %)of water which is in potable form out of 1357 M Km^3 of water on the planet. Most of the Transboundary aquifer regions are enriched with the snow covered areas which are at very high altitudes.This snow melts in summer at the same time other parts of continents face drastic scarcity of water. These storages of water in the form of ice at the highest altitudes of the continent are a bounty for mankind.So we can say that these Transboundary regions are tremendous sources of energy and water for every need. But the tragic thing is that all such points are interlocked in boundary dispute.If any how we could open the these locks ,the earth will become the green earth in the truest sense.

3. TOPOGRAPHY OF CONTINENTS ,TRANS BOUNDARY AQUIFER REGION AND IT'S ADVANTAGES;

Every continent has similar landscapes & watershed structures. At one extreme end there are the high mountain ranges followed by silt gradient basins then by low hilly ranges ,next plateaus ,river basins and slopes till the ocean (as shown in fig no.1).Trans boundary regions lie somewhere between two ranges, banks of rivers ,coastal regions. Here I wish to discuss the trans boundary aquifer region especially in hilly regions & its potential energy content to perform the tremendous work for the sake of mankind & to reduce global warming rate. In the above table we see how much quantity of energy is utilized till precipitation,only for $1Km^3$ water. According to law of thermodynamics we can regain the energy.Such sources are most probably in trans-boundary Aquifer regions.

4. BEST ILLUSTRATION OF TRANSBOUNDARY COOPERATION IN CHINA & INDIA

This can be best explained with help of one of the region like the Indian sub continent & China.Brahmputra(known as Tsanpo).Transboundary Aquifer region Tsanpo-Brahmaputra has a perennial source & it is abundant even in summer because of the melting of ice. We all know because of global warming process,the melting of ice is continuously increasing.Then why not take advantage of the global warming phenomenon to produce green energy, which may help in reducing the global warming rate? As we have observed in the above table 1 Km^3 water possesses a potential energy convertible into 17.41X 10^7 Kilowatt electrical energy.Brahmputra has 586 Km^3 water per year in all it's forms on the Himalayan Ranges near Gayala & Peri hills in China. It is at 8,000 meter altitude above the sea level. This much quantity of water possesses tremendous potential energy according to formula P.E.= mgh (where m- Mass of water- ,g-Gravity constant 9.8 ,h=8000 metre Altitude) This potential energy can be utilized for work done (Wmax) in two ways. The Beneficiaries will be both the neighboring countries i.e. India & China. It is as below-

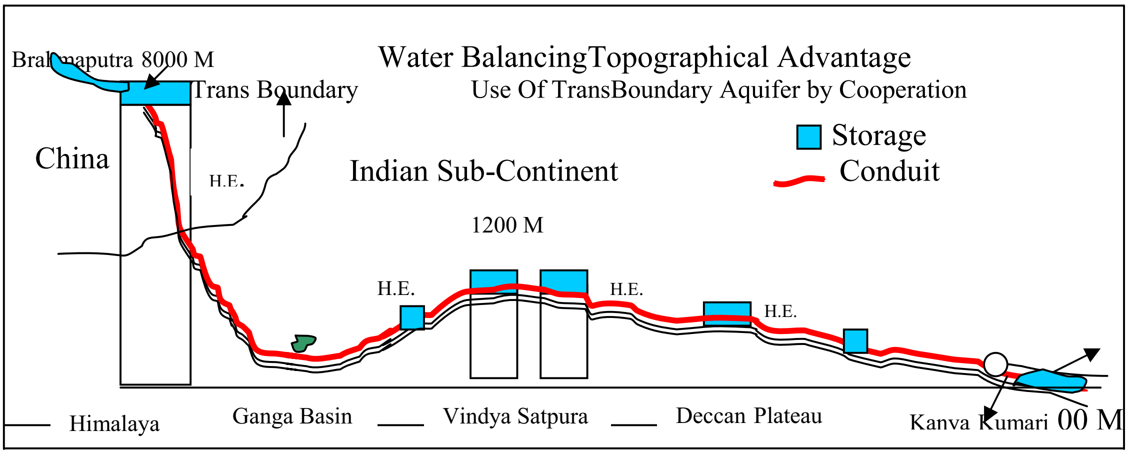


Fig.No. 1

Above TransBoundary Aquifer can perform Two Major Functions;

1)Part of this potential energy can be converted into electrical energy by setting numerous hydro electric projects in the region .This is possible because of the silt gradient which is nearly free falling water. It can produce millions of megawatt electrical energy which can be utilized by China as well as India & other neighboring countries.

2) Secondly near about 586 Km^3 water is available at Gayala & Peri at 8000 meter height above sea level. This much quantity of water possesses huge potential energy which is acquired because of its altitude against gravity. If we could construct a sort of Sump there (not a big Dam) & if this sump could joined by conduit to the storages present on the top of Vindhya & Satpuda (1200 meter) at a distance near about 1800 Km away from Gayala and Peri in China .Head difference between the two ends will allow the water to flow from Gayala & peri

region to the Vindhya ,Satpura Ranges (1200 metre above sea level) by crossing the Ganga Basin (300 M) only by gravity . Once the water comes up to the top of Vindhya & Satpura ranges, we can distribute it throughout the peninsular region of India with different storages & dams upto kannyakumari. Again we can install a series of hydroelectric projects using same flow of water As shown above in fig.No.1

5. ADVANTAGES OF STRENGTHNING COOPERATION BETWEEN CHINA AND INDIA

1) China will get electricity 2) India will get crystal clear & pure water for drinking & for irrigation 3) India can install a series of hydroelectric projects across the peninsular region .
4) Global warming melts the extra ice every year; we can use it to produce green energy.5)These projects will help to reduce the global warming rate by lessening the need for thermal & nuclear power generation which adds direct heat & pollution to the atmosphere 6) These will be a pioneer example of the use of potential content of transboundary aquifer which can be replicate for other such regions on the planet.

CONCLUSION

WWF,ISARM & conf.2010 should take the initiative to open the such boundary interlocks of dispute in order to use hidden potentials of transboundary aquifer regions for the benefit of green planet.

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Nanosafety as a new direction of transboundary biomonitoring

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1. INTRODUCTION

The recent advances in nanotechnology and the corresponding increase in the use of nanomaterials in products in every sector of society have resulted in uncertainties regarding environmental impacts. The detection of nanoparticles in virtually all water domains, including the oceans, surface waters, groundwater, atmospheric water, and even treated drinking water, demonstrates a distribution near ubiquity. The novel and potentially reactive characteristics of nanomaterials have lead to predictions on potential undesirable ramifications of exposure to these materials on human health.

The effect of these nanomaterials on microbes is an important consideration due to the role of microbes as the basis of food webs and the primary agents for global biogeochemical cycles. Bacteria are the dominant organisms in aquifers, and their occurrence and activity is related to the biogeochemical conditions, there is often a complex relation between water quality and microbial communities (Lehman, 2007). The long-term monitoring of autochthonous endokarst microbial communities during years or decades may be an interesting approach to assess the general water quality and to detect potential changes in ecosystem functioning due to chronic low level contamination or climate change (Pronk et al., 2009).

Microorganisms should be used in biomonitoring for several compelling reasons. (1) A cosmopolitan distribution facilitates comparisons of test results in geographically different regions. (2) Problems of scale are diminished. (3) Replicability is as good as, or better than, tests with larger organisms. (4) Environmental realism is higher than in tests using larger organisms... (6) Testing with microorganisms is less likely to antagonize animal rights activists (Cairns, 2005). Microscale testing methods and the earliest pollution prevention are the most cost-effective (Wells et al., 1998).

The goal of our investigation was to develop the background for microscale integrated information systems related to subterranean water quality.

The main objectives are: to find some indicator groups of ubiquitous microbial organisms suitable for multispecies toxicity testing and global integrated ecological standards for assessing water quality.

Other objectives are: assessment of toxicity and risk of NanoParticles and nanomaterials to humans and the environment, modelling and data management: including the creation and implementation of a common database in cooperation with the PCCP, EU NanoSafety Cluster and other UNESCO Programmes.

2. RESULTS AND DISCUSSION

New methods based on periphyton communities using polyurethane foam units (PFU) as artificial substrates, was included into the monitoring system of China and Korea (Shen et al., 1994; Jiang et al., 2007).

By far, the most commonly used artificial substrate has been 2.5 - 7.5 cm glass slides, which have the advantage that they can be used to detect the more fragile attached protozoans in vital microperiphyton communities, while the PFU method measures fewer attached species, because direct counting under the light microscope impossible inside the PF units (Bamforth, 1982; Duplakov, 1933; Ertl, 1970).

We have found more than 100 species of heterotrophic flagellates and more than 50 species of ciliates and sarcodines inhabiting the glass slides in different water-bodies (Zolotarev, 1985, 1988, 2007). The most widely distributed species at the initial stages of colonization of glass slides (pioneer species) were the attached colonial choanoflagellates. By undulating their flagella, choanoflagellates generate

local water currents to propel themselves through their aquatic environments and to collect bacteria and nanoparticles on the walls of their collars.
The feeding strategies of the protozoa were used to assign species to functional, trophic groups. The chief functional role of substrate-associated protozoans appears to be the processing of dead organic matter and its associated bacterial flora.
We have found three main functional groups of flagellates inhabiting glass slides:
- unicellular attached choanoflagellates, feeding by filtration, dominant in oligotrophic waters,
- colonial attached choanoflagellates, dominant in mesotrophic waters,
- vagile bodonids and euglenids, feeding by active hunting, dominant in polluted waters.

A new index of periphyton flagellates (IPF) as an indicator of the trophic status of a water-body was developed:
IPF = Sa/Sv
where Sa is the number of attached species, Sv is the number of vagile flagellate species. The index takes the greatest value in oligotrophic waters (1.0 - 3.0), decreasing in mesotrophic waters (0.3 - 1.0), and minimal in heavy polluted waters (0 - 0.3).

Periphyton biodiversity and relative abundance of ciliates and other protozoans can be used also as indicators of toxic pollution and acidification. Naturally derived periphyton communities were collected from the natural water-body and transported to the laboratory for use in designed experiments. Multivariate statistics were used to design the model of microbial communities development across a gradient of toxicant stress and organic compounds (Zolotarev, 2007).
So, microperiphyton communities can be very useful indicators of the water quality. Their ability to rapidly colonise artificial substrates, the cosmopolitan distribution and other advantages, provide an assessment capability not generally available for higher organisms.
Nanoflagellates are common and abundant in most natural and artificial periphyton communities and fulfil every trophic role from primary producer to carnivore. This relationship, together with rapid reproductive rate and their intimate contact with the environment, make them more useful monitors of aquatic environments than the more frequently studied macroinvertebrates and fish.

3. CONCLUSIONS

The necessity of having an effective international automated biomonitoring network for benchmarking anthropogenic changes in aquatic environments is rapidly growing alongside the development of global water crisis. We use methods for water quality assessment based on biodiversity of microbial organisms having cosmopolitan distribution, so the outputs of the project could be employed globally.
For the foreseeable future, with the development of online biosensors and implementation of information technology, a major application of microscale methods will be to predict, developing the new integrated standards, as a "Dow Jones" for water quality. Simplified methods for education and training (the "Microcosm" project and video library) are available. Several advantages of utilizing the new methods are discussed http://biomonitoring.narod.ru
As implications of the work, we developed some new methods (two patents) and suggest the project "Automated Biomonitoring International Network (ABIN) - integrated information system for benchmarking the health of aquatic ecosystems".
The main features of the project are:
design and implementation of information technologies for international monitoring networks (advancing monitoring technology),
global strategies (promoting interdisciplinary approaches for integrated transboundary water resources management),
modelling aquatic ecosystems (moving from monitoring to prediction), interdisciplinary educational resource.
New trend of IT development - online biosensors (peripheral equipment), or standard multispecies microscale "eco-sensors" (MES), using robotics for collecting data from automated monitoring stations.

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Origin of Salinity of Water Resources: Climatic and Anthropogenic Impacts (Western Morocco)

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Abstract

The southern part of the Rharb basin is represented by the Mamora basin. Thanks to its hydraulic potentialities, the Mamora groundwater supplies not only Rabat (the capital) and Kenitra cities, but also the economic city of Morocco: Casablanca, as well as industrial and agricultural sectors. Along with this heavy sollicitation, and like other basins belonging to the Atlantic margin of Morocco such as the Essaouira Basin (Laftouhi et al. 2003; Mennan et al., 2001), the Doukkala Basin (El Achheb, 2000) and the plain of Souss (Hsissou et al., 1999), the declining groundwater levels and rainfall fluctuations expose the water to salt pollution.

This work aims to monitor the spatial quality of hydrochemical groundwater and to understand the process of the mineralization in according to the saltwater intrusion, the hydraulic gradient and the water-aquifer interaction. Hydrochemical correlations which are realized in the coastal area showed contamination by seawater. The analysis and the interpretation wells highlights benches salt which may explain the mineralization of water in the zone far from the cost. The seawater intrusion and the identification of the Pre-Rifean complex were identified by the electrical and seismic methods.

Key words: hydrochemical evolution, saltwater, correlation, interaction, geophysics

1. INTRODUCTION

The Rharb–Mamora Basin is bounded in the east and north by the frontal ranges of the Rif Cordillera (Figure 1a), and to the west by the Atlantic coast. Hydrogeological investigations realized in the study area (Zouhri, 2002) revealed a heterogeneous permeable Plio-Quaternary facies mainly composed of sandstones, conglomerates, limestones and sandy clay more or less depending on location. The basement is composed by the Mio-Pliocene blue marls.

In order to study the origin of salinity of groundwater resources of this aquifer, the study area has been the subject of the hydrogeoloical, hydrochemical and geophysicals studies.

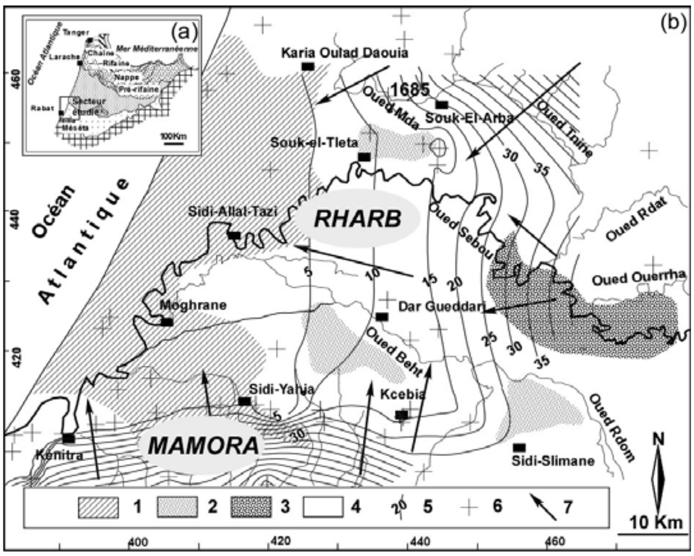

Fig. 1 (a) Location of structural domains in the north of Morocco**.** (b) Piezometry of the Rharb Basin and the alimentation zones (1. Levels sandstone and sandy clay, 2. Artesian groundwater, 3. Pebbles and gravels, 4. Sand and gravels, 5. Isopiez, 6. Samples, 7. Groundwater flow).

2. PIEZOMETRIC STUDY

The analysis and interpretation of the piezometric map showed two divinding limits: i) the first one in the west, which guides the direction of groundwater toward the northeast and north-west. The second one is located in the eastern part of the region of Sidi Yahia (Figure 1b) where the flow takes the same direction (north-east and north-west). In the western area, the groundwater flow toward the Atlantic Ocean. The groundwater flow is generally northward and westward. Comparisons between the groundwater level in the low water (1999 and 2000) have identified the drawdown of about 0.5 m. This reduction is related to the effect of drought years. The reversal of hydraulic gradient founded along the coast, over two kilometers of it are produced at the downstream drainage axes, which helps explain the existence of seawater intrusion.

3. HYDROCHEMICAL INVESTIGATION

The groundwater chemistry of the Mamora aquifer system has been studied in terms of the major ionic constituents Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, NO_3^{-}, and of the physical parameters (pH, electrical conductivity, *EC*, and temperature, *T*). The water intrusion has been studied by using the spatial distribution of the Cl/electrical Conductivity. In the western part, some wells are recorded an electrical conductivity about 1500 µS cm^{-1} and Chloride concentrations about 952 mg/L.

The description of the hydrochemical facies has been presented in the Piper diagram and show the dominance of two main facies: ($Ca+Mg-CO_3+HCO_3$) and (Na+K-Cl). The first facies is due to the presence of sand. The second could be coming from the seawater intrusion given the density of wells in the coastal zone.

3. GEOPHYSICAL AND SEISMIC APPROACHES

The electrical method has been used in order to delineate the interface salt/fresh water. The behavior of the advancing wedge of saltwater to the continent could be affected by the dip of the basement. The work in this area have revealed a tectonic block. The correlations in hydrogeological boreholes showed a deepening of Mio-Pliocene blue marls to the north-west (Zouhri, 2002). This extension is controlled by synsedimentary faults NW-SE and NE-SW. This advance is limited to less than one kilometer in the south of Mehdia where the basement has an average gradient of 2.5% to the ocean. The analysis and the interpretation of the seismic lines highlight the saline bench in the aquifer system of the Rhab Basin.

4. CONCLUSION

In the framework of the North-South collaboration, we will couple the geoelectrical informations with hydrochemical modelling and tracers investigations in order to understand the behaviour of the saltwater intrusion in the aquifer of the Rharb Basin.

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