United Nations Educational, Scientific and Cultural Organization

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ISARM2010 International Conference

TRANSBOUNDARY AQUIFERS

Challenges and new directions

Abstracts

6–8 December 2010
UNESCO, Paris

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Preface

It is my great pleasure to be able to present in this booklet the abstracts of the papers that constitute the technical programme of the International Conference on 'Transboundary Aquifers: Challenges and new directions' (ISARM2010), organized by UNESCO and its partners at UNESCO Headquarters in Paris, 6– 8 December 2010.

The UNESCO International Shared Aquifer Resources Management (ISARM) programme was launched in June 2000 at the 14th Session of the Intergovernmental Council of the UNESCO International Hydrological Programme (IHP). It is a multidisciplinary programme that works in close cooperation with IAH, FAO, UNECE, OAS, UN-ESCWA as well as with other international, regional and national institutions.

The timing of the Conference is crucial as it marks the end of Phase I of the ISARM Programme (2000-2010) and the start of Phase II. The first phase of the programme was dedicated to compiling a global inventory of Transboundary aquifers that has since been published by UNESCO-IHP (www.isarm.net/publications/324). The debates taking place during the Conference are expected to contribute towards the formulation of the second phase of ISARM as well as provide guidance to stakeholders in the management of these 'invisible', and yet essential, groundwater resources.

Within the framework of the UNESCO ISARM programme, UNESCO-IHP provided technical support to the United Nations International Law Commission (UNILC) for the preparation of the draft articles on the 'Law of Transboundary Aquifers'. The UN General Assembly (UNGA) adopted the Resolution (A/RES/63/124) on the 'Law of Transboundary Aquifers' in December 2008. By means of this resolution, the UNGA encourages the States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers, taking into account the provisions contained in the draft articles. Considering the importance of the UNGA Resolution and capitalizing on the growing body of inter-state experience related to the management and development of transboundary aquifers, the ISARM 2010 Conference aims to provide a platform for discussion to consider ways to promote cooperation amongst States in the management of transboundary aquifers.

The technical papers, as well as a report of the discussions and the recommendations of this Conference, will be published in the final proceedings following the event in early 2011.

As the programme officer responsible of the UNESCO-IHP Component on Groundwater Resources I would like to thank the co-conveners and partners of this Conference as well as all the participants for their valuable contribution and their recommendations.

Alice Aureli
Coordinator of the Scientific Committee – International Conference ISARM2010
Responsible for groundwater resources
UNESCO-IHP

Acknowledgements

This publication contains the abstracts of papers and posters, received from countries all across the world, to be presented during the UNESCO International Conference on Transboundary Aquifers (ISARM2010). We would therefore like to acknowledge the work of the Scientific Committee for their initial remarks and recommendations on the selection of these Conference papers.

We would like to express our gratitude to our co-convenors, UNESCO-IGCP, IAH and UNEP for their continued support in the preparation of this Conference. In addition, to the many organisations that have also collaborated with UNESCO-IHP, including, amongst others, GEF IW, UNECE, FAO, UNESCWA and OSS, and who, in some cases, also provided financial support.

Special thanks go to the Chairs and Rapporteurs of this event, for their time and commitment, notably to Ambassador Chusei Yamada, Professor Andras Szöllösi-Nagy and Professor Robert Varady.

This Conference was possible due to the work of the members of both the Organization Committee and the Conference Secretariat, and in particular due to the special dedication of Ms Marina Rubio and Ms Lucilla Minelli. The abstracts were edited by Ms Renate Heileman, Ms Lylia Khennache and Dr. José Luis Martin-Bordes. We also wish to thank Ms Lucilla Minelli and Ms Ros Wright for their proof reading skills.

Finally, to all the speakers and their affiliated organisations, we gratefully acknowledge their technical input; without their expertise this Conference could not hope to achieve its full potential.

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POSTERS

PLENARY SESSIONS
High Level Panel
ISARM Overview

Codification of International Law for Transboundary Aquifers by the United Nations

Chusei Yamada[1]

One of the important functions of the United Nations General Assembly is to codify international law in order to establish rules of law for the justice and order of the international community. The UN International Law Commission was established in 1947 as a subsidiary organ of the UN General Assembly whose mandate is to prepare the basic documents in the form of draft articles for such codification.

Around the turn of the century, the United Nations became aware of the rapidly expanding exploitation of groundwaters for portal, industrial and irrigation uses in both developed and developing countries and of the resulting critical overexploitation and pollution problems. Consequently, it instructed the Commission to proceed with the work in 2001. UNESCO mobilized a team of groundwater scientists, managers and water lawyers to assist the Commission. Taking into account the advice of experts and observations from governments, the Commission formulated a final set of 19 draft articles on the law of transboundary aquifers in 2008.

The UN General Assembly received the draft articles favourably and adopted the resolution by consensus which took note of the draft articles, encouraged the States concerned to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers, taking into account the provisions of the draft articles. Further to this, the UN General Assembly decided to include in the provisional agenda of its 66th session in 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.

The draft articles are based on the scientific evidence provided by experts and also on ample State practices as well as almost 400 relevant treaties - general, regional and bilateral. The States have shown keen interest in the draft articles as aquifers exist in almost all States and the overwhelming majority of them possess transboundary aquifers with their neighboring States.

It is hoped that the participants in the ISARM2010 Conference would render their valuable support to transform the draft articles into a formal convention in 2011 which would establish a legal framework for a proper management of transboundary aquifers in order to achieve the objectives of equitable and reasonable utilization of natural resources, protection of the environment and international cooperation.

Keywords: International Law for Transboundary Aquifers.

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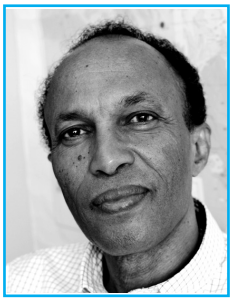
Shared Water Resources in the Western Asia* Region: An Inventory of Shared Aquifer Systems

Yusuf Al-Mooji[1] and Andreas Renck[2]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An overview survey of water resources availability in the ESCWA region** identified about 25 major water basins shared between at least two riparian countries. 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 neighboring 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 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.

Keywords: shared aquifer systems; riparian; cooperation; inventory; comprehensive report

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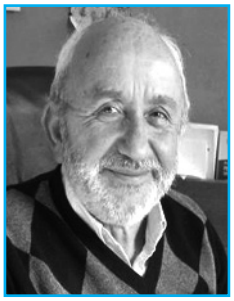
** Western Asia in this paper refers to the region comprised of Member States of the United Nations Economic and Social Commission for Western Asia (ESCWA) which lies entirely within the Arabian Plate, geologically speaking, and has a common geo-tectonic setting, physiography, and climatic conditions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

** ESCWA, Water Resources Database in the ESCWA Region, E/ESCWA/ENR/1992/4, April 1992.

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

J. Ganoulis[1], A. Aureli[2] and G. Stournaras[3]



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 also play a major role as vital sources of freshwater. Sixty-five 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 (INWEB)* at the Aristotle University of Thessaloniki, in cooperation with UNESCO/IHP, as part of the UNESCO/ISARM worldwide initiative.

TA in SEE, especially those that are karstic, are highly vulnerable to contamination from different 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 the 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. After completing the project preparation phase in December 2009, the FSP (Full Size Project) is expected to effectively start in 2010.

Keywords: transboundary aquifers, inventory, databases, South Eastern Europe.

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* UNESCO/INWEB, 2007: http://www.inweb.gr

Assessment of Transboundary Aquifers in the Context of Transboundary Basins in Europe, Caucasus and Central Asia: the UNECE Approach

Annukka Lipponen[1]

The key goals 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), are 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 that face the biggest challenges.

The first Assessment, 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.

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 all countries in the UNECE region. Moreover, the second Assessment is carried out in cooperation with a number of international organizations including UNEP, UNESCO, Regional Environment Centres, etc.

In this paper, preliminary results of the second Assessment in South-Eastern Europe, Eastern and Northern Europe, Caucasus and Central Asia are reported on, with focus on transboundary aquifers. In general, transboundary cooperation related to groundwater is low in the region and most 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. There is a constraint to assessing the status of transboundary aquifers in many parts of the region where recent groundwater monitoring data is very scarce or in some cases no monitoring activities are currently performed. This limits the identification of appropriate management responses, and groundwater being covered by different legislation from surface waters for historical reasons in many countries does not support integration. Cooperation between riparian countries in monitoring and assessment may provide an initial point for cooperation, and therefore joint characterization of groundwater bodies according to the requirements of European Union's Water Framework Directive is encouraging.

The groundwater part of the assessment is carried out in cooperation with UNESCO and the International Groundwater Resources Assessment Centre (IGRAC). IGRAC will have a key role in describing the major physical characteristics of the transboundary aquifers and delineating them.

Keywords: transboundary waters, assessment, monitoring.

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TOPIC 1
Global overview of transboundary aquifer systems

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

A. Alakbarov[1] and F. Imanov[2]


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There are 18 aquifers across the whole territory of the Republic of Azerbaijan, 14 of which are considered transboundary. The country shares five aquifers with Georgia, three aquifers with Armenia, seven aquifers with Iran, and two aquifers with Russia. However, some of these aquifers are shared by multiple states. Due to the downstream nature of Azerbaijan's terrain compared to that of neighboring countries, surface waters and some groundwater from Georgia and Armenia flow towards Azerbaijan.

Average long-term rates of surface run-off and potential groundwater sources are approximately 31 km^3 and 9 km^3, respectively. While over 70% of surface flow is formed beyond the borders of the country, a significant volume of transboundary groundwater is formed within the country.

In mountainous areas of the Greater Caucasus and the Lesser Caucasus, groundwater is basically found in the areas where weathering occurs and tectonic fault lines.

Piedmont and intermountain troughs are considered areas rich in fresh and low-mineralised groundwater. These troughs are formed by merged coarse-grained alluvial fans of rivers, effective thicknesses of which reach 300-500 m, and 1,000-1,500 m (though seldom). Yields observed at natural outflow points (springs) vary between 0.1-0.3 and 200-250 l/s. The wells drilled here produce groundwater in volumes ranging from 0.1 to 90-100 l/s. Depending on location, piesometric heads of pressurized groundwater are defined as below (0-3 m to 70-80 m) and above (1-3 m to 20-50 m) ground surface level. The lowlands of the Republic, composed of continental-marine and marine sediments, are characterized by unfavorable hydrogeological conditions.

There are no serious and critical problems between Azerbaijan and the neighboring countries with respect to the use of transboundary groundwaters. The main problem, however, is that the Kura and Araz rivers (and their tributaries), as the most significant recharge sources of groundwater, are heavily contaminated in the territories of Georgia and Armenia. Industrial and domestic wastes are discharged into the rivers in the territory of these countries almost without any treatment. In addition, these rivers and their tributaries are used for the disposal of irrigation waters contaminated with chemical infiltrates. Even in the territory of Azerbaijan, such contamination is enhanced by the discharge of various contaminants. Therefore, local contamination of transboundary groundwater is also a matter of concern.

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Groundwater in the occupied territories is also contaminated due to the fact that all wastewater from the towns of Khankendi and Askeran is discharged directly into the rivers, which serve to recharge groundwater at the foot of the mountains.

Natural transformation of river banks as a result of erosion and variation of river bed routes is occurring in the transboundary rivers of Araz (Iran) and Samur (Russia), though it is not reflected significantly in the conditions of the groundwater under the riverbeds.

Possibilities exist to mitigate the above problems. It would therefore be sensible to:

- organize and maintain independent monitoring of river and groundwater under supervision and direction of international organizations, such as UNESCO, IAH, IAHS, etc.;
- carry out a comprehensive study of the conditions of recharge and the chemical and biological content of groundwater sources considered as vulnerable due to the impact of contaminated rivers;
- prepare an action plan to restrict contamination processes;
- develop a scheme for the integrated use of water resources of aquifers;
- ensure compliance with the 1992 Helsinki Convention;
- take steps for technical modernization of water treatment plants and avoid disposal of untreated wastewater into rivers, at least in large cities and settlements;
- construct drainage facilities;
- erect facilities for the entrapment and neutralization of infiltrates in heavily contaminated irrigation waters.

Keywords: Aquifer, groundwater contamination, piezometric levels.

Transboundary Groundwater Sharing and Contamination

Karamat Ali [1]

It is a proven fact that water plays a pivotal role in the economic development of a country like Pakistan. There is no substitute for water; water is finite, has economic value and is vulnerable to misuse, overuse, pollution and poor management. Pakistan can be classified as one of the most arid countries in the world with an average annual rainfall of 240 mm. 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 the 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 aquifers with a total potential of 68 BCM of groundwater, mostly recharged through canal networks and partially through some limited structural arrangements. Eighty-one percent (81%) of 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 domestic use especially in areas where groundwater is brackish. In general, Pakistan is a water scarce country, has highly variable precipitation, 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. Transboundary aquifer mining and transboundary surface water pollution are factors that adversely affect both surface water and groundwater resources of Pakistan.

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

Pakistan faces the major issues of transboundary groundwater sharing and contamination because of the very liberal groundwater extraction policy with very subsidized electricity tariff for farmers of Eastern Punjab in India and the release of industrial effluents into the Ravi River that flows into Western Punjab in Pakistan. This not only causes the rapid decline of the groundwater table but also contaminates Pakistan's groundwater reserves.

This paper will thoroughly review the occurrence of transboundary groundwater, uses in both neighboring countries India and Pakistan, groundwater reserve health in Pakistan, factors causing the contamination and decline of groundwater resources, and possible suggestions to improve the situation without compromising relations with the neighboring country. The paper also suggests some measures to improve groundwater management on a sustainable basis.

Keywords: Transboundary Groundwater, Shared River Flows, Contaminating Groundwater, Health Hazard.

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GEOAQUIFER: A Practical International Consultation Exercise with the North-Western Sahara Aquifer System

African Development Bank/African Water Facility/Sahara and Sahel Observatory

This presentation highlights the main achievements of the GEOAQUIFER project, financed by the African Water Facility (AWF), and executed by the Sahara and Sahel Observatory (OSS), in cooperation with Algeria, Tunisia and Libya. GEOAQUIFER demonstrates the use of satellite images in a large transboundary basin: the North-Western Sahara Aquifer System (SASS).

Over time, studies have been conducted to assess the quantities of useable water in SASS. The accuracy of these assessments depends on several factors, e.g. the estimated quantity of water actually collected, good knowledge and information determine the objective, equitable and sustainable operation of the consultation mechanism established by the SASS riparian countries.

This objective is achieved through analyzing images produced by earth observation satellites, which provide precise and timely digital maps of the land use status including irrigated areas. The quantity of water used for irrigation can be deducted through analysis of the digital maps and calibration of these maps through ground surveys by the national water management agencies.

The joint activities of the project teams and stakeholders of the three countries have been exceptional opportunities for exchanging experiences, practical learning on joint decision-making, as such, allowing the strengthening of international cooperation around the North-Western Sahara Aquifer system.

Keywords: Aquifer, Sahara, Remote sensing, Consultation, Soil.

Preliminary Results of a Detailed Inventory of Transboundary Aquifers in Benin (West Africa)

F. Azonsi[1], A. Alassane[2] and M. Boukari[2]

Transboundary aquifers of Benin are inventoried in the framework of the UNESCO-ISARM project entitled "Inventory of Transboundary Aquifers in West Africa". The data and information collected through this project will help establish the database of the UNESCO-IGRAC Centre of transboundary aquifers in West Africa. They will also help develop a GIS inventory of transboundary aquifers of West Africa as a contribution to ISARM Africa. This inventory will help develop specific projects for cooperation. The identification of transboundary hydrogeological formations 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 continuous transboundary aquifers in two sedimentary basins: the coastal sedimentary basin in the South and the sedimentary basin of Kandi in the North-East. In the former basin, there are four aquifers that are shared with Togo in the West and Nigeria in the East. From the base to the top, there are: the Turonian-Coniacian (Upper Cretaceous) aquifer (sands and sandstones), the Paleocene aquifer (limestones and sands), the Continental Terminal aquifer (sands) and the Quaternary aquifer (the coastal and alluvial sands). In the latter 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). These inventoried aquifers have varied hydrodynamic types (free, captive or semi-captive) and are of varying quality (including facies and total load).

Keywords: Inventory, Coastal Sedimentary Basin, transboundary Aquifer, Primary, Upper Cretaceous, Paleocene, Quaternary.

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Challenges in Communication of Groundwater from Community to Policy Maker and Transboundary Aquifer Management in the SADC Region

P. Beetlestone[1], B. Lopi[1] and A. Tuinhof[1]

In the Southern African Development Community (SADC) over 70 percent of rural populations rely on groundwater for basic water provision and economic stability. In addition, multiple major population centres (> 70 million persons) as well as major sectors of several countries' economies are dependent on groundwater. As the SADC continues to develop, and hence its demands on water resources increase, it is faced with the challenge to secure water availability under changes in climate variability. Groundwater is touted as one of the key resources to address the economic goals and achieving the UN Millennium Development Goals (MDGs). However, even with this level of importance to human wellbeing and economic development, it appears to be low on the agenda when it comes to its management. Why is this? Is it because there is not enough data? Is there not an interest in the resource, or do we not have the human resource capacity? Or is it as technical practitioners that we are not successful in conveying the complex concept of groundwater to the stakeholders that matter: community, government institutions, policymakers and the private sector? Are we doing enough as practitioners to promote groundwater simply and coherently to the populations/stakeholders that matter? This presentation and paper will present several alternative options being employed in the SADC region to improve the effectiveness of communication on groundwater management to non-practitioners such as political decision makers, non-governmental organizations (NGOs), investors, parliamentarians, etc. The overall objective is to simplify the complexities of groundwater and the perceived difficulties in its management. Dealing with the communication amongst stakeholder, the presented options apply for management of groundwater on all levels, including transboundary aquifers (TBAs). Specific features of communication in the TBA context will be included.

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Karst Transboundary Aquifers: Challenges for Management

Ognjen Bonacci[1] and Tanja Roje-Bonacci[2]


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The karst has very different characteristics compared to all other environments; water circulation in karst is more heterogeneous than in non-karst areas and karst terrains show strong different hydrological and ecological characteristics compared to 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 (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 that serves as a basis 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 are very often 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. For this reason, water resources management for 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 the hydrological, hydrogeological and ecological regime in a very complex and not well known transboundary karst aquifer system of the Trebišnjica River. These changes could open serious problems in water management between two neighbouring countries that share 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.

Keywords: karst aquifer, karst catchment, interbasin overflow, karstology, Timavo karst spring.

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Cross-Border Resource and Good Neighbours: Cases of Joint Management of Fossil Groundwater in the South

Larbi Djabri[1], Azzedine Hani[2], Mohamed Cherif Djouamaa[3], Imen Guasmi[4], Saad Bouhsina[5], Jacques Mudry[6], Antonio Pulido Bosch[7]


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Algeria, a vast territory bordering seven countries, shares water resources with some of them such as Tunisia, Libya and Morocco. These resources are of two types: in the north, they are superficial and are formed by the waters of the wadi Medjerda in the East and the wadi Tafna to the West of the country; in the south, there is groundwater, made up of fossil water layers, shared with Tunisia and Libya

The waters in the north can only be considered interesting during rainy periods as water is carried to downstream dams such as Ain Dalia at Souk Ahras. At the wadi Medjerda in the East, the water flows from Algeria to Tunisia. To the west of the wadi Tafna, the water flows from Morocco to Algeria.

The waters enclosed by the Southern basin form an important reservoir whose volume reaches 50,000 billion m^3. While this resource must be managed carefully as it is not easily renewable, it is exploited by the three countries that share it. In addition, it is threatened by overexploitation – the extracted volume in 1970 was 0.6 billion m^3 whereas, at present, it is around 6 billion m^3. As a result, the Sahara Aquifer System (SAS), the resource's managing system, had to be established.

In Algeria, the exploitation of this resource began slowly. Today, the launch of various agricultural development plans has resulted in the creation of farmlands requiring large amounts of water.

Currently, the SAS is recognized and used by nearly 9,000 watering holes (drilled wells, springs and foggaras), 6,500 of which are in Algeria, 1,300 in Tunisia and 1,200 in Libya. If this exploitation is not controlled, it will cause various problems including increased water salinity and the decline of the water level (causing an increase in costs and prompting many farmers to drill deeper). In addition, natural outlets such as artesian wells and springs dry up (e.g. in Tolga where irrigation was spring fed). The interaction between different parts of the basin is sometimes important, for example, when there is often a change in the direction of flow. To avoid these constraints, the three countries should implement effective management of the resource.

Keywords: transboundary resource, SAS, CT, CI.

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A Case Study of Transboundary Aquifers in Yemen

M. Kalinin[1]

I would like to highlight the issue of water cycle variables in the management of the transboundary aquifers of the wadi Hadramaut (Saudi Arabia and Yemen). I tried to integrate 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 southern and eastern provinces of Yemen. The lack of regular scientific observation on the natural waters and absence of data in some of the areas is a prominent feature of the region. There are no permanent large rivers and water reservoirs in the region; only one small permanent water flow exists on the surface of wadi Hajar.

Surface water is formed only from atmospheric precipitation during the monsoon rains. A distinctive feature of the basin hydrology is the predominance of the water supply in the mountain region over the plain region. Flood water flows on the surface to the sea quickly then infiltrates the water-bearing strata. Temporary ground dams are constructed to increase irrigated areas. Water for agriculture and drinking is mainly extracted from underground.

Regular observations on subsurface water levels and its chemical content are not carried out in the provinces. Records on undergroundwater consumption for irrigation and other needs are not recorded. Indirect quantitative data on groundwater consumption is only collected in small areas.

I had estimated the stock of the undergroundwaters, used for drinking and agricultural purposes, in the investigated area. The operational stock was estimated by analytical and mathematic methods. The map developed on this data might allow the conduction of the reconnaissance of the undergroundwaters. It was stated that a sufficient amount of groundwater is located in the wadi Hadramaut as well as in the eastern part of the Ramlat-es-Sabatine desert (Saudi Arabia), where the estimated stock for the next 50 years is over 10 liters per km^2 per 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.

As previously stated, the surface waters are formed due to monsoonal precipitation. Floods occur once or twice a year. However, there are years when it rains up to 15 times or when there are only dry periods. During these dry periods, surface waters may not be formed for a couple of years and the river beds in the wadi remain dry. Rain floods of various intensities and duration are observed throughout the monsoon periods. Depending on the area of formation, the streamflows run either to the sea or to mountain cavities. They can also be trapped in the desert.

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The creation of underground reservoirs was suggested as a rational means of water consumption in arid territories. This means that an artificial mountain cavity would be used for the accumulation and operation of the underground waters and streamflows. The complex hydrogeological study, which was carried out in the mountain area, revealed 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 basis of data I collected. Natural stock of the underground waters is estimated in 350 km^3 in the wadi Hadramaut. The main part is located in sandstones while relatively small areas are in alluvial water-bearing strata – around 15 km^3.

Some issues in the territories of the Arabian Peninsula have yet to be studied and are as follows:

- The role of precipitation and condensation in the augmentation of transboundary aquifers of the arid territories Arabian Peninsula;

- Issues connected to fossil waters (transboundary aquifers) that are 7,000 - 20,000 years old;

- Sea-water intrusion of the water-bearing strata and the resulting danger of coastal water withdrawal (as groundwaters flow to the Red Sea and Indian Ocean). Issues connected to the interaction of sea-water and underground water in the costal areas of Yemen still needs to be resolved.

Keywords: arid territories, transboundary aquifers, underground reservoirs, irrigation, mathematic modeling.

The SADC Hydrogeological Map and Atlas: Towards a Seamless Understanding of Groundwater Regimes in Southern Africa

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The development and management of water resources in the Southern African Development Community (SADC) region has traditionally focused on surface water despite the fact that groundwater is the primary water source in most rural areas. In recognition of the increasing value of groundwater as a result of increasing aridity and limited surface water resources, the SADC Member States have embarked on a coordinated programme for the sustainable development and long-term security of groundwater resources within the region.

The preparation of a Regional Hydrogeological Map was identified as an early priority within the Regional Groundwater Management Programme as a means of increasing knowledge and understanding of regional groundwater systems and promoting cooperation in water resources planning, development, management and protection at international scale. The compilation of the SADC Hydrogeological Map has been undertaken through a consultancy, supported by the SADC member states and the Botswana Department of Geological Survey as the Project Implementation Agency, with financial support provided by The European Union and the German Government through GTZ.

The result is a comprehensive groundwater information system visualized by means of an interactive web based regional hydrogeological map and atlas. The SADC hydrogeology map is a general hydrogeological map. It provides information on the extent and geometry of regional aquifer systems, and is intended to serve as a base map for hydrogeologists and water resource planners, as well as presenting information to non-specialists. The map is a starting point for more detailed regional groundwater investigations by showing current data and knowledge gaps. Many aquifer systems in SADC, including transboundary aquifers, have low transmissivities and are relatively low yielding. As a result, what constitutes a transboundary aquifer or aquifer system requires further refinement in SADC, together with a consideration of appropriate policy responses. 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. The natural extent and hydrogeological significance of these systems will need thorough research and detailed field investigations.

Keywords: SADC, Southern Africa, Regional, Hydrogeological Map, Atlas, Groundwater, Aquifer Systems, Transboundary.

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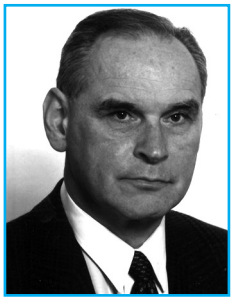
Exploration and Management of Deep Transboundary Pannonian Basin Aquifers in the Republic of Croatia and Surrounding Countries

Slobodan Kolbah[1]



Oil and gas exploration and production (O&G E&P) information in north Croatia creates an opportunity to delineate and characterize the deep water bodies of the Pannonian basin, or the Danube-river basin, where deep transboundary water bodies are shared between Croatia and the surrounding countries.

The aim 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 highlight their existence to the countries where the process of their delineation is in progress. In addition, there is need for greater open discussion of deep transboundary water bodies. This can be achieved by introducing knowledge of deep geology, here obtained by the process of O&G E&P, to point out strategic water reserves and water as a carrier of minerals 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 assists in the implementation of world standards in the area. Countries that have deep transboundary aquifers should assist each other in harmonizing national laws, rules and procedures and ensuring institutional capacity in fulfilling the planning, regulation, reporting and information requirements to match world standards. Multilateral collaboration of international experts meeting specific local experience and vice-versa is important in the delineation and characterization of these features, and in supporting the process with new knowledge and experience.

Delineation of deepwater bodies

Croatia is located in the south eastern area of the Pannonian basin, between the Alps, and the Carpathian and Dinaric mountain ranges. The basin water bodies are connected with reservoir rocks developed in the buried parts of the surrounding ranges of Hercinian and Mesozoic consolidation and Basin fill of Tertiary and Quaternary (mostly sedimentary carbonate and clastic rocks).

The most prolific waterbodies are available in reservoirs of fissured massive rocks, especially karst developed carbonates, and the 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 that of geothermal aquifers. The results of geological, geophysical, petrophysical and geochemical information from the O&G E&P process are an available base for the delineation of deepwater bodies.

Keywords: exploration and management, deep transboundary aquifers, Pannonian basin, fresh water, mineral water, geothermal water.

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Global information and Knowledge Sharing on Transboundary Aquifers

Neno Kukurić[1] and Cheryl van Kempen[2]
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During the last decade, with the increase of general awareness of the importance of groundwater, the issue of transboundary aquifers (TBAs) has also started to receive more attention from the international community. The initiatives of UNECE (to conduct the first inventory of TBAs in Europe), UNESCO & IAH (to set up an international program: International Shared Aquifer Resource Management (ISARM)), and the Global Environment Facility (GEF) (to include groundwater in its International Waters (IW) projects) were very instrumental in this process. In addition, various TBA inventories and assessments have been conducted worldwide, producing valuable information and knowledge about this complex issue.

This paper addresses the two following questions:

- Which part of information and knowledge on a particular transboundary aquifer could be of practical use to others (besides 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 its consistency, completeness and dissemination. The consistency is very much dependent on a methodological approach used in the inventory or assessment of aquifers. Thus, IGRAC has already proposed a common, consistent methodological approach, whereas GEF is working on further specification of its transboundary diagnostic analysis procedure.

General availability of GEF project information (especially project results) has improved since the introduction of the IW LEARN project sites. Compulsory Lessons Learned provide some insight into specific project experiences but certainly not all potentially useful information is readily available. Information on ISARM activities is available via the ISARM portal (www.isarm.net) maintained by IGRAC. The portal is linked to the Global Groundwater Information System (GGIS) that includes a GIS-based global overview of TBAs. Aquifer attribute values (e.g. quantity, quality, management measures) and sources of information (reports, maps, websites, organizations and specialists) are available as well.

Based on the overview, a thorough analysis is made, resulting in suggestions for more systematic and specific (relevant) dissemination of TBA information. Due attention is paid to implicit knowledge and people networks, as well as to contemporary technological means for information storage and dissemination (e.g. distributed information systems and information harvesting).

Keywords: transboundary aquifer assessment knowledge sharing.

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Toward a New Paradigm for the Great Artesian Basin: Hydrologic Mixing, Partitioned Sub-Basins, and Mantle Influences on Groundwater Quality

Andrew Love[1], Laura Crossey[2], Karl Karlstrom[3], Pauline Rousseau-Gueutin[4], Jennie Fluin[5], Paul Shand[6]

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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 important in its own right, the GAB is an iconic example of a continental-scale artesian groundwater system and of international scientific importance as sustainable groundwater management is emerging as one of the great global scientific challenges of the new millenium. New geochemical and hydrologic data suggest that existing models involving recharge in Eastern Australia, relatively simple flow paths, and discharge in springs and bores in the western GAB need modification. New geochemical data indicate a small- volume flux of deeply-derived (endogenic) fluids mixing into the aquifer system at continental scale. New hydrologic data indicate multiple sources of recharge. Thus, new conceptual models for the GAB need to incorporate: 1) hydrologic sub-basins with varying chemistry, flowpaths, and mixing implications, 2) the importance of faults as conduits and seals between sub-basins, and that serve as sources of endogenic fluid inputs, 3) characterization of endogenic inputs that include mantle-derived ^{3}He and CO_2, salts from deep brines, and metals that degrade water quality.

A testable new hypothesis is that endogenic fluids leak up faults into the J-K aquifer system from below causing mixing of fluids and degradation of water quality. Although numerous tracers are being applied, $^{3}He/^{4}He$ ratios are an unequivocal indication of mantle derived fluids. Helium consists of two isotopes: ^{3}He (dominantly of primordial origin) and ^{4}He (dominantly from radioactive decay of Th and U). In MORBs, the ratio of $^{3}He/^{4}He$ is uniform at ~8R_A; values in crustal fluids in stable cratonic areas approach 0.02 R_A, and anything greater than 0.1 R_A in non-airlike gases is evidence for mantle contributions (R_A is the atmospheric $^{3}He/^{4}He$ ratio of 1.4×10^{-6}). It has long been known that values up to R_A= 3 (Mount Gambier; 37% mantle helium) and 0.81 (eastern GAB, 10% mantle helium) are present in groundwater from eastern Australia. Preliminary $^{3}He/^{4}He$ data from mound springs in the western GAB also indicate mantle inputs. Warburton Spring has R_A= 0.16 (2% mantle helium); Bubbler Spring has R_A= 0.72 (9% mantle helium). Importantly, fluids rich in endogenic component are also rich in CO_2 (the carrier gas for the ^{3}He), Cl, metals, and radiogenic Sr. Carbonate-depositing

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groundwaters are a record of large volume CO_2 flux and thus provide a laboratory for evaluating fluid mixing and resulting degradation of water quality. The travertine (a.k.a. tufa) rock record in these same mound springs, likely extending back several million years, is an archive of GAB paleohydrology. Additional studies are underway to evaluate complexities of mixing models, variable flow rates, variable water quality, and tectonic influences in different sub-basins of the Great Artesian Basin at different time scales. 1) Hydrologic modeling will quantify recharge from western and northern sources, 2) $CO_2/^3He$ values can be used to resolve asthenospheric, lithospheric, and surface system CO_2 contributions, 3) hydrochemical modeling, stable isotope studies, and $^{87}Sr/^{86}Sr$ will elucidate contributions from radiogenic basement, 4) paleohydrology will be approached via modeling of changes in equipotential surface through time as constrained by U-Series dates from the travertine record, 5) neotectonic studies involve scales ranging from the mound springs fault line to the Australian plate. New understandings of the Great Artesian Basin will require holistic models that merge these hydrologic, geochemical, and tectonic perspectives.

Keywords: Great Artesian Basin, Conceptual Model, Helium hydrochemistry, Environmental isotopes, Hydrogeology.

Circum-Saharan Transboundary Aquifers: Inventory and Challenges for Management

Ahmed Mamou[1]

The circum-Saharan transboundary aquifers have a large structural configuration, with a thick sedimentation in a border of the crystalline basement cratons. These multilayer aquifers have an extension across the political boundaries of many circum-Saharan countries. They represent the major water resources of the area.

During the Pliocene and early Quaternary, the paleoclimate conditions contributed to have a good recharge of these aquifers who became big reservoirs. Most of these groundwater resources are non renewable. In recent years the increasing of exploitation has imbalanced the hydrodynamic equilibrium of these aquifers. In many cases, it has been noted the dropping of springs flow, the decrease of storage in the flowing wells, the degradation of water quality and the decrease of production of irrigated soils.

A sustainable management of these aquifer groundwater resources 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 (NWAS) 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 as well as in others cases such as the Illumeden Aquifer system (IAS) and the Nubian sand Stone Aquifer (NSA).

Keywords: Circum-Saharan, multilayer, non-renewable, management, consultation.

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Aquitards and Flow Connections in Palestine: Shared Aquifers Revisited

Clemens Messerschmid[1]

The equitable and reasonable sharing of transboundary groundwater resources stands at the centre of the ongoing Palestinian-Israeli conflict. Shared aquifers are considered here as a system of groundwater flows in permeable geological formations rather than merely the rock layers themselves. Hence the question of flow connections between different groundwater bearing strata, stratigraphically and geographically, stands at the centre of this investigation.

This paper draws on and presents exhaustive first hand experience and hydrogeological field data of aquifers underlying Palestinian territory in combination with literature and some original work on aquifers inside Israeli territory. It presents the nature and aquifer characteristics of formations commonly addressed as aquitards or aquicludes and focuses on the geographic extension of both rock formations and flow paths under and across existing political borders. By offering this enhanced understanding, the current system where aquifers are divided into discreet independent basins will be put to the test.

This novel concept approach will lead to a surprising find of the utmost importance with regard to the question of equitable and reasonable shares of existing groundwater resources between Palestinians and Israelis. In fact, it is the case that most of the groundwater flow systems and 'aquifers' in Israel/Palestine are actually interconnected and constitute common flow, recharge and discharge entities.

The paper concludes with some of the hydropolitical implications of this new conceptualization of the groundwater shared by Israelis and Palestinians applying International Water Law.

Keywords: shared transboundary aquifer, aquitard, aquiclude, groundwater flow connection, recharge, discharge, equitable and reasonable share, downstream riparian, upstream riparian, Israel, occupied Palestinian territories (oPt).

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The Silala/Siloli Watershed in Bolivia/Chile: Lessons from the Most Vulnerable Basin in South America

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The dispute over the relatively unknown Silala 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, or Siloli, begin as a wetland formed by groundwater springs that discharge onto the Bolivian *altiplano* (high plain) 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 captured by Río San Pedro de Inacaliri, which is currently used by Chilean copper mines and to supply potable water to nearby populations. Silala flows at a rate about a million times less than the Amazon River but in the Atacama Desert, the driest place on Earth, every drop counts. Silala is also considered a transboundary aquifer, but little is known about the underground flow. Preliminary evidence supports claims that the groundwater is 'fossil water,' principally recharged thousands of years ago by retreating glaciers.

In 1904, following the War of the Pacific, Bolivia lost its coast, and, in redrawing the borders, the Silala became an international watercourse. In 1908, the Prefecture of Potosí, Bolivia granted the Chilean 'Antofagasta-Bolivian Railway Company' a concession to construct canals in Bolivian territory and use the waters of Silala to fill its steam engines. This 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 exploit the waters.

It is difficult to imagine two countries with more polarized philosophies governing the management of their water resources. On one extreme is Chile, which embraced privatization with its 1981 Water Code, creating water markets and establishing transferable water use rights. 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-globalization movement. Yet Bolivians, to whom water is not for sale, seem to agree that

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Chile should pay for its use of Silala. How the neighbouring states reconcile their differences in water policy remains to be seen.

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 February, 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.

The Silala case provides an illuminating example from which to test the applicability of both the UNILC's Convention on the Law of the Non-Navigational Uses of International Watercourses and the Draft articles on the Law of Transboundary Aquifers. Moreover, it provides an opportunity to attempt to reconcile the two legal instruments with regard to the overlap between surface and groundwater regimes.

Keywords: Latin America, Bolivia, Chile, international water law, international groundwater law, water dispute.

Some Problems of Monitoring, Assessment and Management of Transboundary Aquifers

Oleg Podolny[1]

As Phase I of the ISARM (Internationally Shared Aquifer Resources Management) program comes to an end, fifteen transboundary aquifers have been defined in Kazakhstan. Now there is the possibility of producing results and problems with monitoring, assessment and management of transboundary aquifers, which will demand scientific decision, can be defined as follows:

1. Problem of scale of research: In Kazakhstan 15 transboundary aquifers have been allocated with reference to a mapping scale of 1:10,000,000. Such a quantity corresponds to the quantity of transboundary hydrogeological regions of 3-4 orders that are, in effect, groundwater basins. Designing a network of transboundary aquifer monitoring, even of the very first level - monitoring for early prevention - demands a larger mapping scale (1:500,000 and larger). Hydrogeological stratification should be constructed according to such a scale and should be more fractional. It will demand a more detailed description of transboundary aquifers and will separate layers in which points of an observation network of monitoring should be defined. The assessment and management should also be constructed according to such stratification.

2. Problem of area of transboundary aquifers: There is some uncertainty about the definition of 'the area of a transboundary aquifer'. A transboundary aquifer is one that exists on either side of a country border (i.e. one that traverses different political regions). For confined aquifers, this condition is fully satisfied, and withdrawal of groundwater from one country leads to transboundary issues. good example is groundwater extraction from the Preirtysh transboundary aquifer system, which is more than 400,000 $km^{2.}$ However, in the conditions of an unconfined aquifer, which has a large area and its existence area coincides with the area of recharge, transboundary problems do not exist. It reduces financial and other costs for research, monitoring, and evaluation and, as a result, the cost of management of such aquifers, considerably.

3. Risks of occurrence of transboundary problems: Concluding from the previous point, the problems of depletion and pollution of transboundary aquifers are not limited to transboundary issues and can be divided into two groups. Group 1: The transboundary water problems are of the qualitative and quantitative conditions of groundwater on sites of the transboundary river basin. The reason for the occurrence of such problems is the exploitation of aquifers in which groundwater is connected to the river, leading to the reduction of river flow, or pollution of groundwater on sites of the drainage basin, and filtration of these polluted waters into the transboundary river that leads to degradation of the quality of river waters. Group 2: Transboundary issues of quality and quantity of the transboundary groundwater resource. Resources and storage of groundwater are decreasing due to exploitation and other actions occurring on the other side of the border or the polluted groundwater flow is filtering through the boundary to other side. In this case, methods of integrated water resources management have some transboundary (interstate) specificity.

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

Keywords: transboundary aquifers; Republic of Kazakhstan; monitoring and assessment, transboundary groundwater problems.

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

Gerhard Schmidt[1] and Fernando Larroza [2]

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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^3, and lies underneath Argentina, Brazil, Paraguay and Uruguay. Growing industrialisation and urbanisation in the region have lead to rapidly increasing groundwater extraction rates and increased contamination of the resources.

Until 2009, the multinational project 'Environmental Protection and Sustainable Development of the Guaraní Aquifer System', a GEF/World Bank project executed by the Organisation of American States, supported the four countries in jointly elaborating and implementing a common institutional and technical framework for managing the Guaraní Aquifer System (SAG).

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 with meeting the requirements in the fields of hydrogeology and groundwater resources evaluation and prognosis. In this context, the SAG in Paraguay has been analysed and brought into a conceptual and numerical groundwater simulation model including the neighbouring zones of Argentina and Brazil.

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 directly neighbouring the Brazilian city of Ponta Porã. The twin municipalities form a bi-nationally characterised region with a good potential for future development.

The study area is predominantly used for agriculture (on the favoured lateritic soils of the basalts) and livestock rearing. The Brazilian part of the area is already dominated by farming at an industrial scale. The outcrop zone of the Guarani aquifer is only found in the western part of this area, the rest of it is covered by a variable thickness of volcanic basalt flows.

The majority of the water demand of the region is covered by groundwater extraction from the shallow aquifer system, which shows signs of environmental contamination, sometimes leading to the abandonment of wells in Pedro Juan Caballero. Due to the fact that almost no public sewage collecting system is installed within the entire area, general health problems occur occasionally.

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 integrated transboundary water resources management in a regional and bi-national context based on updated hydrogeological and socio-economic information.

Keywords: Guaraní Aquifer System, transboundary groundwater resources management and protection, conceptual and numerical modelling.

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Transboundary Water Resources of Lebanon: Monitoring and Assessment

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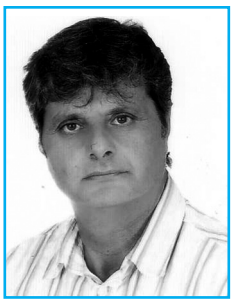

Lebanon, the Middle Eastern country with an area of about 10,400 km^2, is known for its plentiful water resources. It receives between 800 and 1,500 mm of precipitation and snow covers around 2,000 km^2; hence this small land area encompasses 15 permanent watercourses (rivers) and more than 2,000 major springs. In addition, there are a number of aquiferous formations and karstic galleries that 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 transboundary water resources are amongst the geo-environmental problems that affect these resources, the last being the major water problem in Lebanon today. More than 74% of Lebanon's border is shared with neighboring countries allowing surface and subsurface water from Lebanon to intermingle with that of the neighboring countries. As a result, no volumetric measures are known. There are two transboundary rivers between Lebanon and Syria in the north and one river with Israel to the South. Further, snow covers large areas of the Anti-Lebanon mountain range shared with Syria. Snow cover from Mount Hermon, part of the Anti-Lebanon chain, is 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 occur 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 the transboundary water resources of Lebanon, including quantitative measures and spatial delineations. This could be obtained through a systematic analysis of the shared hydrologic and hydrogeologic elements and thus conventional and recent tools and techniques.

Keywords: shared rivers, transboundary, geo-political, Lebanon.

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Ajloun and Golan – a Transboundary Groundwater Resource?

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The climate gradient from semi-arid to arid in the Levant is important for the generation of modern groundwater. Large groundwater aquifers occur all over the countries of Israel, Palestine and Jordan. Since precipitation decreases towards the south, the resources are only renewable in the northern parts of Israel and Jordan. Further, freshwater resources are overexploited in the entire region. The Golan Heights (Israel and Syria) and the Ajloun (Jordan) rank as the major extraction areas of groundwater of good quality and quantity. Both are separated by the tectonic gorge of the Yarmouk River, which forms the border between Jordan and Israel and, further eastwards, between Syria and Jordan. The gorge is assumed to be a hydraulic barrier.

Within the 'German-Israeli-Jordanian-Palestinian Joint Research Program for the Sustainable Utilisation of Aquifer Systems' and the multilateral Integrated Water Resources Management (IWRM) project SMART (Sustainable Management of Available Water Resources with Innovative Technologies), hundreds of water samples were taken from all over the Jordan-Dead Sea rift system to understand groundwater flow-systems and salinisation. 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 a radioisotope.

The REY distribution in groundwater is established during infiltration by the first water-rock interaction and consequently reflects the leachable components of sediments and rocks of the recharge areas. Stable isotopes of water $\delta^{2}H$ and $\delta^{18}O$ are less controlled by water-rock interaction than by climatic and geomorphological factors at the time of replenishment. Applying the REY signature as a grouping criterion of groundwaters, $\delta^{18}O$ *vs.* $\delta^{2}H$ plots yield a new dimension in interpreting isotope data.

The combined use of hydrochemical and isotopic methods enabled us to constrain the areas of replenishment and the flow-paths of the investigated groundwaters in both regions. Despite the location, salinity or temperature of spring or well waters, stable isotopes showed that the main area of recharge is the elevated Hermon-Massif and the plain area of southern Syria and northern Jordan, with high to medium amounts of annual precipitation. Flow paths of infiltrated groundwaters show partial occurring lateral flow across boundaries from Syria to Jordan and Israel.

By means of the investigated groundwaters we 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.

Keywords: REY, stable isotopes, inter-aquifer flow.

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Complex Hydrogeological Study of a Hungarian–Ukrainian Transboundary Aquifer

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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 cooperative 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 Hungarian participants gained a lot of experience from a NATO Science for Peace Project previously carried, which involved three scientific partners (Hungary, Romania and Belgium) and was carried out between 2000 and 2004 in order to undertake the complex hydrogeological investigation and groundwater modeling of a regional transboundary aquifer between Hungary and Romania.

To achieve the sustainable water management of the investigated transboundary aquifer, the main tasks of the 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 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 outputs, a common regional groundwater flow numerical model has been built and calibrated on historical data. It is already and will be in the future very useful for possible joint management of groundwater resources. The derived results allow a better evaluation of groundwater resources and a sustainable management of these resources. The targeted aquifer, which extends on both sides of the Ukrainian-Hungarian border for a 550 km^2 area, supplies drinking water to a population of about 120,000 inhabitants in both countries. The project focused on improving 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, new campaigns of field measurements were carried out focusing on two aspects: piezometric levels and pumping tests for hydrodynamic parameters. Priority was given to measurements in areas with low density of observation wells in order to ideally prepare all the data needed, allowing for 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.

Keywords: modeling, transboundary aquifer, water management, hydrogeology.

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

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TThe thermal groundwater of the Malmkarst (Upper Jurassic) in the 'Lower Bavarian and Upper Austrian Molasse Basin' is of transboundary nature and the only important deep aquifer in Lower Bavaria and Upper Austria according to the terms of the Water Framework Directive.

To avoid an overexploitation and to guarantee a sustainable use of the thermal water a detailed research work has been carried out. This study became necessary because of the increasing economical importance of thermal-water use in the concerned area on both sides of the German-Austrian border. Especially the use of thermal-water for spa and for hydrogeo-thermal purposes are of immediate importance.

From 1995 to 1998 a model for the thermal-water aquifer was developed in the framework of a German – Austrian cooperation. First a hydrogeological model was developed to describe the hydrogeological, geothermal and water management facts. Based on these facts, a conceptual model was 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 the framework of a 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 an ad hoc expert group was asked to elaborate joint protection and utilisation strategies and to lay down the results in guidelines.

Keywords: Groundwater Modelling, Groundwater Management, Geothermal Groundwater use.

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Transboundary Aquifers in Great Mekong River Basin

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Transboundary aquifers in Great Mekong River basins are located in the South-East part of Asia. These precious freshwater resources are shared among several countries, including China, Myanmar, Laos, Thailand, Cambodia, and Vietnam.

There are four transboundary aquifers in the basins. 1) The aquifer located downstream of the Lancang – Mekong River is an aquifer shared by China and Myanmar. 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. 2) The aquifer located midstream of the Mekong River is a transboundary aquifer shared by Thailand, Myanmar and Vietnam. The strata of the aquifer show continental classic sedimentary rocks of Jurassic, sandy conglomerate of middle and upper Cretaceous and the alluvial layer of Holocene. 3) The aquifer in Kele plateau is shared by Thailand and Laos and it is a porous and fissured aquifer. The strata consist mainly of Cretacic limestone, rhyolite, silexite and Holocene loose sediment. 4) The aquifer in the Mekong River delta is shared by Cambodia and Vietnam, extending from the Bian Dan Mountain in Cambodia to the Mekong River delta. It is a typical flood alluvial basin, of which the east part is located in the Changshan Mountain in Vietnam, the west in the Oula Mountain, and the north in the Biandan Mountain. The most important freshwater aquifer is a confined aquifer.

Transboundary aquifers in the Mekong River basin

No.	*Designation*	*Countries sharing*	*Area (km^2)*	*Type of aquifer*
1	Aquifer downstream of the Lancang River	China, Myanmar	39,508.50	Massive rock, single formation, fissured aquifer
2	Aquifer in the mid of the Mekong River	Thailand, Laos	106,815.75	Double layer porous and fissured aquifer
3	Aquifer in the Kele plateau	Thailand, Laos	95,510.50	Multilayer structures fissured aquifer
4	Aquifer in the Mekong River delta	Cambodia, Vietnam	223,422.50	Loose sediment, multilayer structure, porous aquifer

Water resources in the Lancang River-Mekong River basin are abundant, but the surface water distribution is irregular both in time and space. The groundwater resources in the basin can be found in: plains, basins, plateaus and mountains. The development and utilization of groundwater in the region has a long history. In drought inland areas, groundwater is mainly used for irrigation and drinking purposes. In major cities, such as in Phnom Penh and some cities in Vietnam, the exploitation of groundwater is mainly for urban water supply.

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The main impacts on the environment caused by excessive exploitation of groundwater are the continued depletion of regional groundwater levels and land subsidence. The development and utilization of internationally shared groundwater resources meet the needs of the countries for freshwater. At the same time, they also allow to maintain the ecosystem balance of international rivers, which is not only a regional issue for cooperation, but also international. International organizations, research institutions and many non-governmental organizations should be involved in the cooperation mechanisms. Water experts regularly call for the improvement of an effective water-saving social awareness, for the protection of groundwater resources and shared aquifer resources.. Countries in the region should strengthen cooperation, exchange and research on cross-border aquifers, in view of a better coordination and joint management of groundwater resources in order to provide the scientific basis to achieve the sustainable use of water resources.

Socio-economic and economic governance indicators need to be considered for the four transboundary Aquifers in great Mekong River basin. Using the DPSIR framework and sub-indexes, these aquifers could be categorized in three grades: Most sensitive-inconsistent, more sensitive-lesser harmonious and less sensitive-harmonious.

Keywords: Great Mekong River, Transboundary aquifers, Environmental issues, Indicators.

Investigation of Transboundary Aquifers in Russia: Modern State and Main Tasks

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

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 of both internal and external types. Among the internal criteria are limitations of hydrogeological and hydrodynamic operation conditions such as groundwater recharge rate, tolerance of the dynamic level lowering throughout the estimated period, and the risk of non-standard groundwater drawing up to a water well field. The external criteria that can restrict groundwater use are related to possible impacts of planned water extraction on different environmental components including river runoff, suppression or death of vegetation due to excessive lowering of shallow groundwater level in the upper unconfined aquifer, activation of karst and suffusion processes, earth surface subsidence, etc.

The main tasks of hydrogeological investigations are as follows:

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

Specific examples of transboundary groundwater use perspective assessment, particularly for adjacent regions of Russia, are presented.

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

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Characterisation of a Transboundary Karst Aquifer: the Classical Karst

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In the hydrogeological sense, the Classical Karst aquifer is a uniform unit, but politically it is divided between two countries. The main part of the aquifer is located in Slovenia, but the whole karst coast and springs area are located in Italy. To understand how it functions and to protect it properly, close co-operation between experts from both countries is necessary.

Classical Karst is a limestone plateau of 900 km^2, and extends from the SE of the Isonzo River to the town of Postumia across the Slovene-Italian border. To understand the functioning of the transboundary karst system, much research was carried out with close co-operation between Italian and Slovene researchers. One of the important goals was the protection of this karst aquifer in which large quantities of groundwater are stored. The Timavo River springs and their feeding area are one of the highest-discharge regions in the Mediterranean (medium discharge of 40 m^3/s, maximum of 175 m^3/s). In the Slovene part of this area, there is a pumping station for the water supply of many municipalities. In Italy, the Sardos spring is still used for the water supply of the town of Trieste.

Spring hydrodynamics and chemical characteristics are well known, but there is not much information about autogenic and allogenic recharge waters and only little data about hydrodynamic behavior within the hydro-structure. In fact, hypogean karst phenomena spatial development is very unpredictable. Karst voids organization is driven by several aspects like geological and structural settings, climate characteristics, geomorphological context, etc., but even so, it is difficult to model the groundwater circulation and to define underground karstification development and karst voids connection especially in a mature karst.

Keywords: hydrogeology, karst aquifer, karst waters management, transboundary groundwater monitoring, Classical Karst.

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TOPIC 2
Managing transboundary aquifers: challenges and opportunities

Sustainable Development of Non-Renewable Transboundary Groundwater: Strategic Alternatives for the Nubian Sandstone Aquifer System

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The sustainable development of a resource that will surely be depleted is an extremely challenging process. In this case, sustainable development refers to prolonging the use of such a 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 non-renewable groundwater resources may entail that what is left today will not necessarily be saved for future generations, 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 what may be considered sustainable strategies for the utilization of the NSAS in Egypt. This study focuses on all four riparian countries and scenarios will be drawn based on their developmental needs. 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 for non-renewable groundwater use; it could be the only sector using abstracted fossil groundwater. Other sectors can rely on the resulting treated waste water, which appears to be the most affordable option for NSAS countries. 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 the NSAS will clearly identify its life expectancy and, accordingly, the maximum yearly drawdown. Alternative plans on utilizing other water resources such as seawater desalination may 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.

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Sustainability of Water Resources Management in the Gaza Strip, Palestine

Mohammed Ahmed[1]

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 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 intrusion and the up coming 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 to 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 a 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's lives in Gaza.

Keywords: water demand, resources management, desalination, water supply.

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Getting Riparian States to Co-operate in Transboundary Groundwater Management: Challenges and Opportunities to Water Security

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Riparian ecosystems, with their rich flora and fauna, are critical to the sustainable management of groundwater resources as much as groundwater resources are critical to the sustainable management of riparian ecosystems. Interdependence of these resources is even more crucial in the face of continuous global environmental change where subtle, but somewhat permanent, variations in the hydrological and hydraulic cycles are not readily detected. Characteristics of riparian ecosystems are as good an indicator of the quality and quantity of groundwater as the health status of riparian ecosystems.

Nonetheless, the management of riparian ecosystems is characterized by conflicts as much as the obscured groundwater, threatening the indicative ability of these resources. The conflict gets even bigger and more complicated as riparian ecosystems traverse political boundaries.

To surmount these managerial conflicts, water experts worldwide suggested several management approaches that can be broadly categorized under co-operative, non-cooperative and myopic. Most sustainable, practical and popular among them is the co-operative management approach, which involves a single comprehensive plan to manage transboundary groundwater.

However, there are issues with the co-operative management approach that arise as a result of social, economic, cultural, ecological and technical differences from one user (right owner) to the other within and across a boundary. These issues can either be viewed as challenges or opportunities. Thus, this paper looks at the challenges or opportunities associated with the co-operative approach for transboundary groundwater management. Further, it seeks to prescribe the best way forward.

Keywords: watershed, conflict, cooperative, way forward.

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SADC GEF Groundwater and Drought Management Project - Tools Developed for Transboundary Aquifer Management

Philip Beetlestone[1], Albert Tuinhof[1] and Phera Ramoeli[1]

The Southern African Development Community (SADC) has, over the last four years, been implementing the Global Environmental Facility (GEF) SADC Groundwater and Drought Management Project within its Regional Strategic Action Plan on Integrated Water Resources Development and Management (1998). The objectives of the project were to move SADC's regional Groundwater Management Programme (1999) forward and, more specifically, to focus on *"the development of consensus on a SADC regional strategic approach to support and enhance the capacity of its member states in the definition of drought management policies, specifically in relation to the role, availability (magnitude and recharge) and supply potential of groundwater resources."*

This would be accomplished by groundwater focused information exchange, research and training, monitoring, mapping, and characterisation and development of a transboundary groundwater resources management framework. This presentation follows up on previous presentations at the ISARM Conferences held in Tripoli in 2002 and 2008 and highlights the outputs and tools developed within the Project to assist the SADC Member States with national and transboundary aquifer management into the future. In addition, mechanisms for sustaining the Project's outputs, which aim to assist in maintaining the momentum for managing regional groundwater resources that have been supported by the implementation of the Project, are highlighted.

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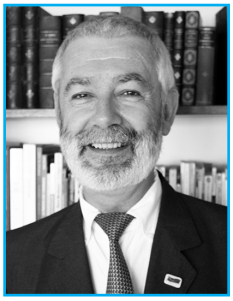
The Guarani Aquifer and Its Systems: About Rules Profusion and Implementation Scarcity for Aquifer Water Resources

C.G. Caubet[1]



The Guarani Aquifer is one of the largest groundwater reservoirs on the planet. It is located under the territories of four South American countries: Argentina, Brazil, Paraguay and Uruguay. This abstract underlines dimensions of the legal problems of the Aquifer: 1) the legal frame for groundwaters is far from able to give effective guaranties for 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 the La Plata River Basin, or drafted in regional contacts; 2) the conviction that safe reserves for the future exist in the Aquifer leads certain executive branches of both governmental and private corporations to misunderstand and disregard decisions concerning the effective protection of surface waters in real public policies (why do we need to carefully use surface water today, if we have large quantities already saved for tomorrow?). If any use of an aquifer is decided, immediate action needs to be taken in order to preserve surface waters simply because, in future, when people start looking to groundwater to supply all human necessities, surface waters are already in such bad conditions that they are rendered totally or partially useless.

Existing legal providences require detailed analysis to know whether comprehensive regimes are effectively preventing irrational uses of groundwater or tolerating, through inadequate management of public decisions, their progressive and non-return consumption and pollution. A *both ends* legal methodology must, on one hand, consider 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. Constant monitoring of the state of the water has to provide feedback to legal rules and lead to planned results.

As a check and balance of actual practices in the four Guarani Aquifer countries, it can be stated that groundwaters have national regimes and lack an integrated previous vision and field application of the rules of law. Some priority was and still is given to the consumptive uses and users. Very little was done to prevent pollution in the past, create common concern, ban harms and risks, and include the application of effective penalties.

The Guarani Aquifer is not a groundwater tank. It is a disrupted chain of eventual opportunities of obtaining freshwater in many places. Once its water has been used, there is the possibility for surface waters to occupy and contaminate the reservoir, or to facilitate contamination by acting as a vector of percolation. An *International Clean Water Act* is not sufficient by itself if it lacks prevention and implementation and therefore control of public policies. Common actions in the boarder areas could be of more effect than signing a treaty without practice goals and common concern. A good ground and starting point for international cooperation could be the common identification of the identical national rules in all the States sharing the same aquifer.

Keywords: International Groundwaters Regime. Regional Rules for Guarani Aquifer.

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Reviewing the Criteria for the Sustainable Management of the Carboniferous Limestone Aquifer

Dirk De Smet[1]

Vlaamse Maatschappij voor Watervoorziening (VMW) supplies water in the northern, Flemish part of Belgium. Water basin management is a regional matter in Belgium. Therefore the Carboniferous Limestone aquifer is not only situated on the Belgium-France border but also on the internal Flemish-Wallonia border. In Western Belgium, qualitative good groundwater is poor due mainly to the occurrence of a 100 m thick clay layer at shallow depth and natural salinization near the coast. The Carboniferous Limestone, which occurs in the southwest of Belgium, 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 Carboniferous Limestone is composed by strongly fissured and karstified limestones and dolomites. A layer of fine sands (Wealdien) often occurs on top. Those sands have seeped entirely or partially into the fissured rock. The aquifer is covered on top by cretaceous, clay and marly sediments north of the 'Gaurain - Ramecroit Fault'. South of the fault, the aquifer is phreatic. VMW abstracts water from the confined northern part. Very high capacities per well are regular; 250 m^3 on an hourly basis is no exception.

The intensive use combined with poor feeding induced a continuous water level decrease 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 in Kain, near Tournai, in a wet period after an extremely hot and dry summer. Water from the river invaded the aquifer, causing a sudden rise in level. This temporarily had a very negative impact on the water quality in several production wells when the rising water washed the oxidized Wealdien Sand. Very high concentrations of iron, manganese, sulfate, chalk and heavy metals caused major problems for the purification process and for meeting drinking water standards.

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 demand for the industry 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', there has been a strong increase in water levels (> 1.5 m/year). As after the Kain-incident, a strong negative influence on water quality in different wells and on aquifer level now occurs.

A revision of 'the Transhennuyère agreement' will probably be necessary on short terms to get water level and quality under control. In longer terms it is expected that, within the International Commission of the Scheldt, French and Belgians can cooperate to reach a proactive and sustainable management for the aquifer. The modeling study within the Interregproject 'Scaldwin' can be an important trigger. This case study shows that the accomplishment of a sound balance between piezometric level, quality and abstraction should be the target of the aquifer management and not pure abstraction-tied criteria. Protecting the quality of this strategic reserve is vital in view for the constraints of phreatic and surface catchments in a period of fast climate change and ambitious ecologic objectives.

Keywords: transboundary aquifer, drinking water supply, quality detoriation.

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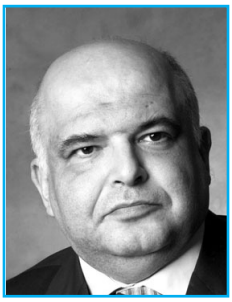
Solutions for Groundwater Management in Areas Affected by High Arsenic Content: Vojvodina Case Study*

Milan Dimkic[1], Dusan Djuric[2], Jovan Josipovic[3] and Goran Jevtic[4]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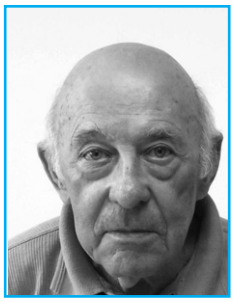
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On the territory of Vojvodina (Serbia), water supply is predominantly based on the abstraction of groundwater from the so called "main" aquifer in the southern part of the Neogene Pannonian Basin shared with Hungary, Romania and Croatia. Over-exploitation of groundwater in the past and insufficient groundwater recharge resulted in aquifer depletion and the lowering of groundwater levels, with the prospect of continuing this trend. Along with insufficient groundwater quantity, poor groundwater quality has become a growing problem for 339 waterworks existing in Vojvodina. Quality parameters such as natural organic matter, ammonia, methane, boron, along with natural high arsenic content (in some parts higher than 150 µg/l) in the groundwater, have become a serious threat to the health of the local population (DKMT, 2006). To treat this groundwater, a complex technology is required (aeration, flocculation/sedimentation, ozonation, multilayer filtration and disinfection, in some cases reverse osmosis) (Stauder, 2007).

In order to restore the balance in sharing groundwater between the environment and water users, i.e. to set a solid background for sustainable utilization, management and protection of the internationally shared aquifer, and the opening of new renewable groundwater sources in the Danube and Sava alluvium are foreseen. Field investigations and hydrodynamic analyses (NPV46B, 2006) showed that sufficient quantities of groundwater can be provided from the Danube alluvium (the Apatin-Bezdan and Kovin-Dubovac areas), and that the water quality is such that application of basic treatment methods (aeration, retention, filtration and disinfection) will produce high-quality drinking water.

Addressing current water supply issues in Vojvodina through the construction of regional water supply systems that rely on riverside water sources would have several positive effects. In addition to providing sufficient quantities of good-quality drinking water, these systems would allow for the 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.

Keywords: arsenic, alluvium, depletion, drinking water, Vojvodina.

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Towards the Concerted Management of Hydrogeological Risks in the Iullemeden Aquifer System (IAS)

Abdelkader Dodo[1]

The Iullemeden Aquifer System (SAI) constitutes a strategic water resource for the sustainable development of Mali, Niger and Nigeria. However, the SAI is:

- *exposed to a fragile and constraining environment*: (1) reduction of rainfall by 20 to 30% since 1968; 2) reduction of the Niger River flows by 20 to 50%, sometimes with severe low water levels causing the flow to stop; (3) silting and establishment of sand dunes in the recharge areas of the aquifers and in the hydrographic network of the Niger River;

- *confronted with multiple constraints, particularly*: (1) difficulties accessing the groundwater resource in some places due to excessive depth (more than 600 meters); (2) degradation of water quality (pollution, pumping very mineralised groundwater); (3) shortcomings on concerted groundwater management among riparian countries.

- *subjected to:* (1) increasing water demand linked to a growing population (about 6 million inhabitants in 1970, 15 million in 2000, 30 million inhabitants in 2025); (2) increasing water abstractions (about 50 million m^3 in 1970 to 180 million m^3 in 2004).

To identify, analyze and evaluate the transboundary risks that can affect groundwater of the Iullemeden Aquifer System, the GEF TDA process for International Waters (OP9) (Transboundary Diagnostic Analysis) was applied. It is the first case in Africa, and the second in the world after the Guarani Aquifer System in Latin America. The GEF process is based on the results and outputs obtained from the development of management tools (Database, Geographic Information System, Mathematical model and Remote Sensing).

For concerted and sustainable management of their common water resources, in order to support the data and information exchange, and to alert the potential Users of these risks, Mali, Niger and Nigeria adopted a Draft-agreement for the establishment of a legal framework.

Keywords: Shared aquifers, Transboundary risks, Transboundary Diagnostic Analysis, Management tools, Legal framework, concerted Management, West Africa.

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The Hydrochemical Characteristics and Evolution of Surface- and Ground- Waters in the Western Part of the River Nile, El Minia District, Egypt

M. El Kashouty[1] and E. El Sayed[2]

A combination of major and trace elements have been used to characterize surface water and groundwater in the El Minia district, Egypt. Surface water versus groundwater chemistry data enabled geographical zones and chemical types to be differentiated. The main objectives of this research were to investigate groundwater quality and to carry out a hydrochemical evaluation. Conventional methods and multivariate techniques were applied to achieve these goals. The situation is further complicated by contamination with lithogenic and anthropogenic (agricultural and sewage wastewaters) sources as well as low plan exploitation techniques. The Pleistocene aquifer, which is composed of sand and gravel of different sizes with some clay intercalation, was the subject of this investigation. The semi-confined condition around the River Nile shifts to unconfined outside the floodplain. The groundwater flow is generally from south to north and diverts towards the east where large amounts of groundwater are drained into the River Nile.

Fifty-six, 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 the Al Moheet drain are higher than those in the River Nile and the Ibrahimia canal. Chromium (Cr), Mercury (Hg), Arsenic (As), and Cadmium (Cd) concentrations in the River Nile and Ibrahimia canal fluctuated above and below the World Health Organisation (WHO) drinking standards. Selenium (Se) concentrations in the River Nile and Ibrahimia canal are below WHO drinking and irrigation guidelines. The total dissolved solid concentration in groundwater is generally low but has increased in the western part of the study area. The geographic position of the River Nile, Ibrahimia canal, and Al Moheet drain has an impact on groundwater quality. The PHREEQC (a computer program) results confirm high mixing proportions from the River Nile into the groundwater and a decline away from it. In addition to the thicknesses of the Pleistocene aquifer, an aquitard layer enhances the River Nile and agricultural wastewaters intrusion into the aquifer system. The toxic metal concentrations [Lead (Pb), Cd, Cr, Phosphate (PO_4), Se, Manganese (Mn), As, Hg, Nickel (Ni), Aluminum (Al), Iron (Fe), and Silica (SiO_2)] in groundwater were increased mainly in the northwestern and southeastern part (far from the River Nile). It is attributed to a high vulnerability rate (unconfined), and anthropogenic and partially lithogenic factors.

Four factors control the overall mineralization and water quality of the aquifer system. The 1st factor represents the recharge from the surface waters and agricultural wastewater, while the 2nd factor includes the fertilizers and manures. The 3rd factor corresponds to the lithogenic impact, whereas the 4th factor is composed of a Fe-Mn oxyhydroxide phase. The dendrogram analysis revealed 2 clusters that were subdivided into 4 groups. The areal distribution of these groups matches the geographic position of the River Nile and anthropogenic sources. The study highlights the description capabilities of conventional and multivariate techniques as effective tools in groundwater quality evaluation. Most groundwater is unsuitable for drinking and irrigation purposes with respect to Se concentrations, while they are unsuitable for drinking according to Mn, As, and Hg contents. There are some Cd and Pb anomaly concentrations, which cause severe restriction if used in irrigation. The results suggested that significant changes are urgently needed in water use strategy to achieve sustainable development.

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Guarani Aquifer System Project: Strengths and Weaknesses of its Implementation *

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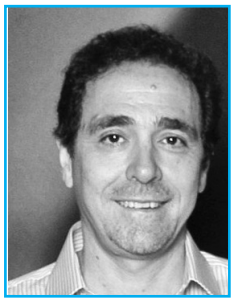
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Between March 2001 and January 2009 and with a budget close to U$D 27,000,000, the Project for Environmental Protection and Sustainable Development of the Guarani Aquifer System (GASP), was implemented by Argentina, Brazil, Paraguay and Uruguay. These 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 countries involved had an impact that went beyond the scientific-academic domain. Thus, the project aroused the interest of the general society, motivating analysis, debate and sometimes questioning the process of implementation.

Taking the significance of the project and its pioneering nature in the field of cross-border groundwater of regional magnitude into account, the relevant aspects of the implementation of GASP in Argentina were analyzed as "*lessons learnt*", pointing out the strengths and weaknesses of its implementation.

Among other relevant matters, it strikes as evident that the 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 the Government.

It has also been demonstrated that long-standing projects of ambitious targets, dependent on top-level political decisions, are affected by government rotations. Therefore, it would be desirable to undertake initiatives of smaller reach, with more austere but attainable objectives, that include a smaller run time in order to avoid or to mitigate these situations.

With the experience that "the urgent prevails on what is important", it is understood that: The end of international financing and the "preventive" character of the project constitute risk factors for continuity and for the realization of the objectives originally raised. In terms of optimization, we should achieve a constant coverage to avoid interruption and/or postponement of objectives, for urgent matters and urgent response.

Keywords: Cross-border groundwater, Guarani Project, Lessons learnt

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Note: The concepts expressed in the document do not constitute an official position of the Republic of Argentina; they display the personal opinion of the authors who have taken an active participation in the project.

A Hydro(Geo)Logical Model for the Holocene History of the South-Western Part of the Nubian Sandstone Aquifer System Using Climate Model Scenarios and Analyses from Lake Yoa (Chad) Sediments: Best Scenario, Evaluation of Uncertainties and Elements of Calibration

Christophe Grenier[1], Weipeng Zheng[1,2], Gerhard Krinner[3], Marie-Alice Harel[1], JulietteAnglade[1], Pascale Braconnot[1], Anne-Marie Lézine[1], Philippe Paillou[4]

The Nubian Sandstone Aquifer System (NSAS) is one of the largest African Aquifer systems, spreading over four countries (Chad, Sudan, Egypt, Libya). Its large extensions (roughly 2 million km and maximum depth of 4,000 m provide very large water reserves. Several hydrogeological models were developed to account for the slow transitory evolution of its water levels and to study the impact of various pumping strategies aiming at exploiting its water resources.

The present study focuses on the SW part of the NSAS, roughly the region in Chad. It brings together (i) climate proxy analysis and reconstruction from Lake Yoa sediments (Ounianga lakes in NE Chad, sustained in the hyper arid environment by groundwater inputs from the NSAS) , (ii) recent climate model simulations (IPSL coupled ocean-atmosphere model and zoomed version of the atmospheric component of the coupled model - LMDz), and (iii) a surface model of the Lake Yoa water catchment and a groundwater model of the SW part of the NSAS.

The main objectives of this paper are to (i) present the hydro(geo)logical models and the simulation results (including the evolution of groundwater reserves following recharge and discharge history), (ii) address the uncertainties resulting from the low level of information contained in the dataset (mainly climate forcing for rainfall, evaporation and recharge histories; hydrological parameters; geological units geometry and hydrological properties), (iii) analyse the constraining power of hydrological information associated with the lake history (lake level and salinity evolution) and current aquifer conditions (measured heads).

The hydrological and hydrogeological models were developed within the Cast3M model (www-cast3m.cea.fr). The hydrological model uses topographic analyses and radar pictures to identify Lake Yoa water catchment properties (area, former flow network, presence of lakes and their geometrical properties, partly from to build a hydrological model. A groundwater model simulates the evolution of underground water levels (Boussine sq equations) and provides groundwater inputs to the modelled lakes (Lake Yoa, Ounianga Serir and 8 other topographical depressions analysed as former lakes).

Keywords: NSAS, Chad, hydrological model, climate proxy.

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Concepts for Transboundary Groundwater Management in a Region of Extensive Groundwater Use and Numerous Contaminated Sites

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The aquifer of the Basel region is located in northwestern Switzerland and extends to both Germany and France. Since Basel developed into a major center for the chemical and pharmaceutical industry in the 19th century, vast areas in the region of Basel 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 territories that 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. 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. The second case study illustrates long-term changes to a groundwater body due to changed hydraulic boundary conditions as a consequence of (A) the construction of a hydropower plant in the Rhine and changed hydraulic gradients, as well as (B) the development of a municipal water supply in the mid 19th century. Whereas the first case study illustrates short-term impacts, the second case study shows the influence of changes in groundwater flow regimes on the regional distribution of contaminants. Both case studies show that river-groundwater interaction along the Rhine is an important element of the regional groundwater flow regime. Depending on the hydrological constraints, the river acts both as a loosing and gaining stream.

It 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. Furthermore, these areas may suddenly 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 to 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 for the evaluation of the impacts of planned changes at an early stage and the development of suitable groundwater management systems.

Keywords urban groundwater management; contaminated sites, management concepts.

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The Water Paradox: Is There a Sharing crisis?

M. Kamruzzaman[1], S. Beecham[2], G. M Zuppi[3] and D. Mulcahy[4]


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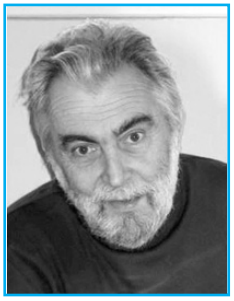
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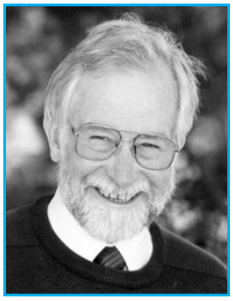
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Water resources management has undergone significant change since the beginning of human civilization. This study investigates water sharing and the nature of the Dam "Farakka Barrage" in the Ganges basin area that has led to conflict between the Ganges 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 1996 historical treaty covering 30 years. Our study found that a deadlock prevailed between Bangladesh and India during dry seasons. The 1996 water sharing treaty adopted Article IV of the 1966 Helsinki Rules and granted 35,000 m^3/s water releases to Bangladesh. The results suggest that availability of flows is crucial during the period of March 1 to May 31. Moreover, the average flow availability at Farakka had gradually declined during the 1997–2007 period. For 2005 and 2006, we found that the average flow availability had declined by 12% and 25% respectively. We describe the Stackelberg leader-follower model for optimal water allocation in the Ganges River Basin between Bangladesh and India both with and without additional water transfer from Nepal. The results suggest that India will divert less water with flow augmentation than in the case where there is no provision to buy water from Nepal. Furthermore, considering Indian welfare, water transfer has also been deferred by India that has unilaterally reduced the supply of water to Bangladesh. Although Bangladesh gains from the water transfer agreement, India may not accept any agreement proposing water transfer from Nepal. We strongly recommend market-based water transfer from Nepal for both Bangladesh and India. This would be a better solution to sustainable water resources management in the Ganges River Basin.

Keywords: Bilateral agreement, conflict, deadlock, human civilizations, institutional framework, Memorandum of Understanding, welfare.

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Transboundary Aquifers of the Fergana Valley: Challenges and Opportunities

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The recent competition between the upstream hydropower and the downstream irrigation water uses in the Syrdarya river basin has highlighted the focus on the groundwater of the upstream Fergana Valley. Several features characterize the groundwater aquifers, most of which are transboundary in nature and underlie the small river basins. First, losses from the canals and percolation from the irrigated fields form over 65% of the recharge. Second, abstraction has a minor value in downstream groundwater discharge. Third, the shift of upstream agriculture from rangelands to irrigated grain production causes groundwater table rise, water-logging and salinity build up in the topsoil. Current attempts to solve these problems by enhancing the drainage of the irrigated lands do not correspond to the long-term objectives.

In contrast, the indicated externality can be addressed in three interrelated ways: 1) shifting from surface irrigation to conjunctive use; 2) temporarily "banking" the free surface flows in the aquifers; and 3) adopting water saving technologies to manage the aquifer recharge. The studies, carried out in the Uzbek part of the Fergana Valley, showed that 32% of the irrigated land can be shifted from canal to groundwater irrigation and another 27% to conjunctive use. While the free capacities of the aquifers available for water banking exceed 3 km^3, the proposed intensive groundwater abstraction would create extra subsurface capacities over 150 Mm^3 per each meter of the drawdown of the water table. This strategy will form capacities for "banking" winter hydropower releases from the upstream Toktogul Reservoir on the Naryn River. As a consequence, almost 1 km^3 of the winter flow of the Naryn and small rivers can be stored in the subsurface aquifers of the Fergana Valley. The shift from canal irrigation to conjunctive use will increase water use efficiency and create conditions for wide adoption of water saving technologies. This managed aquifer recharge and discharge approach, and adoption of the water saving technologies in this valley can ensure savings at the Syrdarya River basin scale at 3 km^3 that would be available for beneficial use and the environment in the lower reaches. The proposed strategy could be a part of the small river basin plans and requires the cooperation of the riparian states.

Keywords: Groundwater recharge, Water banking, Groundwater irrigation, upstream/downstream impact, Central Asia.

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Spatial Dynamics and Hydro-economic Modeling of Transboundary Aquifers

Pamela Giselle Katic[1]

Extraction from a transboundary aquifer, where no single entity has the authority to control all the withdrawal, 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. 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.

Keywords: hydro-economic modeling; spatial dynamics; groundwater extraction; transboundary aquifers.

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Legal and Institutional Framework in the Management of the Transboundary Aquifer Systems of the Americas

Julio T. S. Kettelhut 1

In 2005, the UNESCO/OAS ISARM Americas Programme, started to produce a book called "Legal and Institutional Aspects of the Groundwaters in the Americas", in order to attend a request made by the representatives of the Member States, including a diagnosis of the existing aquifer-related legal and institutional framework in the Americas. The book, finished in 2007 , brings data, information and coments about these issues up that date. The information were provided by the National Coordinators of the Member States in response to the questionnaires developed by the UNESCO/OAS ISARM Americas Programme. The Book shows, for each country member, data about its national legislations related to the surface water and groundwater resources and about institutions with national and local jurisdiction on water resources, both for surface waters and for groundwaters, that participate in the national management of water resources.

It was observed that the American countries have surface water and groundwater laws and, in general, their institutional frameworks are largely complex, often with conflicting roles and overlapping responsibilities. Also, they have most developed national and local regulations for surface water than to groundwaters.

On the other hand, there almost none TAS legal instruments. One of the reason for that is that the subsoil is traditionally considered as a subject matter of the national rights of each State. Hence, the possibilities of defining a legal framework for such transboundary resources are conditioned by national sensibilities. Other reason, maybe the main one, is related to the lack of knowledge about the TAS general characteristics. It is very difficult to establish agreements if the available data and information about issue under discussion is insufficient. It was observed that there are growing number of projects in the stage of planning and execution, among them the ISARM-Americas Programme, which will enrich the knowledge on the region's aquifers. They could become a starting point for progress in the development of cooperation and TAS protection among the Member States. .

In order to evaluate the legal and institutional aspects of the transboundary aquifers, was analysed, for each country, the legislations related to its respective legal regime of water and, also, the role of the national and local institutions responsible for water management. The majority of the countries has a hierarchical preeminence of national legislation on local regulations (state, province, municipality). This fact facilitates a management organization based on countrywide uniform rules. Institutional jurisdiction powers are largely concentrated around national institutions, particulary environmental ones. In some countries they are shared with water resource-specific institutions, departments or local water management entities, in diferent institutional levels.

The data presented in the Book, were systematised by regions (North America, the Caribbean, Central America and South America) showing the relevant information about them. It presents, in a concise and systematic manner, the international agreements on transboundary aquifers, as well as the national legislations and local regulations. Following the data collection, it was made a analysis of the national legislations and international agreements on groundwaters in the Americas regarding a rules concerning to four main topics: ownership and jurisdiction on groundwaters, groundwater institutional system, groundwater use and protection regulations and transboundary aquifers.

This presentation will inform the data and conclusions got in this book and also discuss some of them.

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Changing Land and Water Systems in Endorheic Basins of the Northern Sahara

Caroline King[1]

The geomorphological depressions of the North Western Desert of Egypt and the Chotts of the Tunisian Nefzaoua region in Southern Tunisia form terminal outlets in two major North African transboundary aquifer systems: the Nubian Sandstone Aquifer System and the Continental Intercalaire. Accelerated groundwater extraction in these areas over the past three decades has supported land reclamation activities to develop agriculture for both domestic and export markets. In recent years, there has been increasing recognition of the need to combine regulatory approaches in groundwater management with policies to support and encourage sustainable land and water uses.

This paper presents a comparative assessment of the impacts of environmental change on groundwater resources in the two regions over the past fifty years. Remote sensing, national statistical data and national research archives at the Institut des Regions Arides, Tunisia, the University of Alexandria and the Egyptian Desert Research Center were combined with surveys of cultivators in selected oases to cross-examine these changes, and local efforts to manage the degradation of the land and groundwater resources. This research was supported through an award for interdisciplinary research towards the completion of a Doctoral degree at the Oxford University Center for the Environment. A portion of the fieldwork in the Western Desert was carried out in cooperation with the Egyptian Case Study Team of the UNU-UNESCO joint research project on Groundwater and Human Security Case Studies (GWAHS-CS).

Generic measures of increasing groundwater scarcity and hydrochemical changes accompanying the increases in groundwater extraction are explored through archived databases generated by regional institutions, where available, and through cultivators' observations. These effects were associated with loss of agricultural productivity and agrobiodiversity. In response to the changing groundwater conditions, some cultivators have dug deeper wells, and others have adapted to more drought- and salt- tolerant production patterns. In a number of cases, cultivation intensity has been reduced or abandoned altogether. While digging deeper wells solves the immediate problem for individual cultivators, this strategy further exacerbates the threats to the common pool resource, and decreases the resilience of the production systems. Opportunities to manage and reuse available shallow groundwater resources in the cultivation of salt- and drought-adapted species can increase the resilience of the cultivation systems.

In order for sustainable management adaptations to succeed, local institutional capacity is challenged with the need to combine environmental knowledge with marketing chains and conditions that can support the shift to better adapted cultivation practices and production activities. These processes should also build in systematic improvements to the current management databases on groundwater conditions and vulnerability.

Keywords: changes to groundwater resources, Nubian Sandstone Aquifer System, Continental Intercalaire, comparative approach, contemporary management practices, assessment of impacts, adaptation to environmental change, groundwater vulnerability databases, regional institutions.

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Toward Management of Transboundary Aquifers in Two of Africa's Rural and Urban Areas? The Cases of the Lake Chad Basin and the Togo-Benin-Nigeria Coastal Aquifer

Hubert Machard de Gramont[1], Didier Pennequin[1] and Raya Stephan[2]

Located in the Sahelian part of Africa, the Chad Basin covers an area of some 2,400,000 km^2, where five main and widespread sedimentary aquifer systems are found. The economy of the area underlain by these sedimentary aquifers is mainly rural and its population accounts for about 20 millions inhabitants spread over Chad, Cameroon, Nigeria, Niger and Central African Republic.

In this basin, the recharge of the unconfined aquifers is tightly linked to the regime of the main rivers, Logone and Chari, and Lake Chad itself is the main source of recharge for the Quaternary sandy aquifer. However, due to changing climatic conditions and to the development of human activities, most of the aquifers' levels are actually dropping and their quality is deteriorating.

Despite the Lake Chad Basin Commission's (LCBC) efforts to boost cooperation on the Chad Basin aquifer systems between the riparian countries, the groundwater resources are still far from being accurately assessed and the abstraction rates are also quite undetermined. Meanwhile, the population is increasing at a rate of 2 to 3 percent per year, so that the number of inhabitants would reach 50 million people by 2050, while the water needs -mainly provided by aquifers- increase at a rate of 5% per year.

Conversely, the much smaller and narrow Togo-Benin coastal aquifer area, extending 12,000 km^2 from Ghana to the Nigerian border, faces a tremendous development of its already very dense urban population mostly installed along the sea shore. Due to high rural-urban migration and population growth rates (4.5 % per year and 2 to 3% per year respectively), it is expected that a 100 million inhabitant megalopolis will be created along the 400 kilometers of the sea-shore between Accra and Ibadan by the year 2050, increasing the population by more than five times that of the population at present.

In this coastal area, groundwater is mainly used for drinking purposes, but the aquifers' over-exploitation already causes salt water intrusion while industries, wild dumps and settlements are spoiling coastal fresh water lagoons and unconfined groundwater currently used notably for drinking water purpose by the low-income population. Despite favourable recharge conditions, the aquifers are, as in the case of the Chad aquifers, not well known because of their complex environment (sea water wedge, surface water/groundwater relationship, etc.), and because of a lack of regulation that often leads to undeclared water-wells, often resulting in uncontrolled abstraction in riparian countries.

These two examples demonstrate that countries sharing aquifers have to take urgent cooperative steps in order to improve their regulation and monitoring systems, share their common knowledge on their own groundwater resources and possible alternatives, measure the impact of their development plans on their aquifer system, and together build a proper management plan to preserve the quality and availability of their groundwater resources.

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Modeling Surface Water Depletions Due to Groundwater Pumping in a Transboundary Basin

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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.

Keywords: surface water capture, groundwater pumping, riparian system, hydrologic modeling.

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Transboundary Aquifers in Karst – Source of Water Management and Political Problems: Case Study - SE Dinarides

Petar Milanovic[1]

The groundwater regime in karstified rocks is quite different from the regime in nonkarstified rocks. The main properties of groundwater regimes in karst are: large conduits with huge transmission capacities; very fast, long and deep underground flows; high and fast water table fluctuation; short residence time; enormous and mostly concentrated infiltration; and large springs with large fluctuations of discharge. In a region with such complex hydrogeological characteristics, transboundary aquifers become a very complicated problem between different political entities.

One of the most karstified regions in the world is the South-eastern area of the Dinarides, a mountain range situated between the Neretva River to the West, Kotor Bay to the East and the Adriatic Sea to the South-west. This area is the most abundant natural "reservoir" of fresh water in the Mediterranean region and has the highest precipitation in Europe (locally 8,000 mm). Surface flows are rare and temporary. Between 70% and 80% of water flows through the well developed net of underground conduits. In addition, underground karst is globally famous for its number of different endemic species.

In the past, this region belonged to one country – Yugoslavia. Of late, the region has been separated into three countries: Croatia, Bosnia and Herzegovina, and Montenegro. Furthermore, a boundary exists between two entities in Bosnia and Herzegovina. The situation is further complicated by the construction of a large hydropower system and the transfer of water from one country/entity to another. Main karst aquifers discharge through the large spring zones. In a few cases the serious problem of transboundary aquifers appears. In those cases, parts of catchment areas (and aquifers) are not within the same political boundary as the springs. The main questions that already asked are:

- who has exclusive rights to use water potential for power production if water belongs to the transboundary aquifer;
- how to control locations of concentrated infiltration into the transboundary aquifer to provide proper groundwater quality protection;
- how to control flood in closed karst depressions (karst poljes) if boundaries cross the polje;
- how to protect the environment, including underground endemic species, in the case of transboundary aquifer disturbance.

Groundwater resources of the area have excellent and important water potential, extending beyond local purposes. In the near future, this potential could be of significant interest for a large portion of the Mediterranean; the south-eastern Dinaric karst region can potentially be declared as a Mediterranean "Water Treasure". Presently, a large amount of water flows through the underground channels or power plant structures directly to the sea. As a result, all 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 for optimal management and proper groundwater resources utilization.

Keywords: transboundary aquifer, karst, south-eastern Dinarides, hydro power, endemic species.

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Managing Transboundary Aquifers for Climate change: Challenges and Opportunities

Magdalena A. K. Muir[1]

The paper focuses on managing transboundary aquifers and aquifer systems in the light of climate change, in recognition of the challenges and opportunities that will be presented by climate change. The first part of the paper adresses the complex impacts of climate change on transboundary aquifers and aquifer systems. The second part addresses the management of affected aquifers and aquifer systems to minimize adverse implications of climate change. The third and last part proposes the exploration of opportunities for States to use transboundary aquifer management to adapt to climate change and to mitigate greenhouse gas emissions.

Prior to managing transboundary aquifers and aquifer systems considering the uncertainties related to climate change, it is necessary to understand the complex impacts of climate change on transboundary aquifers and aquifer systems. One impact is sea level rise and the related saline intrusion in transboundary aquifers. This saline intrusion may extend significantly inland, and impact other aquifer systems. Saline intrusion may also be aggravated by withdrawals from the aquifers, where these withdrawals may increase due to additional exploitation as a response to climate change. Flooding and extreme flood events could also affect the recharge and discharge patterns of aquifers, and lead to contamination of aquifer systems. More generally, climate change may impact the pace and nature of the recharge and discharge of aquifers. Last, there will be a specific examination of the impact of climate change on transboundary aquifers and aquifer systems in arid and semi-arid regions, and for coastal aquifers, in order to evaluate the vulnerability and resilience of these aquifers and systems.

Once there is an understanding of the possible impacts of climate change, it is necessary to consider how to manage transboundary aquifers and aquifer systems to minimize adverse implications of climate change. Management will require monitoring and data collection of aquifers and their recharge and discharge zones. Management will require the development of appropriate tools and processes. The legal and institutional frameworks for transboundary aquifer management are also important. For example, it could be useful to have explicit references to climate and groundwater issues in bilateral, regional and international agreements for transboundary aquifers, river basins, watersheds, and regional seas. Some agreements to be considered include the United Nations International Law Commission's draft articles on the Law of Transboundary Aquifers; the European Union's Water Framework Directive, the Groundwater Directive, water and adaptation policies; and the United Nations Economic Commission for Europe's Water Convention and Guidelines on Water and Adaptation to Climate Change.

In addition to the challenges, it is always useful to consider the opportunities presented by climate change for transboundary aquifers, whether to assist in the adaptation to climate change, or to mitigate the greenhouse gas emissions that contribute to climate change. Management of transboundary aquifers, and their inter-jurisdictional recharge and discharge zones, could allow countries to alleviate water scarcity and contamination associated with local surface waters. It could also reduce the seasonal and international risks of flooding as well as maintain important ecosystems. For example, depending on the structure of the tranboundary aquifer and aquifer systems and whether it recharges, water could be abstracted from aquifers when necessary, and re-injected when beneficial. Similarly to depleted hydrocarbon reservoirs, transboundary aquifers could be developed as a managed water storage which benefits all aquifer states.

Though this research is still in a preliminary stage of knowledge and development, transboundary aquifers and aquifer systems could play a beneficial and economic role for aquifer states in the sequestration of greenhouse gases. Deep saline aquifers provide the greatest volumetric potential for storage of greenhouse gases globally. In additional to facilitating the long term disposal of greenhouse gases, sequestration of greenhouse gases into portions of transboundary aquifers or aquifer systems, particularly brackish or saline aquifers, could enhance the recovery of potable water from aquifers and aquifer systems.

Keywords: aquifers, climate change, salination, adaptation, mitigation.

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Developing a Typology of Conflict in Transboundary Aquifer Management: Some Insights from Practical Local Case Studies

E. Lopez-Gunn[1], J. Story[2] and F. Villarroya[3]

The paper aims to shed light on how, in some cases, transboundary aquifers (in the sense of aquifers shared by sovereign states) do not necessarily generate conflict as can be seen with some small transboundary aquifers between Spain and Portugal. Conversely, some 'local' small regional aquifers at the intra-state level present interesting examples and challenges for agency coordination.

The paper will focus on three specific case studies. The first is the Rus-Valdelobos aquifer located in the Guadiana Basin. This is a relevant case because fulfillment of regulatory requirements on good quantitative status derived from the implementation of the European Union's (EU) Water Framework Directive (WFD) means addressing groundwater abstractions in the neighboring Jucar basin. Therefore, addressing the problem of aquifer overdraft in a federal country relies on cooperation and success at the inter-state level. The second case looks at the aquifer of Mancha Oriental in the Jucar river basin, an interesting case because of the downstream impacts of intensive groundwater abstraction on traditional surface water users downstream. The third case looks at international aquifers shared with Portugal, along the Portuguese-Spanish border.

The aim of the paper is to highlight the diversity of potential conflicts (and resolution and mediation) in the case of transboundary aquifers and the need to develop a typology of potential conflict and the most suitable policy measures and scales to address them. In particular, it provides examples of cooperation and regulatory measures at local, regional, national and supranational level (EU implementation of the WFD).

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Regulating Transboundary Groundwater: Big Challenges for Brazil

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Brazil is considered to be 'wealthy' in terms of its fresh water reservoirs. Some say the country has approximately 13% of the world's fresh water. Two of the biggest river basins in the world are in Brazil's territory and they are both transboundary: the Amazon and La Plata. One of the largest aquifers in the world, the Guarani, covers a total area of 1.2 million square kilometers, most of it in Brazil (71%), but also in Argentina (19%), Paraguay (6%) and Uruguay (4%). 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 e Minhas Gerais. According to Internationally Shared Aquifer Resources Management (ISARM) studies, Brazil shares another 10 aquifers. All this 'richness', however, demands strong institutions with legally appointed powers, in other words, an up-to-date water management system. This abstract will present the main legal aspects of water management in Brazil and its weakness on the subject of groundwater and transboundary groundwaters.

According to Brazil's Constitution of 1988, surface waters that exist in the territories of two or more states are under the jurisdiction and control of the Federal Union. The same occurs with transboundary waters that comes from or go to other countries' territories and the reservoirs of federal construction (art. 20, III), as well as all mineral resources, including those from underground (art. 20, IX and art. 176). On the other hand, surface water that does not belong to the federal government is under state jurisdiction. Likewise, groundwater in general belongs to the States (art. 26, I).

Under the Constitution, the Federal government has the competence to legislate on water resources as well; it is allowed to establish a national water resources management system and to define criteria to authorize its uses (art. 21, XIX). Therefore, in 1997, the Federal Law n. 9.433/1997 that creates the National Policy of Water Resources and establishes the National Water Resources Management System was enacted. The National Policy is focused on surface water mentioning groundwater only to prescribe that groundwater exploitation depends on a permit (art. 12), the same one needed for surface water. The attempt to integrate the management of surface and groundwater is being made *infralegis* by the National Council of Water Resources (Conselho Nacional de Recursos Hídricos – CNRH), which, in 2001, enacted Resolution n. 15, and the National Council of the Environment (Conselho Nacional de Meio Ambiente – CONAMA), that ratified, in 2008, Resolution n. 396 as a regulatory framework for groundwater.

Since the Brazilian Constitution establishes that groundwater belongs to the States, but mineral water (all mineral resources, including those underground) is under federal domain, one can perceive that there are two

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different legal regimes for groundwater and mineral water and two different administrative acts to allow the use of one or the other. Groundwater considered to be mineral is subject to the Mining Code (Decreto-lei n. 227/1967) and the Mineral Water Code (Decreto-lei n. 7841/1945), and its exploitation depends on authorization from the National Department of Mine Production (Departamento Nacional de Produção Mineral – DNPM). Generally, groundwater is subject to the permit of the State, according to its own state policy (the guidelines of which are given by the National Policy). The Federal government is trying to change that: since 2000 there has been a proposal to emend the Constitution (PEC n. 45/2000) on that matter, placing all transboundary groundwater under federal jurisdiction.

Besides being weak in terms of groundwater, the National Policy for water resources 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 External Affairs Ministry must have a chair on the river basin committee.

In this context, one can say 'Guarani is an outlaw'. There is no legal framework to conserve it or to regulate its use. It is known that the four countries within Mercosul tried to negotiate a treaty (unsuccessfully) and its draft is confidential. One study on the aquifer was carried out by the Organization of American States, in the context of a Project financed by the Global Environment Facility, but it did not propose any drafts of agreement to regulate the aquifer. In 2009, the United Nations General Assembly adopted the Resolution on the 'Law of transboundary aquifers' (Resolution 63/124), based on the works of the International Law Commission and UNESCO'S International Hydrological Program (IHP)/ISARM programs. It encourages States to adopt agreements regarding principles (like equitable and reasonable utilization, sovereignty of the States, the obligation to not cause significant harm, obligation to cooperate) and the need to take measures for the protection and management of the aquifers. These articles are welcome and must be used as guidelines on propositions to regulate the Guarani.

Keywords: Legal framework, Transboundary groundwater, Guarani Aquifer.

Transboundary Groundwater Aspect in Past Water Management Practices and New Water Policies of Turkey

A.K. Onur[1], H. Ozguler[2] and S. Fakıoglu[3]


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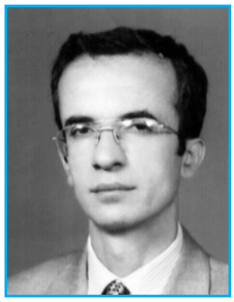
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So far, groundwater exploitation has not been well managed or controlled in many cases, and groundwater sources have been exploited intensively without considering their recharge rates. In addition, intensive use caused the drawdown of water tables that were associated with other environmental problems such as land subsidence, saltwater intrusion and water pollution. These problems were often irreversible or have not yet been remedied.

In this paper, technical, administrative and legislative challenges of a successful groundwater management scheme will be analyzed in light of data and information obtained from previous case studies. In addition, it will discuss challenges and opportunities introduced into a surface and groundwater management context by means of Turkey's new water policy.

Keywords: excessive groundwater exploitation, land subsidence, saltwater intrusion, groundwater pollution, transboundary aspects, water policy.

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Beyond 'Transboundary' Aquifers: Australia's Great Artesian Basin

Maureen Papas[1]

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 appropriately regulate groundwater resources. 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 across four jurisdictions. The important standards set out in the resolution need to be recognized for other types of aquifers, namely 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 utilization 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 practices of all shared groundwater resources.

Keywords: GAB, groundwater, shared aquifer, cooperative federalism.

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The Concept of Permanent Existing Models as the Main Instrument for Assessment of Transboundary Groundwater Flows

Irina N. Polshkova[1]

Study and prediction of hydrogeological processes in aquifers of neighboring states demand exact quantitative estimates especially in cases of increasing groundwater technogenic pressure. Assurance of estimate accuracy is possible only by considering the hydrodynamic flow as a whole, as well as existence and properties provided by recharge and discharge areas especially if these areas are located on the territories of different states.

Thus, rational use of groundwater resources requires development of regional constant-working models with boundaries corresponding to boundaries of natural hydrodynamic groundwater flow that can be located on the territory of neighboring states. To assess model correspondence to the studying process, it is necessary to have actual data from groundwater monitoring networks of different states for the entire period of their exploitation. Information about the location of existing and planned groundwater contamination sources is also of great importance. This approach requires an interstate agreement on free exchange in all initial and regime information, both hydrogeologic and hydrologic.

An important peculiarity of the mathematical modeling is to obtain new information on regional groundwater flow conditions due to the possibility of separate components of the total water balance calculation. These possibilities allow studying and predicting the influence of development pressure on the underground hydrosphere. The following criteria are suggested for assessing possible joint groundwater use on the basis of the common regional model of a nonsteady filtration regime under existing or planned water withdrawal that can be situated on neighboring states:

- the level of possible groundwater depletion;
- the possible damage to the underground component of surface water;
- the prediction of contaminated groundwater spreading dynamic in accordance with the size of sanitary zones during exploitation of well-fields.

The constant working models, as an instrument for hydrogeoecological forecasting, have to be part of the whole interior monitoring subsystem. Using this approach, both the geological service and government authorities meet the real instrument for assessing present-day and predicted conditions of the underground hydrosphere and efficient regulation of the anthropogenic pressure load.

The described methodology was approved for calculation of transboundary groundwater flows between Russia and Kazakhstan, and Russia and the Ukraine.

Keywords: transboundary groundwater flows, permanent existing models, groundwater use optimization.

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Challenges Facing the Management of Shared Aquifers

Omar Salem

Libya benefits from 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 was adopted. Since the early seventies of last century, bilateral and multilateral committees have been established mostly thanks to Libyan initiatives to exchange acquired information about the geometry, extension, and properties of transboundary aquifer systems as well as about the levels 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 to the establishment of shared data bases and monitoring networks with 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 effects of which extend beyond national boundaries. Other difficulties/challenges are closely related to financial and administrative aspects and technical inputs received 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 aspects 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 a sustainable management of aquifers.

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Towards the Concerted Management of Transboundary Aquifers: A Methodological Approach

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Aquifer systems, which represent an important part and sometimes the only source of a country's available water resources, are unequally known.

Occurring more frequently than transboundary rivers, transboundary aquifers are shared between various countries that generally use them independently, partially for drinking water supply and for industrial uses, but mainly for irrigated agriculture. This leads to more and more cases of overexploitation and pollution, creating tensions at all levels with a risk of crises and conflicts arising between countries sharing the same aquifer.

For all these reasons, it is now important to improve the knowledge and promote a reasonable and sustainable integrated management of transboundary aquifers.

In order to contribute to the suitable management of transboundary aquifers, the French Development Agency with its partners, BRGM, UNESCO, IOWater, INBO and the Water Academy, launched a study aimed at presenting a methodological approach for the management of shared groundwater. This document will highlight the challenges linked to the management of these resources, give a progress report on the state of the art and ongoing practices, and suggest a set of recommendations to implement effective management of transboundary groundwater.

Keywords: challenges, tools, joint management methodology,.

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Transboundary Aquifers and Groundwater Resources Management between Provinces of Japan: in the case of Kumamoto Prefecture, Kyusyu Island, Japan

Tadashi Tanaka[1]

In addition to aquifers that continental countries share with other countries, there are aquifers within Japan that cross boundaries between different Japanese provinces/prefectures. These aquifers are distributed in different parts of Japan with diverse regulations and social conditions. The monitoring and management of such aquifers need at least the same amount of attention as those of transboundary aquifers. One typical management system called 'Transboundary Groundwater Resources Management' is proceeding in the Kumamoto Prefecture of Kyusyu Island, Japan. The artificial groundwater recharge system proposed by this system, using paddy fields, is considered an excellent example of transboundary groundwater management in Japan by the local governments. In 2004, the system was introduced and the Kumamoto Prefecture and city governments have created a unique funding system to encourage artificial groundwater recharge through abandoned paddy fields that exist in neighboring towns outside the city boundary for the sustainable management of the regional groundwater resources. This groundwater management system is regulated by the local government, Kumamoto City, and the large groundwater users in the city areas support the funding system. Together with Japan Agricultural Cooperatives (JA), two local town governments, Kumamoto City and Kumamoto Prefecture, discuss development initiatives and the preservation of water reserves each year. The people of the city have experienced the effect of the system over the past four years. Under Japanese law condition, groundwater resources belong to the landowners and there is no unified national law to manage the groundwater resources at the present time. However, as mentioned above, a new concept is emerging – one of shared natural resources for groundwater resources management within the local governments and citizens of Japan. This may be a good example for assessing the impacts of human activities on groundwater resources and managing aquifer systems that cross boundaries between different provinces/prefectures.

Keywords: Transboundary GW resources management, artificial GW recharge, abandoned rice paddy fields, funding system, Kumamoto region.

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Optimizing Groundwater Yield through Enhanced Stream-Aquifer Interaction: a Case Study of Lower Ghaggar Basin in India

N.K. Tyagi[1]

The Lower Ghaggar Basin (part of the Indus system) extends over the three Indian states of Punjab, Haryana and Rajasthan, which have a predominantly agrarian economy. The overall water supply is deficient and often leads to interstate tensions. The Ghaggar River is largely seasonal with high monsoon flows, creating a flood-like situation in part of the basin towards Rajasthan. The basin has alluvial deposits of varying grades up to depths ranging from 200-300 m. Though there is only one aquifer complex in the area, it is possible to differentiate locally shallow unconfined and deeper confined layers with thicknesses ranging from 20-50 at a depth of 200 m. The transmissibility shows wide variation ranging from 50-1,200 m^2 per day. Groundwater quality along the river is fresh, but shallow aquifer layers away from the river have waters of marginal quality. This study explores the possibility of augmenting groundwater supply by inducing recharge from the river along its length.

A steady state hydraulic optimization model with the objective of maximizing sustainable pumping yield was set up. The steady state excitation rates are values of pumping and recharge that, when applied to the system continuously, maintain constant potentiometric surface elevations. For a set of potentiometric surface elevations, a corresponding set of steady state pumping values exists. The model had various constraints relating to acceptable drawn, hydraulic heads, pumping rates and volumes, stream aquifer interaction, etc. The linear programming mathematical model was translated into GAMS and the model outputs included maximum pumping rates, resulting potentiometric surfaces and the stream aquifer interaction, etc.

The optimal pumping rates depended largely on the type of aquifer formation and the recharge opportunity, with cells along the river having a higher opportunity for recharge. The optimal pumping rates varied from 0.25 m^3s^{-1} to 8.48 m^3s^{-1}, the values, particularly in river cells, being several times higher compared to the existing pumping rates. The optimized pumping induced about 60% additional flow from the stream to the aquifer. In few locations, the difference between existing and desired pumping rates was responsible for a rise in water table. The potentiometric surfaces have implications for groundwater management as their high value may lead to water-logging and salinization, whereas very low values will increase pumping costs.

It is inferred from this study that it would be desirable to increase pumping in river as well non river cells. In river cells, the induced stream-aquifer interaction will substantially increase groundwater availability in the basin. In non-river cells, which have marginal quality groundwater, higher pumping will eliminate the possibility of water-logging and salinity by lowering the groundwater table. The increased groundwater supply in both situations, 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.

Keywords: Groundwater, Aquifer, Sustainable, Salinization, Productivity.

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Hydrological Investigation Challenges of Transboundary Watershed Aquifer in the Himalayan Region

Anand Verdhen[1]

Transboundary may be defined by political, natural, geographical features or other anthropological activities or geo-referencing system. Further, it may be defined by subsurface geological strata and aquifers. A river has its own natural basin boundary consisting of several 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 can be considered as transboundary or inter sub-basin water transfer. The integrated study and investigation turn out to be challenging and complex. However, scientific and methodical planning makes this study of invisible processes more interesting, useful and applicable for sustainable and optimal development. India's 2002 National Water Policy discusses the optimal, economical and equitable use of water resources, stating that 'water resources development and management will have to be planned for a hydrological unit such as drainage basin as a whole or for a sub-basin, multi-sectorally, taking into account surface and groundwater for sustainable use incorporating quantity and quality aspects as well as environmental considerations'.

Snow and glaciers in the Himalayan regions take 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 an adjacent mountainous watershed and vice-versa. Few major Himalayan river basins of India have their upper catchment in the territory of other nations. In addition, they have no snow or meteorological stations or data sharing platforms leading to problems of hydrological analysis. This paper discusses the transboundary 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 becomes precious due to climate change. This flow is a life sustaining flow. There is need for mutual cooperation and the resolution of legal issues related to the sharing and management of the watershed, water resources and observations for the analysis and equitable developmental utilization.

Keywords: Himalaya, Watershed, Transboundary, Snow and Glaciers, Lean flow, Groundwater, Aquifer, Base flow.

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Simply-Structured Groundwater Model Analysis for Informing Management of Transboundary Aquifers – Examples from the Bengal Aquifer System (Bangladesh, India) and Nubian Sandstone Aquifer System (Chad, Egypt, Libya, Sudan)

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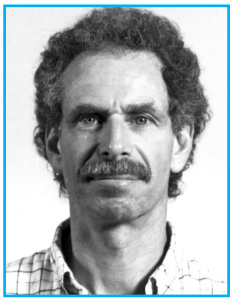
1 

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Powerful information for the management of transboundary aquifers can be developed 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 models when constructing models and model-based analyses. Simple effective models include only the salient features of the aquifer system that control the primary aquifer behaviors of interest regarding understanding and management. They also evaluate the impact of alternative model structures and features on the questions being answered. Whether there is any practical 'value added' to model-based results by introducing complexities and by making analyses more difficult is usually unclear. Potential advantages of complex modeling approaches are limited because of inherent uncertainty in understanding aquifer systems; aquifers can never be completely measured and truly characterized at the spatial and temporal scales required. This is especially a concern for large transboundary aquifer systems that may not have informative and extensive hydrogeologic databases. In contrast, effective simple models and insightful approaches to analysis account for the limitations of modeling approaches and knowledge of aquifer system structure and these can provide clear and robust answers to clear questions. Such an approach is demonstrated for two very large transboundary aquifer systems.

In the Bengal Aquifer System (BAS) of Bangladesh and India, groundwater availability is not a problem and indeed, groundwater is the primary domestic water source for tens of millions of inhabitants. However, the shallow groundwater being used has very high levels of dissolved arsenic that is seriously impacting public health. Deeper groundwater in BAS is currently arsenic-free (As < 10 ug/L) groundwater, but a program of wide scale deepening of all wells to tap this 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. Simple model-based analyses of the entire BAS has allowed evaluation of key controls on regional groundwater flow. This parsimonious analysis has shown that, by only deepening domestic wells in the impacted areas while keeping irrigation wells pumping from the shallow part of the aquifer, a sustainable

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arsenic-free supply solution is provided for much of the region. This solution employs a socially functional approach, deepening the preferred common tube well.

In the Nubian Sandstone Aquifer System (NSAS) of Chad, Egypt, Libya and Sudan, there is essentially no recharge and the resource is being mined. In the NSAS countries, water availability is an important problem and there are both warranted and unwarranted concerns about transboundary impacts of water use. Concerns include excessive depletion of shared groundwater by countries that pump more than others, increases in groundwater crossing national boundaries toward large pumping centers, 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 recharge, and disappearance of oases where most pumping centers are co-located. Simply-structured model analyses, undertaken as part of a GEF project managed by IAEA, have shown that the greatest concerns should be local concerns, especially local drawdown and oasis disappearance in pumping centers. Simple modeling has also shown that the main transboundary concern should be drawdown crossing national boundaries, but given the large scale of the NSAS and its plausible ranges of aquifer parameter values, the magnitude of transboundary drawdown is small and should not be an issue of practical significance.

Keywords: Groundwater modeling, Management, Transboundary Impacts, Bengal Aquifer System, Bangladesh, India, Nubian Sandstone Aquifer System, Chad, Egypt, Libya, Sudan.

Managing Transboundary Groundwaters: Lessons from the Field

Martin Walter[1]

What are the factors that foster or impede the creation of international agreements for the management of transboundary groundwater? While legal scholars and management experts tend to highlight the importance of scientific knowledge in the norm-making process, others connect the development of institutions for international waters to the existence of threats to States' security, sovereignty, and the existence of stakes in the resource's management. Drawing on the analysis of historical documents and more than 40 interviews conducted in three markedly different experiences of transboundary groundwater management – the Franco-Swiss Génévois Aquifer, the Argentinean, Brazilian, Paraguayan and Uruguayan Guarani Aquifer System and the US-Mexican Hueco-Bolsón Aquifer – my study focuses on the intricate relationship between knowledge and policy. This paper contends that different geopolitical, environmental and institutional settings create significant variation in the degrees of formalization, the objectives, and the political complexity of the practice of groundwater management. Furthermore, it demonstrates that the nature of an international groundwater management agreement depends on the availability of scientific knowledge, which drives political mobilization, and on institutional constraints, which define the legitimate decision-making criteria. 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 and social networks in border settings.

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TOPIC 3
Building capacities and strengthening institutions

The Transboundary Guarani Aquifer System and Groundwater Management Mechanisms

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Guarani Aquifer resources are public in all four of the 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, state or local specific law and institutions. In the absence of groundwater management schemes, national and state legislations tried to adapt approaches valid for surface water to groundwater management. Aspects related to time and space are the main problems that occur and must be considered in the definition of adequate laws and management structures. For this reason hydrogeologists did not want to adopt surface water resource 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 are successful. 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 to also be considered in cooperation strategies. According to the results of Environmental Protection and Sustainable Development of the Guarani Aquifer System Project (2003-2009), the main aspects of the aquifer characteristics and functioning can be compared 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 the maxim "think global, act local" is on groundwater protection and management.

Keywords: Guarani Aquifer; groundwater management; management local committees.

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Towards Sustainable Utilization and Management of Transboundary Groundwater Resources in SADC within an IWRM Framework

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The ISARM initiative's aim to promote transboundary aquifer (TBA) management is a positive one, but needs to move away from a groundwater scientist's perspective to one of an Integrated Water Resources Management (IWRM) manager. An important opportunity has recently presented itself in that the Southern African Development Community (SADC) has taken the decision to '*pro-actively add groundwater into the programme of activities of the African Network of Basin Organizations (ANBO)*'. This follows on a resolution coming from the African Ministers' Council on Water (AMCOW) in 2007 to '*promote the institutionalisation of groundwater management by river basin organisations to ensure regional ownership of the initiative*'. This will provide a new dimension to an international basin scale approach to transboundary groundwater, something crucial to raise the status of the strategic, but still generally neglected resource. SADC already has many processes in place to manage water resources in a more holistic manner. The recent SADC Multi-Stakeholder Dialogue (2009) was fully focused on groundwater. Here it became apparent that it must be a priority to generate a combined conceptual understanding of a transboundary aquifer with adequate groundwater data and information to allow for the implementation of cooperative arrangements of groundwater as part of river basins, of which some already have legal agreements. In this regard, a Concept Note was developed to pilot the *'sustainable utilization and management of transboundary groundwater resources within SADC'*. The Project approach aims to achieve simultaneous movement at a local, national and regional level by addressing key issues of groundwater resources at local and transboundary levels as well as to upscale the local experience to both river basin and SADC regional levels. It is planned that the project will be undertaken in two major river basins, with a pilot transboundary aquifer in each, aiming at a maximum regional impact. The multi-partner initiative would like to focus the pilot on the pro-active aspects of the UN Draft Aquifer Articles, i.e. joint:

- resource and water use assessment;
- harmonized database;
- numerical model for TBA;
- management plan for TBA
- transboundary monitoring network;
- assessment towards harmonization of legal/regulatory framework.

It is hoped that this project will reach a continental and even a wider international dimension through SADC's recommendation to initiate their transboundary groundwater initiative by sharing countries' best practices and to have a structured awareness-building linked to this.

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UN Watercourse Convention and the Draft Articles on Transboundary Aquifers: The Way Ahead

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In December 2008, the United Nations General Assembly (UN GA) 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". At a later stage, it also "decides to include in the provisional agenda of its sixty-sixth session *(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 existing UN Convention on the Law of the Non-Navigational Uses of International Watercourses ("UN Watercourse Convention")* of 1997 had 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. On top of the possible prospect of sufficient ratifications in the foreseeable future, it is the correlation between the UN Watercourse Convention and customary international law that makes it sensible to refer to the Convention, even under the current status of ratifications, as a key point of reference.

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 to 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 where they complement each other or on their contradictions, and will draw the consequences with possible solutions.

Keywords: transboundary aquifers, Draft articles, UN Watercourse Convention, scope, rules.

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* United Nations Convention on the Non-Navigational Uses of International Watercourses, annexed to UNGA Res. 229 of 21 may 1997, Official records of the UNGA, 51st session, UN doc. A/Res/51/229; reprinted in 36 I.L.M. 700 (1997).

The United Nations Resolution on the Law of Transboundary Aquifers: Interface with Domestic Natural Resources Legislation

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By Resolution 63/124 adopted in the course of its sixty-third session on 11 December 2008, the United Nations General Assembly (UNGA) acknowledged the draft Articles on the law of transboundary aquifers developed by the United Nations International Law Commission, and it encouraged the concerned States to take the draft Articles into account when making bi- and multi-lateral agreements for the management, development, conservation and use of their transboundary aquifers. In particular, Part three of the Resolution on "Protection, preservation and management" lays down a number of innovative and challenging obligations reflecting specific concern for the vulnerability of aquifers, notably to depletion and to pollution. The implementation of these obligations requires domestic legislation to be in line with and supportive of them. Groundwater and land use legislation, in particular, are the areas of domestic legislation likely to be engaged the most by the international obligations posited by Part three of the UNGA Resolution. The resulting interaction between the said international obligations and the domestic land and water resources legislation of States needs to be mapped out. This will be done with a view to assessing the adequacy of available domestic regulatory and other legal mechanisms of resource management and use to meet the above-mentioned international obligations, and to determining with some level of accuracy the scope and direction of any desirable change. The paper seeks to map out the area of interaction and interface between the two planes, and to gauge the responsiveness of domestic water and land use legislation to the obligations posited by Part three of the UNGA Resolution by reference to the laws of a few selected countries. Tentative conclusions of general importance will be drawn, including pointers for a future agenda of domestic lawmakers in response to the challenges posed, in particular, by the provisions of Part three of the UNGA Resolution.

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Transnational Groundwater: Lessons from North America

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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 are funding 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, agricultural products grown with water from the Hermosillo aquifer are in high demand 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.

Keywords: transnational, North America, groundwater, management, cooperation.

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Juggling Water: Transboundary Issues Facing the Guarani and the Pantanal

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The Guarani Aquifer, the world's largest aquifer, 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. It is integrally connected through overland rivers (the Parana and the Paraguay) with the Pantanal, a wetland larger than the state of Florida that covers part of Bolivia, Paraguay and Brazil. 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 their respective and collective transboundary overlaps present 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.

This paper begins with a brief overview of the regional ecology before turning to the legal and ecological problems facing the region. It focuses particularly on how transboundary legal issues impact the management of the Guarani, looking first at the developments arising from the Guarani Aquifer System Project (GASP). It then examines the Integrated Watershed Management Practices for the Pantanal and the Upper Paraguay River Basin Project, also known as the GEF Pantanal/Upper Paraguay Project (hereafter referred to as the 'Project'). It looks closely at the Project's approach to the legal transboundary water issues facing the Pantanal and its compatibility with the GASP and the United Nations General Assembly Resolution (A/RES/63/124) on the 'Law of Transboundary Aquifers.'

The authors draw on their own on-site experience in the region to analyze the need for effective capacity building and efficient enforcement policies – a need exacerbated by the area's remoteness, fragility and conflicting regional development priorities. Since any effective legal protections must address the ecosystem impacts of the changing climate, the paper also looks at the legal framework's adaptability and responsiveness to present and future stresses presented by climate change. The paper concludes with some observations on how international climate change agreements (existing and proposed) could impact transboundary wetlands in general and the Guarani Aquifer in particular.

Keywords: Guarani, climate change, hard/soft uncertainty.

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The Transboundary Aquifer of the Geneva Region (Switzerland and France): a Successful 30-year Management between the State of Geneva and French Border Communities

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The drinking water supply for the Geneva area comes partly from a large transboundary aquifer known as the 'Geneva aquifer'. This 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 1960s and 1970s, overpumping lowered the groundwater level by more than 7m, thereby depleting about one third of total groundwater storage over a period of 20 years. Certain wells, both Swiss and French ones, have been rendered unusable because of the diminished groundwater level.

While technical and scientific studies were being undertaken to resolve the problem of overuse, 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 country and determined the financial modalities governing the use of the resource. An agreement was signed to that effect in 1978. As of 1980, an artificial recharge station came into use, drawing from one of the biggest rivers crossing Geneva, so as to ensure that the groundwater level would be sufficient for the continued use of the aquifer. A revised version of the 1978 agreement was adopted in 2007, attesting to the success of the joint management plan.

After being in use for some thirty years, the Geneva recharge system, which includes a water treatment plant and a system of infiltration via underground drains into a sewage farm, has made it possible for over 250 million m^3 of treated water to be channelled into the Geneva transboundary aquifer. The entire process is described in this article.

Keywords: transboundary aquifer, aquifer recharge, Geneva, aquifer use agreement.

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The Law of Transboundary Aquifers and the Berlin Rules on Water Resources: Interpretive Complementarity

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From 1990 to 2004, the Water Resources Committee of the International Law Association (ILA) dedicated its deliberations to consolidate the new developments that had taken place in the field of international law rules for water resources following the adoption of the *Helsinki Rules on the Uses of the Waters of International Rivers* in 1966. In subsequent conferences, the ILA had addressed other topics regarding water bodies including underground waters. Even if the Helsinki Rules made reference to underground waters, it was only when defining drainage basins stating that it is the area 'determined by the watershed limits of the system of waters, including surface and underground waters, flowing into a common terminus' (Article II). There was no further reference to underground waters in the Helsinki Rules. However, in 1986, the Seoul Conference filled that gap adopting a specific set of rules for International Groundwater.

In 1990, a broader commitment encouraged the Water Resources Committee to address the law of international water bodies in a general sense, thus including underground waters related or unrelated to surface waters. Accordingly, the new set of rules adopted in 2004 at the Berlin Conference, the *Berlin Rules on Water Resources*, included a chapter on groundwater. The period of sketching out that chapter paralleled the works of the ILA on the Law of Transboundary Aquifers and, mindful of that circumstance, their similarities and differences are worth an analysis, not as an abstract exercise but as a way forward to construe the set of articles attached to the United Nations General Assembly Resolution A/RES/63/124 on the Law of Transboundary Aquifers.

The presentation will deal with the cross-pollination between the ILA 2004 Berlin Rules provisions on groundwater and those of the Law of Transboundary Aquifers as an interpretive method to foster the implementation of the latter as well as with recent developments on transboundary aquifers to illustrate the relationship between law and practice.

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Buried Treasure or Buried Hopes?: the Status of Mexico-U.S. Transboundary Aquifers and International Law

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The 2,000 mile-long border between Mexico and the United States is hot and dry. Few rivers cross this arid expanse. Despite the lack of visible water, the region continues to grow – the combined border population currently is approximately twelve million and is expected to grow to twenty or more million by 2030. The reason is groundwater; more specifically, transboundary aquifers.

There are as many as twenty aquifers straddling the Mexico/United States border. Many of these serve as the primary source of fresh water for overlying populations. The Hueco Bolson Aquifer, for example, provides Ciudad Juarez's 1.5 million residents with all of its water, and thirty percent of that is used by El Paso's 730,000 residents. For others, these aquifers are the only source of fresh water for hundreds of miles, such as for the sister cities of Columbus, New Mexico, and Puerto Palomas, Chihuahua.

Surprisingly, there is no agreement between Mexico and the United States that addresses the allocation and management of these transboundary aquifers. Although a number of pronouncements can be found in local arrangements and the Minutes of the International Boundary and Water Commission (IBWC), none offer any substantive guidance as to how the two countries should manage these important fresh water resources.

As a result, the region's groundwater resources, environment, and communities are succumbing to serious consequences that could threaten the viability of the region. Overexploitation is growing as populations on both sides of the border pump with little regard for transboundary impacts or sustainability. Additionally, growing demands are taxing these finite underground reservoirs as border communities expand and untreated waste, agricultural and industrial by-products, and other pollution sources threaten water quality and quantity.

This study will review the use of groundwater resources along the Mexico-United States border and the impact that population and economic growth has had on those resources. It will also look at the law, from the local to the international level, which is applicable to this unique border region, including, *inter alia*, customary international law, Minute 242 of the IBWC, the Bellagio Draft Agreement, the U.S. Transboundary Aquifer Assessment Act, and the Memorandum of Understanding between the sister cities of Ciudad Juarez, Mexico, and El Paso, USA. The study will also consider the relevance to the region of the Draft Articles on Transboundary Aquifers, the work-product of the UN International Law Commission in its effort to codify the international law of transboundary aquifers. Finally, the study will identify the shortcomings of the current situation and offer recommendations for an arrangement between the two nations.

Keywords: Mexico, United States, international water law, international groundwater law, transboundary aquifer, Hueco Bolson, water dispute.

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Regional Transboundary Groundwater Management: a Comparative Analysis between the European Union and the Mercosur Normative System

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International groundwater regulation is very difficult and one of the reasons for this, as in other environmental fields, lies in the fact that while the transboundary effects of groundwater use are evident, one cannot ignore the local nature of many of the cause/effect variables involved.

In consideration of this complex scenario, especially the very bipolar character of the issue, we suggest the need for a multi-dimensional normative structure system. Given these conditions, without entering the polemic 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 environmental normative structure. Phillippe Sands supports this position with the following statement: '*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'.*

It is generally recognized that, up to now, 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 European Union (EU) Water Framework Directive, adopted in 2000, replacing a range of directives in the field of water policy. It works as a central document and is related to other specific and localized norms as the 'daughter directive' concerning groundwater protection. The Framework Directive embodies the concept of integrated river basin management and sets some goals to be achieved sequentially within national and basin levels. The success of the system can be observed to date as the majority of the essential specific norms at national and basin levels are already in place·

I propose a 'system' approach to compare the EU water regulation structure (going from the general water framework directive to the groundwater specialized directive) with Mercosur laws and regulations relative to water management. The aim is to compare the Mercosur experience with that of the EU in order to review the goals of Mercosur and draw some conclusions concerning the pitfalls of the Mercosur integration process with respect to groundwater management concerns.

We can find many deficiencies within the Mercosur water protection initiatives. In fact, even though there is a precise 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, in this scenario, groundwater regulation has yet to be further addressed. Despite this, it is encouraging to see that some valuable documents have been produced, such as the elaboration of Mercosur's Additional Protocol to the Framework Agreement on Water Resources Environmental Management.

Keywords: groundwater management, European Union, Mercosur.

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Strengthening Water Governance Capacity for Transboundary Aquifers Management

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Groundwater reserves constitute the main source of fresh water available on Earth and represent a potential solution to the contemporary water availability, particularly in arid and semi-arid regions. The lack of information on groundwater status and the absence of comprehensive norms for their regulation allow an uncontrolled and unsustainable use of aquifers that can lead to their rapid and alarming depletion. Transboundary aquifers are subject not only to competing demands from different uses at the national level, but also to diverse national jurisdictions. Moreover, competition for water resources, including groundwater, can lead to conflict, particularly in areas already affected by socio-economic problems, political instability and cultural tensions. The establishment of an appropriate legal framework for managing shared aquifers is a topic that remains unsolved in the international agenda, despite the UN General Assembly Resolution on the 'Law of Transboundary Aquifers' of December 2008. 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 their political unwillingness and diverging economic interests. Experiences on the ground show the benefits of managing shared aquifers through specific projects implemented by international and local organizations. These projects require the recollection 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. Moreover, they intend to rationalize the exploitation of groundwater resources and guarantee equitable benefits to participant States. Such projects might represent a more rapid venue 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, demonstrate the positive effects of implementing appropriate and joint utilization schemes therefore promoting and developing groundwater governance capacity. This paper argues that although such project framework does not represent a long-term solution, it offers the foundations for the creation of an institutional structure and for the adoption of agreements. Further, this paper intends to sketch out the relevant features of such agreements in terms of institutional set outs, monitoring and evaluation, compliance and enforcement, and other provisions relevant for promoting interstate cooperation and the sustainable use of groundwater.

Keywords: Water governance Capacity; Transboundary aquifers; legal and institutional; framework; cooperation mechanisms.

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Integrating Groundwater Boundary Matters into Transboundary Aquifer Management

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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'.

Keywords: Typology of boundaries, 'blurring the boundaries', governance.

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Transboundary Water and Transboundary Aquifers in the Middle East: Opportunities for Sharing a Precious Resource

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Surface and groundwater resources in the Middle East are largely transboundary. While much attention is given to 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 Euphrates, Tigris, Jordan and Nile Rivers as they connect Arab and non-Arab countries. However, both surface and groundwaters cross political boundaries between Arab countries 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 the Economic and Social Commission for Western Asia (ESCWA) member countries and between ESCWA member countries and non-member countries will be presented. Often, detailed hydrogeological knowledge is still limited at the national or trans-national level on an individual transboundary shared aquifer. Some bilateral or multilateral cooperation between riparian states (water course and aquifer states) have taken or 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 Integrated Water Resources Management (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 in 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.

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International Shared Aquifers in Arab countries

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Arab countries share many aquifers, some of which prove to be one of the most important sources of water in various countries. We will focus on groundwater resources in the Arab region between Arab countries as well as between Arab countries and neighboring countries. In addition, we will give case studies from the region and discuss the benefit of cooperation

The UN General Assembly Resolution on the 'Law of Transboundary Aquifers' and the draft convention could be, if it is amended, an international Water Law and Convention for the benefit of all the countries especially Arab states.

Keywords: Arab States, Successful agreements, Occupied Territories, Legal Instruments, Water Security Strategy, Council of Arab Ministers for Water.

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Dig Deep: Conflict Prevention through Protection of Vital Human Water Needs

Christina Leb[1]

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.

Keywords: international groundwater law, conflict prevention, equitable utilization, cooperation, vital human needs.

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A Critical Analysis of the 2008 Draft Articles on the Law of Transboundary Aquifers in the European Context

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In 2008, the International Law Commission (ILC) adopted a set of 19 articles that aim to contribute to the codification and development of the law governing transboundary aquifers ('ILC Draft Articles'). In 2009, during its 63rd Session, the UN General Assembly (UNGA) 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 (A/RES/63/124).

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 their provisions to specific regions or transboundary aquifers. In this sense, both the ILC Draft Articles and the aforementioned 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 European Law, with reference, where appropriate, to European statutes, national experiences and decisions by the *European Court of Justice*. The goal will be to assess the extent to which the law emanating from these global and regional developments could be applied and adjusted to inform the adoption of specific aquifer treaties in Europe and beyond.

The paper will evaluate how the ILC Draft Articles deal with issues of water quality and quantity, sustainable development, human needs and ecosystem protection. The paper will consider, *inter alia*, ongoing developments under the *UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes*, with regard to its applicability to groundwater resources, as well as the *EU Groundwater Directive* (2006/118/EC). In particular, the paper will consider the latter's relationship to the *EU Water Framework Directive* (2000/60/EC), assessing how effective these instruments are in integrating the management of surface and underground waters. This will allow for an analogy to be made with the ILC Draft Articles and its linkages to the *UN Convention on the Law of the Non-Navigational Uses of International Watercourses*.

Finally, the paper will include a set of recommendations, based on the advances in international groundwater law emerging from the ILC Draft Articles and European Law, in order to inform future negotiations on agreements governing specific transboundary aquifers in Europe and elsewhere.

*Keywords: i*nternational groundwater law, European Law, ILC Draft Articles.

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Transboundary Aquifers with Non-Renewable Water Call for Specific Management Policies

J. Margat[1], D. Pennequin[1] and H. Machard de Gramont[1]

Two types of aquifers have particularly pooled the attention of many hydrogeologists in the last few decades and have lead to diverse recommendations with the aim to improve their management: aquifers with non-renewable water and transboundary aquifers. Nevertheless, many of these aquifers, and notably most of the great aquifers of the world located in arid and semi-arid zones, possess these two characteristics: they are transboundary with non-renewable water.

Aquifers with non-renewable water (or fossil water) call for management of extractable water stocks that have dynamic repercussions that sometimes extend over great distances. Furthermore, when these aquifers are transboundary (shared by two ore more countries or political land units), even if natural transboundary groundwater flow is negligible, the political borders do not impede the propagation of influence on water levels or the transfer of pressure induced by pumping wellfields.

In these cases, sharing water resources and water resources management plans would gain from being based on criteria linked to these influences, which implies cross-border dialogue and consultation to establish short, middle and long term exploitation strategies. Consequently, this must include a multi-phases approach ranging from first groundwater mining scenarios during a transitional period to, in the end, sustainable groundwater withdrawal conditions.

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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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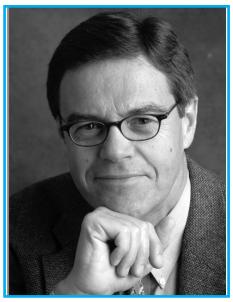

It is a common place today that per capita availability of fresh water is shrinking. In addition, all attending this meeting are certainly well aware that some 60 per cent of global freshwater flows are contained in the 263 river basins that are shared by two or more countries, and that around 40 per 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 water resources. A set of such norms is contained in the 1997 United Nations Watercourses Convention. The Convention, which is largely a codification of customary international law, may be seen as an expression of the meaning of state sovereignty as it relates to transboundary water resources. Sovereignty over such resources while they are in a state's territory is not absolute. It is informed and inflected by the requirement that the needs and interests, expressed as rights, of co-riparians be taken into account. It is in this sense that a country's 'sovereignty' over internationally shared water resources should be understood.

Keywords: Cooperation; conflict; generally accepted legal norms; 1997 United Nations Watercourses Convention; codification of customary international law; state sovereignty over internationally shared water resources.

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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

Owen McIntyre[1]

The key principles of international water resources law are now firmly established and are increasingly well understood in terms of their practical application. Although already part of customary international law, the cardinal principle of equitable and reasonable utilisation and the duty to prevent significant transboundary harm, along with the various associated procedural requirements falling under the rubric of the duty to cooperate relating, *inter alia*, to notification, good faith negotiation and consultation, dispute settlement, and the ongoing exchange of information, received significant endorsement through their inclusion in the 1997 UN Watercourses Convention. This remains the case despite the fact that the Convention has not entered into force, and may never do so, as it largely represents a codification by the International Law Commission (ILC) of the relevant customary rules. In addition, the explicit or implicit inclusion of a number of emerging principles of international environmental law, including the precautionary principle, the ecosystems approach, and the requirement for transboundary environmental impact assessment, has greatly enhanced the normative status of such principles in customary international law.

The ILC has taken a further significant step in terms of the codification and progressive development of international water resources law, and the rules of international law applying to the utilisation and environmental protection of transboundary groundwater resources in particular, by its adoption of the 2008 Draft Articles on the Law of Transboundary Aquifers. The adoption of a specific set of Draft Articles recognizes, belatedly, the vital role of groundwater resources, their unique vulnerability and their quite distinct geophysical characteristics.

However, the Draft Articles are likely to give rise to a good deal of confusion regarding the scope of application of the UN Watercourses Convention and of the ILC Draft Articles respectively, and regarding the potential for overlap. This matters because the Draft Articles take an approach to the utilization and environmental protection of transboundary water resources that is markedly different from the UN Watercourses 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 an 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. Possibly of even greater significance, some aspects of the Draft Articles could be regarded as being regressive and as rowing back on progress achieved under the UN Convention, for example with respect to the 'community of interests' approach applied to shared water resources and the, at least nominal, emphasis on ecosystems protection. Of course, other aspects of the Draft Articles might be regarded as very cutting-edge and progressive, such as the clear emphasis on the distribution of 'benefits'.

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 with respect to the normative content and significance of key principles of international water resources law. Given the dearth of clear State and treaty practice in relation to transboundary aquifers, it would seem appropriate to try to identify which aspects of international law and practice in respect of surface waters might inform inter-State on groundwater resources. Conversely, the more progressive aspects of the Draft Articles can play a role in advancing our understanding of water resources law generally. At any rate, a clear, 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.

Keywords: groundwater, surface waters, sovereignty, fragmentation.

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Sustainable Development of Inter-State Aquifers in Australia: the Legal and Institutional Tools

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Sustainable development law is expressed in a number of statements such as the UNESCO Transboundary Water course convention and the Rio convention. Many Australian acts of parliament at State and federal level (the Water Act 2007) also express and require implementation of 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. The impact of the legal norms and how they are deployed by actors both within and out of government bureaucracies is essential to the development of International and Australian law and also useful to other nations with sustainable development goals such as Brazil and South Africa.

It has been seventeen years since the term Ecologically Sustainable Development (ESD) was first used in Australian policy and, then, legislation and to guide interpretation of State and federal legislation. 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'. The Intergovernmental Agreement on the environment in 1992 is the most prominent first use of the term in an official Australian context. Although 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.

This paper will present case studies of ESD in two interstate aquifer systems: the Border Groundwater Agreement between South Australia and Victoria and the Great Artesian Basin Management committee. It will examine the new Water Act 2007 and the extent to which this implements the wide ESD requirements, and the legal implications of the wider powers referred to the federal government to manage water in the national interest. In addition, it will draw on legal case analysis, the results of surveys with water supply business managers, and on a technique called *Photostory*.

Keywords: Sustainable development law, reduced allocations, sustainable development limits, social sustainability.

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Institutional Assessment of the Transboundary Santa Cruz and San Pedro Aquifers on the United States – Mexico Border

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Shared, transboundary aquifers along the U.S. Mexico border 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 and Sonora, are essential water sources for growing cities, communities, farms, and ecosystems on both sides of the border. This paper examines the implications of contrasting urbanization patterns and the proximity of border communities for the institutional process of pursuing bi-national assessment of transboundary aquifers. We address issues related to the capacities of stakeholders to undertake and sustain cross border collaboration with specific reference to the U.S. Mexico Transboundary Aquifer Assessment Program (TAAP), which was authorized in the U.S. as Public Law 109 448 and signed in December 2006. It has been found that continuity of programmatic and funding support under TAAP for transboundary aquifer assessment is essential to collaborative initiatives. 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 National Water Commission coordinates the activities of state agencies and municipal water utilities, with university researchers playing a support role. Additional asymmetries include the relative emphasis each country places on the role of the U.S. Mexico International Boundary and Water Commission, with the U.S. seeking a coordination role and Mexico vesting priority setting and decision making in this bi-national commission. A specialized bi-national framework for coordination and data exchange developed specifically for the TAAP program is also discussed. The paper concludes with a discussion of the broader principles of transboundary collaboration as they relate to the management of shared aquifer resources.

Keywords: groundwater management, institutions, policy, asymmetry.

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International Institutional Framework to Allocate Groundwater, US-Mexico Border

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Water is a vital resource that must be managed effectively, especially in areas, such as the US-Mexico border, where this resource is increasingly scarce. The area of study is located along the entire border between the USA (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.

The border contains several major cities with a rapidly increasing water demand such as San Diego (US), Tijuana (Mexico), Ciudad Juarez (Mexico), El Paso (US), and Las Cruces (US) among others, as well as large agriculture exploitation 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 increasing demand and the effects of climate change. Private and public water management is addressed through a multidisciplinary point of view in order to obtain the critical data necessary to improve decision making regarding water allocation.

As surface water is scarce in the border region, a solution for water allocation will be, most likely, based on rational groundwater use. How to preserve and allocate groundwater is the main issue along the US-Mexico border. The study of groundwater levels and an examination of the legal framework surrounding groundwater trading provide knowledge to establish the best conservation practices. An international institutional groundwater framework has been developed. As part of this institutional framework, an umbrella agreement has been designed under the United Nations General Assembly Resolution 63/124 of 11 December 2008, carrying 'The Law of Ttransboundary Aquifers' and the United Nations Convention on the Law of Non-navigational Uses of International Watercourses 1997. The agreement establishes guidelines to allocate water on the US-Mexico border using the most efficient mechanisms. Its provisions also take into account flexibility, the effect of climate change and population growth. Recommendations for an institutional framework attempts to fill the legal vacuum of international and interstate groundwater management on the US-Mexico border.

Keywords: International agreement, border, groundwater, legal framework.

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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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Transboundary waters in Latin America have been and are opportunities for integration and cooperation as well as for 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. One such agreement is the Uruguay River Statute, an agreement signed between Argentina and Uruguay in the mid 1970s, which 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 international river basin tools in the South America region. Although 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. This paper will develop the issues that need to be incorporated into this instrument in order to successfully manage joint water resources as well as foster amicable conflict resolution.

The paper will propose the generation of new 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 updating the issues and treaty-architecture it deals with. These will be explored in this paper and they include, but are not limited to:

- improved civil society participatory processes in order to move away from state-centric outlooks and a more multi-stakeholder method;
- technical and policy inclusions in the organizational architecture of treaty – derived instruments;
- the inclusion of capacity building mechanisms;
- the inclusion of clearly functional governance structures;
- the inclusion of specific joint monitoring of activities and environmental impacts.

In conclusion, looking at a situation where the Uruguay River Treaty has failed to contain a conflict between two countries, but has managed a transboundary river for three decades, the paper will make policy recommendations to improve the instrument in order to minimize conflict and manage water use issues with a developmental framework that mutually benefits the countries and societies involved.

Keywords: Shared resources, international agreements, conflict resolution

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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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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 that receives recharge from rainfall or surface-water sources. 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 resource. Within a transboundary context, the finite and non-renewable nature of non-recharging groundwater has significant geo-political, economic and developmental implications. The International Law Commission (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 these ILC Draft Articles 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.

Keywords: Non-recharging groundwater, Transboundary groundwater, ILC Draft Articles on the Law of Transboundary Aquifers 2008, Bellagio Draft Treaty 1989, Transboundary Petroleum, Petroleum Unitisation Agreements, Joint Development Agreements.

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Effective Governance of Transboundary Groundwater Aquifers through Regional Institutions? – Lessons learned from River Basin Organizations

Susanne Schmeier[1]

While international institutions governing transboundary water resources have been established in a large number of international river and lake basins in order to minimize the risk of conflict and to jointly manage the resources at stake, transboundary aquifers have, so far, been widely neglected in institution building. Nevertheless, as, for example, the UN General Assembly Resolution on the Law of Transboundary Aquifers suggests, the international community has recently recognized the need for joint governance of transboundary aquifers. Creating regional or international institutions is thereby regarded as a means to institutionalize cooperation among riparians of a shared aquifer. Therefore, it seems likely that future years will experience the establishment of institutions similar to River Basin Organisations (RBOs) or that groundwater issues will be integrated in the work of existing RBOs in at least some of the world's transboundary aquifers.

However, it needs to be acknowledged that despite the existence of a high number of RBOs, many international rivers and lakes still face severe collective action problems, suggesting that the institutions in place are not sufficiently effective in governing the respective basins. As a result, recent hydropolitics research has increasingly focused on RBO effectiveness and derived a variety of hypotheses on the different potential explanatory factors that might impact the effectiveness of river basin governance.

This paper asks whether those recent findings on RBO effectiveness can provide insights for effective aquifer governance since the establishment of institutions provides a window of opportunity for applying lessons learned from river- and lake-related experiences to transboundary aquifers, hence avoiding mistakes that have previously been made in governing transboundary watercourses.

Based on an analytical framework for the assessment of the effectiveness of institutions governing transboundary watercourses in general (mapping the different independent variables accounting for variances in the effectiveness of river and lake basin governance), the paper aims at applying lessons learned from river basin governance to the specific issue-area of shared aquifers by adjusting assumptions and hypotheses to the specific characteristics of groundwater. This will allow for the provision of an assessment model for institutionalized aquifer governance that is at hand already when organizations for the management of transboundary aquifers are created or the functional scope of existing institutions is extended.

Keywords: Transboundary Aquifer Governance, Regional and Interstate Cooperation, Institution Building, River Basin Organizations (RBOs), Effectiveness.

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The Management of the Guarani Aquifer System: What Role for the Emerging International Law of Transboundary Aquifers?

Francesco Sindico[1]

The goal of this paper is to critically assess the role that the United Nations International Law Commission (UN ILC) draft articles on the Law of Transboundary Aquifers may have on the regulation of specific transboundary aquifers. The Guarani Aquifer System, shared by Argentina, Brazil, Uruguay and Paraguay, will be used as a case study for this purpose.

A tentative management structure of the Guarani Aquifer System has been laid out by the Organization of American States, the World Bank and the Global Environmental Facility in their 2000-2009 *Environmental Protection and Sustainable Development of the Guarani Aquifer System Project*. 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 Guarani Aquifer System. Countries will have to decide whether these 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 Guarani Aquifer System.

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 Guarani Aquifer System. 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 was held at the University of Surrey in August 2010 whose results will also be presented throughout this presentation. Finally, our study on the Guarani Aquifer System wishes 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.

Keywords: International Law, Transboundary Aquifers, Guarani Aquifer System.

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The UNECE 1999 Protocol on Water and Health and the Right to Water

Attila Tanzi[1]

The UNECE Protocol on Water and Health, adopted in London in 1999 will be presented against the background of the solemn declaration on 28 July 2010 by the UNGA on access to clean water and sanitation as a basic human right.

Accordingly, the Protocol will be analysed in relation to Art. 11 and 12 of the 1966 UN Covenant on Economic, Social and Cultural Rights, particularly as interpreted by the 2002 General Comment 15 of the Committee of the Covenant. In spite of the Protocol stemming from the water law process which has been from its inception a far cry from the human rights diplomacy that produced the Covenant, a comparative analysis of the two shows the complementarity and, in many respects, even the coincidence between them.

The presentation will illustrate how, even if the term 'human right' is not to be found in the Protocol – not even in its Preamble – the latter meets the minimum requirements of the core obligations stemming from Art. 11 and 12 of the Covenant. This applies with special regard to those 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 will be made that the Protocol, though 'duty oriented', is instrumental in the determination of the actual normative contents of the right to water and sanitation. In that respect, it will be shown how the leit motiv that underlies both instruments is to be found in the due diligence nature of their most characteristic provisions. This accounts for their progressive and goal oriented feature of their obligations enhancing the State legal accountability for water services, even under free-market regimes.

I 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.

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Transboundary Water Resources in Latin America: an Opportunity for Friendship and Cooperation Towards Sustainability

Ofelia C. Tujchneider[1]

South America is a very large continent with a great amount of water resources. These resources have an irregular distribution and the continent has arid regions in need of water for development.

This territory has very important superficial basins, most of them shared by several countries. To deal with transboundary issues, there are treaties and other legal tools developed by the riparian countries. Nevertheless, some disagreements or conflict situations arise from time to time, and the countries must perform new strategies to prevent this and develop better solutions.

South America has very large transboundary aquifers, the inventory of which began in 2002 by means of the UNESCO ISARM Americas Programme. Historically, interests and efforts were dedicated to studying and understanding superficial basins rather than groundwater. Unfortunately, much of both kinds of resources have been affected by pollution or overexploitation. As a result, their deterioration in both quality and quantity represents a major risk for future development.

In this paper, a synopsis on transboundary water located both in superficial basins and aquifers is presented. In addition, a general summary that regards legal and water policy is considered.

Keywords: transboundary aquifers, management, protection, cooperation.

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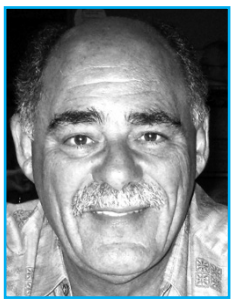
Transboundary Aquifer Institutions, Policies and Governance: A Preliminary Inquiry

R.G. Varady[1], C.A. Scott, S.B. Megdal and J.P. McEvoy



The paper will consider the various types and modes of institutions, policies, and governance that deal with transboundary groundwater basins. The presentation comes at the outset of a research effort that will combine a case-study approach with an analysis of the status of international aquifers and prospects for global governance. The authors begin this project by posing and exploring a number of salient questions:

What have been some prevailing modes of governing transboundary aquifers *multinationally*? Each nation has modes of administering, managing, and governing water resources within its own territory. But to what extent have nations developed instruments —both 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 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)?

The United Nations General Assembly, in December 2008, adopted a resolution aimed at eventually adopting a 'Law of Transboundary Aquifers'. Transboundary aquifers, because they include actual 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?

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?

Keywords: Transboundary, aquifers, governance, institutions, policies.

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Moving Towards the Guarani Aquifer Management: The Brazilian Case

Pilar Carolina Villar[1]

Brazil has eleven transboundary aquifers including the important Guarani Aquifer that has been the subject of international projects that broadened the debate on groundwater beyond natural sciences and engineering. Of the four countries that share this aquifer (Argentina, Brazil, Paraguay and Uruguay), Brazil is the one that has the most structured water-body management system. Nevertheless, groundwater public policy is still in an embryonic stage. This study intends to contextualize the deficiencies in Brazilian regulatory landmarks and the ongoing strategies for the management of the Guarani Aquifer. This is a descriptive study of the laws related to groundwater protection and its qualitative analysis. The absence of an 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 of whether or not 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. Watershed plans are responsible for including the aquifers in the water management but technical, geographic and administrative limitations make this task difficult. The collection for groundwater and the water-body classification have already been regulated, but still await their application by the watershed committees. Parallel to this, the increase in the number of well permits and licenses stands out. 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. Within the state of São Paulo, there is an institutional effort to create a law that transforms Guarani's recharge area into a spring-protection area. This area would span seven watersheds and would be the first joint-management experience of the aquifer between watersheds. Another positive point is the strengthening of the concept of paying for environmental services in the country, even if the existing initiatives are concentrated on superficial resources, which can end up impacting groundwater. 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 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. Initiatives gradually appear to include 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. Greater participation of these players could also contribute to the stimulation of 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.

Keywords: Guarani aquifer, legislation, water policy, Brazil.

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Groundwater and Global Water Security

Mark Zeitoun[1]

The presentation explores how efforts to 'secure' water resources by many states and by the global policy community can be improved. Existing efforts are generally inadequate for two reasons. The first is an incomplete understanding of the resource itself. Water resources managers and policy-makers remain fixated on surface water, all too often ignoring the reserves of groundwater and soil water, as well as the water used to produce tradable goods ('virtual water'). The second reason is that there is a collective failure to recognise that water security is not just about water. The hydrological cycle substantially affects and is impacted by other major global 'security areas', which include climate change, food security, energy security – and the international cooperation required to deliver regional, state, and human security. The growing interest in groundwater by the international water, security and legal communities serves to partially redress the inadequacies. The development and implementation of more effective international regulation guiding food trade, and transboundary groundwater protection and allocation are highlighted as the appropriate guiding policy goals.

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TOPIC 4
Strengthening cooperation

Analysis of the Negotiation to Use Groundwater between the Totora, Pomabamba and Huaraclla Communities, District of Jesus, Province and Department of Cajamarca, Peru

Gilberto Cruzado Vásquez[1]

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The research was carried out in the Llamac basin of Peru, which is composed of three communities. The highest, known as Totora, is situated 3,200–3,680 meters above sea level. The physiographic landscape corresponds to the mountain and is covered by grass known as *ichu* or *hualte*, which allows water to infiltrate through the soil and underlying sandstone. This part of the basin is occupied by peoples coming from several parts of the district of Jesus. They have meals and agricultural products to sell (therefore income) as their lands are green for most of the year due to the large amounts of water in their area.

The aforementioned geological conditions permit the birth of several springs in the central community of the basin known as Pomabamba, situated 2,700–3,200 meters above sea level. This part of the basin is occupied by indigenous peoples whose land is green mainly during winter as water availability decreases during summer. Since there is low crop productivity during summer, a water crisis arises.

Little water flows to the lowest community of the basin, Huaraclla, which corresponds to the valley, is dominated by sands and clay, and is inhabited by Spanish descendants. As a result, conflict between the Spanish descendants and the indigenous peoples of the Pomabamba area has been around for hundreds of years. After several meetings to negotiate and so to solve the problem, they arrived at a simple solution: the inhabitants of Pomabamba will use the water during the day, but at night, water will be used by the inhabitants of Huaraclla except on Saturdays and Sundays when they can use water throughout the day. The people of Totora are not involved in this conflict as their area has abundant amounts of water.

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The Urgency of Preventive Mediation on Water Issues: the Bolson del Hueco Aquifer in El Paso, United States of America and Ciudad Juárez, Mexico

Dominique de Courcelles[1]

The Bolsón del Hueco aquifer forms part of the Rio Grande water system. It starts in the United States of America (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 1,200 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 increase in salinity.

Water from the aquifer is used for domestic and 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 Juárez, 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 Juárez, 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 of 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 (Comisión del Agua del Paso del Norte) was created to promote cooperation on water issues. Along with the International Boundary and Water Commission, the Paso del Norte Water Task Force is working to protect and conserve the transboundary aquifers. 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 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.

Keywords: Ciudad Juárez-El Paso; Global management of water; Education of the demand; Water treatment of waste and sanitation; Redistribution; Mediation; Ethics.

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Managing Hidden Treasures across Frontiers: The International Law of Transboundary Aquifers

Gabriel E. Eckstein[1]

Although there is only one international agreement in the entire world that squarely addresses the allocation and management of a transboundary aquifer (on 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. They have been the focus of local arrangements, such as between the sister cities of Ciudad Juárez, Mexico, and El Paso, USA, and between the US State of Washington and Canadian Provence of British Columbia. Similarly, they were addressed in negotiations between countries such as those underlain by the Guarani Aquifer in South America and the Nubian Sandstone Aquifer in northern Africa. Furthermore, in 2008, transboundary aquifers came to the attention of the UN General Assembly when it acknowledged the work of the UN International Law Commission and the latter group's effort to codify the international Law of Transboundary Aquifers.

The law of transboundary aquifers is in the early stage of development. Nonetheless, a body of experience and practice is slowly developing, indicating that legal principles may be emerging. This is evidenced by both the growing attention that the subject is receiving as well as the increase in the number of states that are considering how best to manage groundwater resources that traverse their frontiers.

This study will review the various experiences of states and the pronouncements of various international organizations as a basis for the development of customary international law for transboundary aquifers. It will begin by considering the importance of transboundary aquifers as a source of fresh water for people and the environment. It will then identify and discuss specific examples where transboundary groundwater resources were subjected to some arrangement over their assessment, use, allocation, and/or protection by aquifer riparians. The study will then assess these examples and identify trends in the practices that might point to the development of generally accepted legal principles applicable to such resources. Finally, the study will consider gaps and shortcomings in the emerging regulatory system and offer recommendations for the further development of the law.

Keywords: international water law, international groundwater law, transboundary aquifer, water dispute.

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Complex Projects Modelling as a Tool to Establish a Cooperation Framework Within Transboundary Aquifers

E. Hassenforder[1], B. Noury[2] and P. Daniel[3]


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Transboundary aquifers are a relatively new subject. In particular cases, when the resource is confined and its flow is relatively slow, parties tend to wait for a problem to emerge before they 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 that can give rise to conflicts and overcome 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 the identification of 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 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:* certain elements that cannot be forecasted by stakeholders and project management teams 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 there is a lot to learn from existing best practices.

Keywords: Modelling, conflict anticipation, complexity, risks, uncertainty, stakeholders' management, project.

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Peak Water Meets Peak Oil: Moving Towards Unitization of Transboundary Aquifers

Todd Jarvis[1]

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), non-renewable groundwater that 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 on how to 'share' 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 non-renewable groundwater situations. A few case studies where unitization concepts are being applied to groundwater will be presented.

Keywords: Institutional advances, unitization, dispute prevention, economics.

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The Use of Water Allocation Models in Managing Transboundary Water Resources: A Case from Palestine

A.F. Jayyousi[1] and M.N. Almasri[2]


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In many regions of the world, water is scarce. This scarcity causes conflicts that, in the case of transboundary water sources, are often between political entities or states. Different states put forward conflicting arguments, usually based on conflicting principles, concerning their water rights to certain a transboundary source. 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 this is the conflict over the transboundary water resources between Israel and Palestine. In such cases, the use of water allocation models, especially by Palestinians, can prove the inequitable distribution imposed by the Israelis in addition to the gain that parties can get through cooperative management of transboundary sources. An example of such water allocation models is the Water Allocation System (WAS), a tool developed by a group of scientists from Massachusetts Institute of Technology (MIT) and involved, among others, a group of scientists from Palestine, Israel and Jordan. The model presents a different way in looking at water disputes, which 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 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 is indeed 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 states of the transboundary water sources.

Keywords: Palestine, Water allocation, Management, WAS, Transboundary.

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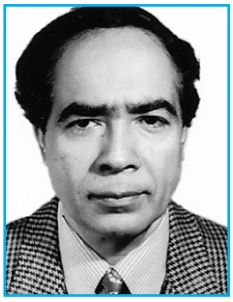
Setting the Stage for Cooperation between Bangladesh and India for Transboundary Aquifers

Abu Taher Khandakar[1]



Bangladesh, a landmass of 147,500 km^2, is sandwiched within 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, originating at the foot of the Himalayas, with a length of 2,510 km (2185 km in India and 325 km in Bangladesh); ii) The Brahmaputra river system, 2,840 km long, traveling only 410 km in Bangladesh; and iii) The Meghna river system with a total length of 946 km, traveling 669 km within Indian territory. Altogether, these river-systems have a 1.72 million km^2 catchment area of which only about 8% is within Bangladesh. Apart from these three river-systems, another 51 rivers enter Bangladesh from India. During monsoon season, from June to September, all rivers originating in India force about 1,250 billion m^3 of water annually into 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). During the dry season, from November to April when rabi and staple food boro paddy (HYV) are produced with irrigation water, Bangladesh faces acute shortages of surface water.

Prior to 1975, Bangladesh had sufficient water in the rivers during the dry season, generated partly by the melting of glaciers in the Himalayas and partly from groundwater at shallow depths released mostly within India. In 1975, India commissioned a barrage on the Ganges at Farakka and started diverting surface water towards Kolkata port during the dry season that would have otherwise reached Bangladesh. This forced Bangladesh to engage in groundwater irrigation practices, sinking shallow tubewells. In addition, about 95% population of the country could have access to groundwater as potable water through shallow tubewells. This has also become a practice within the regions of India bordering Bangladesh.

However, in the 1990s, a serious setback occurred when scientists detected large scale contamination of groundwater with arsenic in the region. This situation led to severe health problems and, of late, scientists have reported that crops have also been affected. Now, both Bangladesh and India extract groundwater from deep aquifers for irrigation and drinking.

For the last three decades, there was insignificant cooperation between India and Bangladesh on sharing common rivers' water. In addition, there was more suffering among the people of Bangladesh than those of India. A similar situation may develop in the future for people of both countries 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.

Keywords: Ganges, Brahmaputra, Maghna, Farakka, Bay of Bengal, arsenic, shared aquifer.

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Mitigation and Prevention of Conflicts on Border Aquifers between Colombia and Venezuela: Far from the Rhetoric, Closer to the Reality

Hernando Martinez[1]

While present day political and social conflicts over water resources in our world should be eliminated completely, realistically, we can only reduce or deter them. It is, however, imperative that we reduce them. The majority of aquifers located in the Colombia – Venezuela border regions are not seriously considered in order to eliminate or mitigate future conflicts over 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 lack of adequate knowledge on groundwater resources and of common public policies in those regions of both countries is of concern. This situation could generate border conflicts in diverse fields such as science, economy, armed forces, international policy and social relations. We must remember the history of the political conflict between Colombia and Venezuela regarding the ownership of the oil reservoirs in the Gulf of Venezuela.

The main objective here is to evaluate any natural and social risks as well as the possibility of mitigating their effects. For this reason, this research is based on field work on groundwater supply and geological exploration in different border regions of Colombia such as Arauca, Casanare, Cesar, Guajira, and Santander, where groundwater use is increasing. Knowledge and experience on public policy in this region, with emphasis on prevention and mitigation of disasters, will be used to support the risk assessment. In addition, there will be a literature review of official documentation from the two countries with a concentration on geology, hydrogeology and public policies. Information from the United Nations and official documentation from different agencies in both countries will be used. This literature review is based on three fundamental questions asked in order to minimize a high risk of future conflicts caused by groundwater supply along the border of Colombia and Venezuela: i) Is it necessary to visualize real interests in regional and local governments for an industrial future?; ii) Are the protection laws and rules of water usage adequate on the border of Colombia and Venezuela?; iii) Did the conflict over oil productivity lead to the vulnerability of the Colombian or Venezuelan governments?

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, there has been a steady increment in the extraction of coal for the last thirty years (e.g. the Guajira area in Colombia that has the largest overland mine in the world). Coal extraction has been developing mining processes that can affect groundwater conditions such as water quality, contamination and a drastic decrease in the water table and piezometric levels. This paper will demonstrate that both governments have a political stake in protecting their border aquifers. It is recommended that the utilization of hydrogeological information using geographical scales should be close to 1:50,000 (km) as a priority. Obtaining hydrogeological data is recommended as well. In addition, it is necessary to elaborate and share public policies for groundwater supply on the basis of an international agreement. For instance, the paper will outline a bill aimed to protect border aquifers that can be considered by both governments together or separately without ignoring the other's interests and public policies. For more efficiency, it is necessary to follow and control these policies with a deep emphasis on education about natural resources, their utilization and, logically, their protection. In the research, we can find constitutional interests for both countries to protect their natural resources through general legislations from their respective congresses without forgetting that it is also necessary to achieve a local and regional compromise on the issue.

Keywords: Mitigation, Risk Assessment, Risk Management, Vulnerability, Political Conflict, Policy, Hydrogeology.

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Transboundary Groundwaters: Experiences of Conflict Management and Regional Cooperation in East Africa

Mathias Joseph Mulagwanda[1]

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 potential threat of dispute over the 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. Tanzania has an abundance of surface water across its nine river basins and is geographically better positioned in that most of its borders with neighbouring countries is mostly water masses in the form of lakes and rivers. 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 behavior between people or groups occurring when they compete over perceived or actual incompatible goals or limited resources. It is often seen as negative. However, conflict can lead to greater self-awareness and understanding and awareness of the diversity and differences between people, organizations and societies. The general lack of technical cooperation, data sharing, training and research between riparian states on hydrogeology hampers a mutual understanding of transboundary groundwater resources. There are, however, initiatives in the Southern Africa Development Community 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 the 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 the African Ministers' Council on Water (AMCOW), the African Union (AU) and their constituent bodies is needed. This paper addresses potential conflicts and cooperation potential as well as conflict management strategies that will result in peaceful transformation.

Keywords: Conflict Management, Knowledge Base, Transboundary groundwater, Regional Cooperation.

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Management of Transnational Groundwater Resources in the East of the European Union: Challenges and Opportunities

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Water is a crucial medium for sustaining human life. Groundwater resources are of increasing significance for the domestic economy as surface waters, the main water source used by humans over the ages, are progressively becoming more contaminated. At present, 70% of Poland's water use is based on groundwater. Interest in water management issues on a transboundary scale is a relatively new phenomenon that has grown over the last few decades. Transnational cooperation is a key issue in the implementation process of Water Framework (WF) and Groundwater (GW) directives, and to minimise the disparities in the status of national water management.

Poland, located in the eastern region of the European Union (EU), divides the Bug and San River basins between the Ukraine and Belarus. Both neighbors use different definitions and terms applicable to the issues of water protection and management. In 2006, the new Science for Peace and Security (SPS) NATO Pilot Study project 'Sustainable Use and Protection of Groundwater Resources - Transboundary Water Management - Belarus, Poland, Ukraine' was launched. The main principle of this project is to prepare an expert discussion platform for rational groundwater management and the efficient protection of transnational resources in Central and Eastern Europe. It was, first of all, very important to strengthen the knowledge about water management systems in riparian countries. In this case, there were experiences of other projects done in the area that were very helpful. The monitoring system is essential in the process of analyzing factors influencing water. The importance of building a united transnational groundwater monitoring system was emphasised during many project discussions.

The Bug river basin, comprising significant areas of the Ukraine and Poland, has been recognized by the international community as an area under serious ecological stress. Working on a transnational groundwater system could not be done without taking the entire water circulation system, especially surface waters, into account. It is a great challenge for scientist to work out a unified system of monitoring water issues as well as introducing the whole management structure and activities procedures. The Bug river basin can be treated as a test area and, in future, the project should evolve into a regional one where more countries from Central and Eastern Europe are involved. Encouraging different groups of scientists from many European countries embroiled in related issues to exchange their experiences will also be one of the important benefits of the undertaken activities. The development of groundwater research will be a great opportunity for the region to strengthen its environmental protection activities and understanding of issues in local society.

Keywords: groundwater, transboundary aquifers, East Europe, water management.

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Towards a Regional Strategy for the Management of the Transboundary Aquifer Systems in the Americas

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1 2 4 5 6 8

The ISARM-Americas initiative has been very 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 UNESCO and the Organization of American States (OAS), succeeded in inventorying 68 TAS in the American hemisphere. The initiative has produced two books; one containing the inventory of the 68 TAS in 2007, and a second one describing the legal and institutional aspects of the 68 TAS in 2008. A third book will be published in 2010 with a synthesis of the socio-economic, environmental and climatic aspects of the 68 TAS.

Following the adoption of the Resolution (A/RES/63/124) on the 'Law of Transboundary Aquifers' by the UN General Assembly in December 2008, the ISARM-Americas group is now preparing a regional strategy for the management of the TAS in the American hemisphere. The Strategy of the American Transboundary Aquifer Systems (SATAS) will take into account 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 three books published, as well as the very successful network of national coordinators 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. 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 neighborliness, and the adoption of common goals for a sustainable management of aquifer crossing two or more jurisdictions in the American hemisphere. The strategy is designed with strong scientifically-based content aiming at guiding the stakeholders toward informed joint-management decisions, and to help meet the expectations of users of transboundary groundwater resources in terms of water security.

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.

Keywords: American collaboration, good neighborliness, common goals for a sustainable management strategy, strategy to acquire necessary knowledge in the countries of the American continent.

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Comparing Conflict in Transboundary Aquifer Management: Some Insights from a Comparative Study between Spain and Australia

Justin Story[1] and Elena Lopez-Gunn[2]

The paper will analyse and compare specific case studies in Australia and Spain that can be considered 'transboundary' from different perspectives. 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 Australia and Spain have large areas that can be considered as semiarid environments. This has lead to, correspondingly, a high value being placed on groundwater resources that act as somewhat of a natural 'insurance' system on drought. Sharing groundwater, given the often competing uses, requires particularly strong institutional frameworks in such cases. Upcoming issues, lessons and opportunities learned 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 will focus on cases in Australia that have competing uses between agriculture, urban water supply, industry and environmental flows (surface water – groundwater interactions) such as the Gnangara Mound in Western Australia. It will also look at how potential conflicts (and resolution and mediation) compares to similar cases on the Portuguese-Spanish border. Issues of scale related to policy measures will be explored with the international and intra-national examples.

Keywords: Comparison, scaling issues, semi-arid environment, policy, conflict.

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Addressing the Socio-economic and Institutional Dimensions in Transboundary Aquifer Management by Using Hydro-economic Modeling and Serious Gaming

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Many present transboundary aquifer (TBA) management studies take a non-political hydrogeological approach. The transboundary aquifer issue is seen as a common hydrogeological problem and activities are directed at improving the understanding of the physical groundwater system. The administrative boundary crossing the shared aquifer is merely considered as a factor complicating the hydrogeological studies as it requires additional harmonization of shared groundwater data and information and coordination between the organizations responsible for data collection, analysis and sharing. This approach only partially addresses the socio-economic and institutional dimensions and often results in not more than a dry enumeration of the various water users, uses and institutional organizations in the TBA.

This is a significantly different picture on TBA management than what one obtains when departing from the disciplines of environmental economics and/or political economy. In environmental economics, TBA management is seen as a special case of studying socio-economics in natural resources management (NRM) answering how to allocate the internationally shared (and scarce) groundwater resources in an economical, environmentally sustainable and equitable way. Political economists consider TBA management as a coordination problem (over shared natural resources) between sovereign states that need to sustain national sovereignty, also addressing the costs and benefits of cooperation and conflict. In the vast literature from these disciplines on transboundary NRM, the socio-economic and institutional dimensions are explicitly addressed. However, knowledge on the functioning of the physical groundwater system is often considered less important or even irrelevant.

Environmental economics and political economy have developed and applied various tools to address the socio-economic and institutional dimensions of (transboundary) NRM. This paper focuses on two of these tools/approaches that may be useful for TBA management. Examples of applications in case studies are given. Firstly, attention is paid to the approach of hydro-economic modeling which combines the distributed hydrological modeling (that is well-known to hydrogeologists) with economic valuations of the groundwater. Such modeling makes explicit the distribution of costs and benefits of groundwater use over the shared aquifer and quantifies the economic externalities of interventions in the aquifer. Secondly, the role of serious gaming in awareness raising, socio-economic and institutional analysis and social learning and thrust-building in TBA management is discussed.

The paper is rounded off with some directions and ideas on socio-economic and institutional analysis in TBA management that are considered relevant and worthwhile exploring for bringing the ISARM program to the next level.

Keywords: socio-economic and institutional dimension, hydro-economic modeling, serious gaming.

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Water as a Parameter of Cooperation between Morocco and Algeria: the Case of the Angad-Maghnia Transboundary Stressed Aquifers of the Bounaïm-Tafna Basin

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1

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 2,650 km^2, 70% of which is located in Morocco. The Angad-Maghnia aquifers, two aquifers (confined and unconfined), constitute a large freshwater reservoir shared between two riparian countries, which symbolise a major asset for the regional socioeconomic development. To date, mismanagement mainly due to groundwater overexploitation has had ominous repercussions on both sides of the border. Currently, a remarkable decrease of the piezometric level has been recorded with the drying up of some wells and the presence of contaminants (nitrate) on the Angad-Maghnia plain. These impacts are felt on both sides of the border but no action has so far been undertaken although both countries have passed water laws and have adopted the principle of Integrated Water Resources Management at the national level.

In this region, groundwater resources are vulnerable in terms of the highest severity on both quantity and quality. It is a hydrogeopolitically vulnerable zone and should be the subject of an assessment and periodic surveillance to ensure sustainable and equitable management. In addition, 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 including the 1963 Sands War, the expulsion of 45,000 Moroccan families from Algeria following the start of the conflict of the Sahara in 1975, and the 1994 closing of the borders that still remains a military zone. 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 groundwater?

The methodology adopted in this work is based on a first 'unofficial' cooperation in order to better understand the hydrologeological system and to assure its improved protection, establish the confidence between the local actors of the two countries, and identify the objectives and actions to be undertaken so as to move from non-cooperation to cooperation.

Keywords: transboundary aquifers, Bounaïm basin, stressed aquifers, Morocco, Algeria, Cooperation.

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POSTERS

Recharge Mechanism to North-Western Sahara Aquifer System (NWSAS) using Environmental Isotopes

Samir Anwar Al-Gamal[1]

Understanding the aquifer system is highly needed to provide successful transboundary cooperation policies. Moreover, an analysis of the NWSAS can be of particular interest for policymakers and researchers. This paper aims to reveal and assess the renewability of North Western Sahara Aquifer System (NWSAS) as one of the major transboundary multi-layered aquifer system, in North Africa, shared by Algeria, Tunisia, and Libya which is often referred to as the "Système Aquifère du Sahara Septentrional' (SASS).The paper is primarily intended for exploring whether the aquifer system receives a considerable portion of new water as recharge or if it is at risk of being depleted and excessively pumped, where the main challenge for NWSAS, would be the rationalization of water extraction for equitable use.

Environmental isotopes data of $\delta^{18}O$, $\delta^{2}H$, ^{3}H, ^{14}C as well as characteristics of d-excess are used to illustrate whether NSWAS is a renewable or non-renewable resource. Geochemical, hydrological and statistical evidences supporting the renewability of NWSAS are provided through pairs of cross-plots.

The study has clearly indicated that NWSAS is receiving a considerable fraction of modern water as recharge to the aquifer because of the following reasons: First, the moderately depleted delta values of O-18 and H-2 of water from Sahara Atlas in Algeria and the Dahar and the Dj. Nefoussa in Tunisia and Libya with $\delta^{18}O$ content (- 6.0‰ to -5.0‰) compared with that of palaeowater (-7.0 to -9.0 ‰) indicate a considerable fraction of modern water recharging NWSAS. This considerable fraction of modern water should be attributed to original from the present-day precipitation (-6.5‰). Second, the presence of significant amount of ^{14}C >2 % and ^{3}H > 5TU frequently found in data should be attributed to a mix with shallow and modern water, where old water practically contains no ^{14}C.

The foregoing facts match with the results of the conventional hydrologic approach ones. It would contradict the assumption that the NWSAS is non-renewable water resource. In this context, the NWSAS is being located in one of the driest regions on the planet; these huge resources have been recognized to be of great importance for the socio-economic development of its riparian countries. The present paper addresses the necessity of identifying specific cooperation problems which evolve out of these hydrogeological attributes and prevalent use patterns.

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-enewable' would therefore be misleading and represent one of the most obvious inaccuracy as well.

Keywords: Stable Isotopes of ^{18}O and ^{2}H, unstable isotopes of ^{14}C and ^{3}H.renewal, Socio-economic Development, Riparian.

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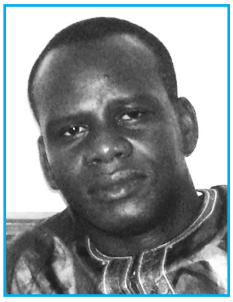
Tools for the Management of Large Transboundary Aquifers: The OSS Experience

Mohamedou Ould Baba Sy[1]



The focal area of the Sahara and Sahel Observatory (OSS) is based in the Sahara and Sahel zone which contains large sedimentary basins that are each covering a surface of several hundreds of thousands of km². The OSS promotes the concept of 'basin awareness' by encouraging the countries sharing a transboundary basin to work together in order to manage the groundwater resource in a rational manner. In the context of this consultation, the collection and the harmonization of data and information are important, because they are unavoidable when knowledge of aquifers needs to be updated. They are then grouped into the common database (DB) for riparian countries to supply management models of groundwater resources.

A considerable volume of information is collected on the aquifers. However, this information is fragmented and thus, unusable without formatting and prior treatment.

The layers of the Geographical Information System (GIS) consist of: treated and homogenized topographic map, digitalized hydrogeological layers, map of the watering places extracted from the database, grid relative to the hydrogeological model layers, and all the thematic maps elaborated from the queries.

The GIS plays a significant role in the system set in place as it is used at each step during the treatment of the data:

- correction or reconstitution of certain parameters;

- queries to detect mistakes;

- grid generation by using the language incorporated in SIG software;

- connection with the numerical model.

The development of all these tools (database, GIS and model) contributes to the update of knowledge regarding the aquifer, improves the exchange and strengthens cooperation between countries.

Keywords: Database, GIS, Model,Aquifer.

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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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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 ‰ ≤ δ2H ≤ 21.66 ‰) and oxygen-18 (-14.76 ‰ ≤ δ18O ≤ 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. Twenty 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.

Keywords: Trifinio, Transboundary Aquifers, Isotope Hydrology, Lempa River.

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Towards the Sustainable Management of the Guaraní Water System in the Argentina Republic

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This investigation is intended to summarize the relevant institutional and legal aspects related to environmental protection and sustainable development of the Guaraní Water System in the Argentine Republic. The present work follows a qualitative-comparative research method of investigation. Up to now, the institutional and legal frameworks regarding underground water in the Argentine provinces (including SAG) are in general signed by a great number of organisms and have to go through a superposition of legislations. The depicted situation risks the elaboration and consequently implementation of an inappropriate model of management applicable to the SAG in the Argentine Republic. Therefore, 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 including all the Argentine Provinces involved in the SGA to harmonize the directions that will lead to environmental order of the territory, control system on the development of the anthropic activities, environmental education, economic system promoting sustainable development, technical norms for the construction of deep wells and systems for the waste thermal resources' drainage.

Keywords: Management, Legislations, Protection, Sustainable.

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Transboundary Aquifer of the Northern Thailand

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The detailed hydrogeology of the Chiang Rai and Pha Yao Provinces in Northern Thailand was studied by the Department of Groundwater Resources, aiming a better groundwater management of this resource. The conjunctive use of surface water and groundwater is planned as a part of a larger project for the development of a green society. The area covers 11,000 square kilometres 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 the 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 a high content of iron, and in some places, by high manganese and fluoride contents. Groundwater flow direction, aquifer hydraulic properties, groundwater potential and groundwater uses are also studied.

This study provides a basic knowledge that benefits the Mekong River Commission (MRC) countries and also the Dialogue Partners of the MRC, i.e. Cambodia, Lao PDR, Vietnam, Thailand, China and Myanmar. A joint management of their shared water resources would form a strong foundation for sustainable development and poverty alleviation in the Greater Mekong Sub-region.

Keywords: Transboundary Aquifer, Northern Thailand, Mae Sai Basin, Mekong River.

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Scaldwin project – Aquifer Sustainable Management

François Crastes de Paulet[1]

Since the beginning of the 20th century, the Carboniferous aquifer between France (Fr) and Belgium (Be) was known as a high potential aquifer. Groundwater has been exploited for decades to provide potable water and supply heavy factories in France (Lille and its suburbs representing 1 million inhabitants) and Belgium. Over-pumped during the second part of the 20th century, the Carboniferous aquifer has seen its water level dramatically decrease up to 90 m deep in France. From the 90s until now, corresponding to the end of the industrial period, groundwater consumption has decreased and the water table has now stabilized and is slowly returning to a more 'natural' level in some areas. However, this recent rise in water level has triggered some chemicals problems such as the release of heavy chemical compounds and sulphurs.

The Carboniferous limestone aquifer is composed of 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 a karstified zone. The study area is 120 km long from Armentières (Fr) to Namur (Be), and 30 km wide on both sides of the administrative boundary.

Recharge areas are located in the eastern part of the aquifer, in Belgium, where limestones lay under a few meters of soil (unsaturated zone). Slightly dipping from south to west, the geometry of the aquifer is not accurately known due to a lot of east - west faults and the presence of a faulted syncline near Tournai (Be). Therefore, groundwater is mainly considered as confined in the western part of the study area due to the impermeable cover by clayey layers (Secondary and Tertiary, depending on location).

A lot of hypotheses have been made in the past regarding geometry and piezometry, and must be analyzed by new borehole and hydrogeological data to be acquired in some zones of the study area.

The establishment of a European legal framework for community action in the field of water policy helped build the international project called 'Scaldwin' in 2009. On one hand, it should encourage and stimulate international cooperation at a large scale: studies and methods standardisation, data transfer and sharing, and common reporting process. On the other hand, this cooperation will reduce scientific uncertainties about the Carboniferous aquifer: more accurate geometry, building of geological and hydrogeological referentials, extension of piezometric maps, hydrochemical and isotopic characterization of different groundwaters, etc. As a result of the next field campaigns, 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 model transfer functions between surface water and groundwater in order to organize the sustainable management of the Carboniferous aquifer between France and Belgium.

Keywords: France, Belgium, Carboniferous, limestone, karst, aquifer management.

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Multi-disciplinary Approach to Improve the Knowledge of South-Eeastern Border of Taoudeni Sedimentary Basin

Denis Dakouré[1]

The south-west of Burkina Faso shares a regional aquifer system with the south of Mali that forms part of West Africa's large sedimentary basin of Taoudeni. With a surface area of around 40,000 km^2 inside Burkina Faso, and a depth that can reach more than 2,000 meters, this sedimentary aquifer system provides most of the water resources exploited for human (drinking water) and economic (mainly agriculture) needs in the country.

In a critical semi-arid context characterised by the notable decrease in pluviometry observed over the last 40 years, and by a demographic explosion resulting in a highly increased need for water for human consumption and for economic development, the management of this important groundwater resource has become a priority not only for the authorities of Burkina Faso, but also for the international community.

A hydrogeological multi-disciplinary approach, combining, amongst others, stratigraphy, hydrodynamic field-data, geochemistry and isotopic techniques with geological and hydrogeological modeling, is being implemented to improve the knowledge of the aquifer system and the efficiency of its management.

Keywords: Burkina Faso, Mali, Taoudeni, sedimentary basin, multi-disciplinary approach, hydrogeology.

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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

Paula A. Diaz

Context: In South America, based on United Nations estimates, 50 to 60 percent of the total domestic and industrial water supply comes from groundwater resources, making them fundamental for the region's development. Through the UNESCO/OAS ISARM Americas Programme, 29 transboundary aquifers have been identified in South America, including a large regional aquifer system called: 'Amazon Transboundary Aquifer System (ATAS)'. The ATAS appears to be shared by six different countries: Bolivia, Brazil, Colombia, Ecuador, Perú and Venezuela, and is potentially one of the largest transboundary aquifers in South America. The initial data collected and compiled by the ISARM Programme indicates that the principal use of the ATAS is for human supply, it also may be the only source of non-polluted water for many communities.

In general, Latin American countries have a sparse understanding of their groundwater resources, demonstrated by the weakness of domestic laws or regulations specific to groundwater, and regional cooperative frameworks for managing transboundary aquifers. The ATAS is not the exception. Currently, there are no frameworks for its governance and management, and there remains much uncertainty regarding not only its physical characteristics but also its socioeconomic impact on riparian communities.

In 2008, the United Nations (UN) International Law Commission (ILC) adopted draft articles for an international framework convention on transboundary aquifers, which was subsequently adopted by the UN General Assembly. The ILC draft articles on the Law of Transboundary Aquifers have been the latest step at the international level toward a framework of transboundary aquifer principles.

Purpose: The intent of this project was to identify and analyze the opportunities and challenges the ATAS States would face in the development of a collaborative framework to govern and manage the ATAS. Additionally, an analysis was conducted to understand how the principles and mechanisms advanced by the ILC draft articles on the Law of Transboundary Aquifers could be employed in order to enhance and address the opportunities and challenges identified. Finally, recommendations for the ILC draft articles were developed.

Findings: Before the ILC draft articles can be successfully implemented for achieving governance and management of the ATAS, the ATAS States have to reach a certain level of action, cooperation, knowledge and understanding. The ILC draft articles are important tools that could help guide this process. Thus, they 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 to reach a common understanding, and how to develop appropriate monitoring and assessment frameworks. The ILC draft articles should also promote and emphasize the importance of coordinating surface water regimes with groundwater regimes. Lastly, the ILC draft articles should embrace better the principles of acting proactively, intergenerational equity, and sustainability.

Keywords: Amazon, Aquifer, Draft Articles, Groundwater, International, Law, Management, South America, Transboundary, United Nations.

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Assessment of the Groundwater Quality Status and Vulnerability of the Coastal Aquifer Systems of Benin, Nigeria and Togo (West Africa)

Aniekan Edet[1]

The coastal sedimentary transboundary aquifer of West Africa is shared by the Republic of Benin, Nigeria and Togo. The groundwater resources in the region are mainly for domestic water supply in both urban and rural areas. Key cities such as Lome, Cotonou, Lagos, Warri and Port Harcourt rely on groundwater for a significant proportion of their water supplies. With the pressure on groundwater, some problems exist that include but are not limited to overexploitation, contamination and pollution from poor waste disposal and intrusion of sea water. The present work entails the identification of the sub-aquifers, determination of the quality status of the groundwater using major ions and assessment of the coastal aquifer vulnerability to pollution. The results identified seven sub-aquifers within the study area and are as follows: Lower and Upper aquifers (Republic of Benin), Deltaic and Benin Aquifers (Nigeria) and Continental Terminal (CT), Eo-Paleocene (Eo-Pa) and Maestrichtian (Ma) aquifers in Togo. The hydrochemical data indicated that the groundwater in the region is of Ca-HCO_3 (Lower, Eo-Pa and Ma aquifers), Na-HCO_3 (Upper, Benin & CT aquifers) and NaCl (Deltaic aquifer) in nature. The average physicochemical compositions are generally within the levels of portability. The mean concentration of nitrate, however, exceeded 10mg/l in all the aquifers assessed except the Deltaic (mean 2.82mg/l) and Eo-Pa (7.88 mg/l). The major factors controlling the water chemistry in the study area are sea water intrusion (enhanced Cl), ion exchange ($Ca+Mg < SO_4 + HCO_3$) and human activities (enhanced NO_3). Vulnerability assessment according to the GOD method indicates that the aquifer systems are lowly (Upper, Eo-Pa and Ma aquifers) through moderately (Benin & CT aquifers) to highly (Lower & Deltaic aquifers) vulnerable. The implication of these results to the management of the coastal aquifers is highlighted in this article.

Keywords: Aquifer, hydrochemical, pollution, transboundary, vulnerability.

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Prospective Regulatory Environmental Services Provider for Aquifer Recovery

Nagwa Elnwishy[1]

Aquifers are a source of potable water in numerous sites of Egypt. For years, farmers have dug many wells to drink, supplementing the rainfall and growing fully irrigated summer crops. But then, overexploitation of this groundwater became a major concern especially with climate change problems. In most of Egyptian sites, the aquifer system does not have the capacity to support full irrigation. Thus, traditional and modern techniques were both employed to artificially recharge the groundwater. And also, optimization of water use efficiency became necessary to face the droughts and these 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 ecosystems, which contain many species of terrestrial and aquatic plants growing in the intertidal belt at the interface between land and sea, play vital role in preserving the environmental ecosystems. In addition to wind breaking, sediment retention, erosion control, supplying aquifers is one of these most positive roles played by the ecosystems. Mangroves are believed to release water from aquifers, thus they contribute to the recharge and discharge of groundwater naturally.

Additionally, while the problem of salt water intrusion to aquifers and the leaching of heavy metals -present in fertilizers and sewage sludge- may all threat the groundwater aquifers safety, mangroves may contribute to water quality maintenance functions by nutrient transformation, retention of toxins, and particle suspension. Also, in addition to the direct support provided by Mangroves to the economic activity and property, the indirect support is high; as the regulatory 'environmental' services like groundwater recharge, might replenish aquifer supplies in the vicinity used for domestic agricultural and industrial purposes in other regions with economical technique.

Therefore, the paper will strive to explain the biological and economical importance of mangroves to aquifers recharging and its vicinity, where artificial recharge of groundwater may be more costly. It will also show the opportunities that may mitigate most of the environmental concerns raised by farmer community, policy makers, and governments.

Keywords: Environmental services, mangrove, aquifers, economic values.

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Fresh Groundwater Resources in Georgia and Management Problems of the Transboundary Artesian Basins

Merab Gaprindashvili[1]

As it is known, fresh water is a conditioning factor for human life and is recognized as such by several international declarations. In spite of this recognition, the worldwide annual number of diseased caused by poor water quality is more than 500 million and the cost of material losses is estimated to be more than 1 billion dollar. The world is experiencing a deficit of good water quality, therefore still 1.5 billion people do not have means to have access today. The future prognosis is disturbing - according to the data of UN for 2025, 2/3 of the world's population will be under water deficit conditions. Thebove-mentioned facts show how important fresh water is for humanity. In this poster we will present briefly a review on the situation of fresh groundwater resources and an analysis of the problems of transboundary artesian basins in Georgia.

Keywords: Groundwater; Transboundary; Artesian basins; Georgian regions; Quality drinking water; Hydrogeological structure; Exploitation resources, Two-way movement.

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Transboundary Groundwater Management - A Case Study for the Eastern Border of Egypt

Kamal Ouda Ghodeif

Groundwater supplies in the surroundings of Egypt and Gaza strip border zone are under severe stress due to extensive Israeli air strikes and bombing to surface and subsurface activities along the border zone. The East Mediterranean Aquifer is an important transboundary aquifer extending along the Mediterranean coast from Egypt in the West until Syria in the East. The key stakeholders of this aquifer along the border zone are Egyptians and Palestinians. It is used by both sides to supply drinking and irrigation water. The political situation is not stable and residents along both sides have continuous emerging and unstable socio-economic conditions. The local inhabitants are greatly affected by deterioration of groundwater resources and spoiling soil environment. The specific hydrogeological characteristics of the Eastern Mediterranean Aquifer (No. 502 on the World Map of Transboundary Aquifer) have facilitated the migration of pollution across borders. The already existing institutions for water management in both sides have failed to protect transboundary groundwater quality and have not the capacity and motivation to raise the issue. There is no international obligation for the deteriorating countries (polluter pay) to pay, since there are confusions in the International Water Law regarding the obligation of not causing harm for water resources and enforcement. It is necessary to have third party that can stop Israeli invasion to the border zone 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. It is important to sign Egypt- =Palestine groundwater agreement to protect the groundwater resource in the border zone (or setting informal arrangements) and benefiting from previous experiences in Jordan River water diplomacy. The formalized management plan for transboundary groundwater resources can be applied by international organizations (third party) in case of conflict (war) among neighboring countries.

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Anthropogenic Change of Transboundary Syrdaria River Regime

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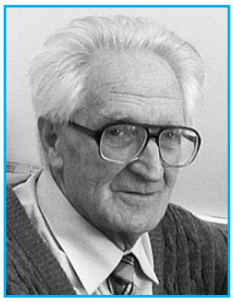
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Syrdaria River is one of the largest and most important water arteries in former Soviet Central Asia. It runs along territories of four new states – Kirgizstan, Uzbekistan, Tajikistan, and Kazakhstan and supplies water to a large part of population of the region. In particular, it flows along the well known Fergana Valley which is the most populated area in Central Asia. Several large reservoirs were constructed on the river for rational control of its runoff before destruction of Soviet Union. The regime of the reservoirs and water offtake to numerous irrigational channels were controlled by centralized direction. It allowed distributing water optimally in time and over the territory. This system was collapsed and each state has used water for its own purpose only and did not take into account interest of neighbors. The situation already causes serious economic losses and political conflicts.

We tried to estimate the measure of distortion of natural Syrdaria River runoff by economic activity, as well as track change of the process at time and along the river course. Regular hydrologic observations at the river were organized in the beginning 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 succeeded to restore characteristics of the natural runoff. It was found that the natural runoff did not change systematically for the period, no significant trends were found and the runoff varied around average value only.

Of course, the runoff regime was more and more disturbed downstream the river. Both the total annual runoff and its annual distribution were violently changed. Comparison of runoff hydrographs at the gouging stations located along the river allows evaluating magnitudes of the distortion at different time intervals.

The results allow evaluating the anthropogenic influence to the transboundary Syrdaria River runoff and should help in planning of optimal management by water resources of the region.

Keywords: Central Asia, Syrdaria River, Water Runoff, Anthropogenic Influence.

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The Shared Resources in the North-Western Sahara Aquifer System (Algeria-Tunisia-Libya): The Use of Environmental Isotopes (Algeria Part)

A. Guendouz[1] and A.S. Moulla[2]

1

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 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 freshwater for domestic water supply, agriculture and other industrial purposes. Groundwater withdrawals from the NWSAS increased 14 m^3/s in 1950 to reach 82 m^3/s in 2000, resulting in decrease in the natural water flows.

Over the last two decades, investigations have been carried out for isotopic (^{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 indicates that waters from CT and CI aquifers are characterised by depleted oxygen-18 and deuterium isotope content as compared to the one of modern rainfall. This would suggest that modern rainfall is not recharging the groundwater. However, 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 transboundary integrated management of the shared resources.

Keywords: Isotope, Shared, Water Resources, Fossil Water, Saharan Basin.

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Transboundary Aquifers in the State of Punjab, India

Sushil Gupta[1] and Sanjay Marwaha[2]


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With the 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 transboundary water aquifer systems are therefore of high priority since nature does not draw its boundaries to coincide with the political boundaries. The 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 BCM. Against this, the water availability is only 17.54 BCM of surface water and 23.78 BCM of renewable groundwater resources. Punjab has a very long international boundary and the groundwater 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 transboundary aquifers of Punjab state in totality and on the basis of proper assessment of groundwater contained down to a certain depth (say 1,000 meters), to decide the allocation of groundwater usage by the neighboring countries. The present paper outlines the above along with the hydrogeological set up of Punjab state with special emphasis on the Upper Bari Doab area covering the districts of Amritsar, Gurdaspur and Taran Taran. Towards the end of the paper, a case study of transboundary aquifers across two states, Haryana and Uttar Pradesh, within India has also been detailed. The main aim of this work was to study the effect of pumping of groundwater through augmentation of tubewells in Haryana on the Yamuna river flows and groundwater resources of adjoining state of Uttar Pradesh. A similar situation can also be present across global transboundary aquifers. This study is a case in point to prove that the study of transboundary aquifers is the need of the day.

Keywords: Eco-hydrological, Punjab, Haryana, renewable, Yamuna river flows.

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Management of Transboundary Aquifers of Kuwait: a Cooperative Approach

Khaled Hadi[1] and Amitabha Mukhopadhyay[2]

In the arid environment of Kuwait where there is no surface water, usable groundwater resource is limited, and the country mainly relies 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 overexploitation 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 concerned stakeholders. The newly adopted draft 'Law of Transboundary Aquifers' by the General Assembly of the United Nations has the advantage to emphasizes such cooperation for the greater benefits of all concerned, may be taken to formulate and execute such a plan in a not too distant future.

Keywords: Dammam Limestone Formation, Kuwait Group, Groundwater, Arabian Peninsula.

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Artesianism State of Intercalary Continental Drillings in Guerrara Region (South-East of Algeria)

S. Hadj-Said[1] and A. Zeddouri[2]


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2

In the Sahara, groundwater represents the main water resource for all the economic activities of the region. In order to satisfy the demand which is continuously increasing, the habitants of the Algerian South often use two main groundwater systems: the Terminal Complex and Intercalary Continental. This latter is a transboundary aquifer shared by three countries of Maghreb: Algeria, Tunisia and Libya. Water is contained in formations that date from the Albian until the base of Barremian. The aquifer consists of detrital formations: sands, sandstone, clays with a dolomite passage attributed to Aptian, reaching a thickness of more than 500m. In Guerrara, 29 artesian drillings exploit the aquifer at approximately 950 m depth with a yield which can reach 100 l/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 is affected.

Keywords: Sahara, Intercalary Continental, Drawdown, Overexploitation, Artesianism.

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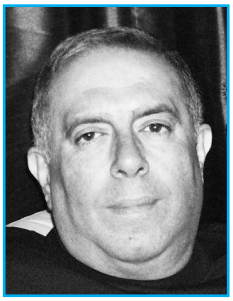
The Challenge of Transboundary Aquifer Resources Management in the Azerbaijan Republic: Multidisciplinary and Multifunctional Approaches

Rauf Israfilov and Yusif Israfilov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Successful management of the shared water resources of the Kura-Araz watersheds (total area of 188,000 km^2 occupies the greater part of the South Caucasus) is critical to the social, economic, and ecological prosperity for all countries of the region – and an essential precursor to regional peace and cooperation. With the disintegration of the former USSR and the emergence of the newly independent Commonwealth of Independent States (CIS) countries, the issue of the shared water resources within the South Caucasus, in the whole, and transboundary aquifer resources, in particular, has attracted the attention of officials at many levels of the new governments as well as former neighboring countries of USSR. Off course, the practical and just solution of this problem requires a multidisciplinary approach that encompasses various expertise and disciplines such as scientific, legal, socio-economic, institutional, ecological, international relations and many others researches. Finding a way to solve this problem is very important, especially, for Azerbaijan, where aquifers systems generally do not follow political boundaries.

Within the geologic-structural features of Azerbaijan, several groundwater basins (aquifers) 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 groundwater) are identified based on the nature of the hydrogeological setting and the geologic-geomorphologic structure. From the 16 identified aquifers of fresh groundwater resources, seven of them are Transboundary Aquifer Resources– Nakhchivan (with Armenia, Iran, Turkey), Lesser Caucasian, Jebrail, Mil-Garabakh, Mugan-Salyan (with Iran), Alazan-Agrichai (with Georgia), and Gusar-Divichi (with Russia). Practically about 90% of the fresh groundwater of the Republic falls in the category of transboundary basin and can potentially produce over 12 million m^3 per day. If we take into consideration that Gyanja-Gazakh (with Armenia), Mountain-Talysh, Lyankaran (with Iran), Ajinour-Jeiranchol (with Georgia) aquifers of fresh groundwater resources are Transboundary Aquifer Resources for Azerbaijan (i.e., despite the fact that the whole groundwater basin is situated within the Republic, the recharge areas are in other countries), one can readily surmise that 11 out of 16 groundwater basins are in need of individual consideration and assessment. Moreover, the particular geographical position and natural conditions of the Azerbaijan Republic has determined its dependence on the transboundary water resources from river basins and aquifers.

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The most effective way to solve the existing problems now is the conclusion of bilateral agreements. In the future they will become the basis for the conclusion of a full-scale and multilateral agreement on the use of the transboundary water resources by all countries of the region. It should be mentioned that so far, these issues have not been addressed at all. Undoubtedly, proceeding from the stagnant situation, there may be other ways to solve this problem as well.

The world experience shows that there is an element which units all countries. This element is the common understanding that to achieve success it is necessary to study all aspects of the problem well. In this connection for Azerbaijan (in our opinion for other States of region as well) it is important 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 entirely transparent results. This is the shortest way to success because 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. Thus, answering the question: 'What are the transboundary water basins for Azerbaijan: conflict or cooperation?' we can say that Azerbaijan is closer to cooperation than conflict. Though, the basic point is first of all the good will of the States of the region.

Keywords: transboundary aquifer; water resources management.

Characteristics of Climatic Indicators and their Influences on Rainfall and Temperature in the Murray-Darling Basin

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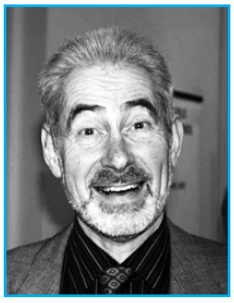
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The association between climatic indices which are calculated on a monthly basis, including the El Niño Southern Oscillation (ENSO), and monthly rainfall and temperature in the Murray Darling Basin during the period 1960 to 2009 is investigated. The 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). Definitions of these indices, in terms of ocean temperatures and pressures, are given. 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 technique 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 realizations of white noise and cross-correlograms functions verifying multivariate time series that cross correlogram of white noise approximately zero for all none zero lag by pre whitening method, which appears to be a stationary process. A factor analysis model is also fitted, and possible interpretations of latent factors will be suggested.

A variety of regression techniques will be compared for assessing the influence of climatic indices on monthly rainfall and on monthly temperature. A principal component analysis will be considered for reducing the number of climatic predictors. The applicability of a nonparametric regression technique, based on wavelet decomposition using Haar wavelets is considered. The analysis will be repeated using deseasonalized climatic indices, and deseasonalized rainfall and temperature indices.

Keywords: Cross-correlogram, Deseasonalisation, ENSO, Generalised Least Squares, Factor Analysis, Wavelet Method.

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Typologies of Groundwaters in Basins Shared between Ethiopia-Kenya, Ethiopia-Sudan and Ethiopia-Djibouti and Their Transboundary Implications

Seifu Kebede, Yves Travi, Jaludin Mohammed, Mumtaz Razak, Chiekh Gaye, Eule Ngata, François Pinard, Tesfaye Taddesse

The implementation of the 'Law of transboundary aquifers' necessitates field knowledge so that the laws developed can be coherent with the reality in the ground. The definition of shared aquifer resources is more complex than the mere shared groundwater body flowing from country A to country B. The region bordering Ethiopia and Kenya is characterized by a low volume of groundwater storage and low volumes of transboundary flows. However, groundwater has visible environmental, social and economic functions. Conflict among pastoral communities for the access to the scarce groundwater resources is common in the region. The sole source of water supply for the pastoral community in the region is groundwater. The principal aim of this work is to demonstrate the list, type andextent of shared aquifers in the Horn of Africa region. Furthermore, this work compares the typologies of flows and storage conditions in aquifers shared between Ethiopia-Kenya, Ethiopia-Djibouti and Ethiopia-Sudan with those typologies used in setting the foundation of the international legal framework on shared aquifer resources.

This work presents an inventory of shared aquifers and the hydrodynamics and current knowledge on 'principal' shared aquifers of the Horn of Africa region including: the Bulal basalt aquifers shared between Ethiopia and Kenya, the Alwero Sandstone aquifers shared between Ethiopia and Sudan, the Afar Stratoid basalt aquifers shared between Ethiopian and Djibouti and the multilayered aquifers of Ogaden shared between Ethiopian and Somalia.

(1) The Mawari Project Coordination Office, CIFEG, www.mwari.netm.

Proposal Methodology for Establishing Limit Distances from Country Boundaries for the Management of Transboundary Aquifer Systems

J.T. S. Kettelhut[1], A. N. P. Ferreira[2] and C. F. Lima[3].


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At present, in the world, transboundary aquifer systems (TAS) agreements are rare, in contrast to ones transboundary and boundary surface water resources. There are several reasons for that happens. Among them can be identified those from legal-institutional, social, political, financial and technical orders. Probably the main reason is related to the lack of reliable and systematized information. The amount of information necessary to do a TAS management is large, diversified, expensive and takes time to get them. 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, due to 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. In consequence is necessary the search for minimum management mechanisms for having understanding instruments about TAS in areas where a water use really 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 which is possible to have common proceedings to aquifer management and protection. However, in general, the wide of this strip of land is established in an empiric way, with low technical consistency. The content of this article suggests a methodology for estimating the wide of this strip of land incorporating most physical, technical, demographical, environmental, social and institutional aspects of TAS in order to have sufficient available information to establish a minimum management understanding to determinate the water supply and demand, as well as facilitate its governability and management.

Keywords: transboundary, aquifer, management, strip, information.

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Effects of Land Use Change on Surface Water Regime (Case Study Orumieh Lake of Iran)

Sh. Khalighi Sigaroodi[1], Shiva Ebrahimi[2], Elham Mohammadi[3]

The change of land-use widely occurring in many parts of Iran (i.e.from rangeland and forest to the agriculture of orchard) has affected the water regime in many areas..

The above mentioned problem has happened in the Orumieh Lake basin with an area of 1,146 km^2 which is located in northwest of Iran. A recent land-use map has been produced using satellite images of 1990, 1998 and 2007 as well as field observations. A map for a previous period was prepared using the aerial photographs of 1955 (which are considered to be the oldest documents available). In the recent period, 14% of rangeland was changed into dry farming and 7% of the irrigated farming was converted into orchard development.

The results of the study show that due to land-use change in this area, the annual average water discharge has not changed, but the daily maximum has increased and the minimum has decreased.

Keywords: land use change, dry farming, means annual discharge, Orumieh Lake, Water regime, Regional Development.

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Transboundary Aquifer within the Mining Areas – The Case Study of the Upper Silesian Coal Basin

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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 of Lower Miocene overburden units of coal-bearing Carboniferous complex is formed by Tertiary coarse-grained sediments of Lower Badenian. These sediments (so called the D bowiec formation or 'Detritus') fill deep depressions in paleorelief, and they form confined geohydrodynamic structure of the area of 635 sq km. Groundwater of marine origin contain serious amounts of Br- and I- enabling their possible utilization in balneology. The groundwater volume is estimated at about 3,8 x 10^9 m^3. 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 of a coal mine in the Polish (the 'Morcinek' mine) increased the risks of mining activity. 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. In addition several projects aimed at the research of the CO_2 sequestration potential of the aquifer are running recently.

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 include:

- Database building – to include 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 sequestration impact modelling and experimental testing.

The effects obtained so far, and the atmosphere of transboundary collaboration give an encouraging outlook for the next activities.

Keywords: The Upper Silesian Coal Basin, transboundary aquifer, coal mining, CO_2 geosequestration, mine flooding hazard.

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ISARM and the Role of UNESCO-IUGS-IGCP Project GROWNET

Shrikant D. Limaye

Internationally Shared Aquifer Resource Management or ISARM deals with equitable management of a transboundary 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 mismanaged on either or both sides of an international boundary, its equitable, transboundary and joint management become even more difficult.

The management of transboundary aquifers is important because they have a total storage capacity of an estimated 23,400 x (10)*4 km^3, while the transboundary flow of surface water, in international rivers is estimated at 42,800 km^3 per year. However, the actual volume of transboundary flow could be much smaller depending upon hydraulic conductivity (K), cross-sectional areas of flow (A) and hydraulic gradient. However, even a small quantity of polluted groundwater flowing from one side to another is capable of spoiling a good aquifer on the other side.

One of the objectives of ISARM is being a joint, multidisciplinary management 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 overexploitation and pollution of the shared aquifer. Negotiations under ISARM have to be conducted in the spirit of PCCP (moving from Potential Conflict towards Cooperation Potential) exploring the opportunities for synergies.

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 groundwater 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.

In 'GROWNET' project, the scale of transboundary 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 of ISARM, 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.

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2) Benefit: Cost ratio of groundwater use for agriculture which is mostly a consumptive use. It also relates to the cost of pumping from a deep aquifer.

3) Political Factors: Inter-Governmental relations and mechanisms of implementation of groundwater legislations, if any, and in both countries. The type of government such as democratically elected or not is also important.

4) Degree of Economic Freedom: This is necessary for movement of funds, agricultural production, industrial products, labor force, and other resources across the boundary, which is related to groundwater usage for irrigation or industries.

5) Water Governance: Rules in both the countries for allocation of pumping quota to farmers and industry; control of industrial pollution; and policies for reuse, recycling and wastewater treatment by industries.

6) Social Factors: Equitable distribution of benefits of ISARM in the society; creation of transboundary job opportunities; flexibility of farmers towards changes in cropping patterns; social acceptance for movement of transboundary labor in industry 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 m^3 of groundwater pumped from the shared aquifer.

The Features of Formation of Araks Basins Rivers Runoff (in Armenia) and Regularities of Spatio-Temporal Distribution

Varduhi Margaryan[1]

The rivers of the Republic are tributaries of the big rivers of the South Caucasia, Araks and Kura rivers. 76% of the territory of the Republic (22,556 km^2) belongs to the Araks river basin. The Araks river basin in the territory of the Republic is mainly covered with volcanic rocks, which leads to the resorption of atmospheric precipitation and results in an increase of groundwater recharge.

In the Republic 20 % of the surface water flow is from transboundary rivers which are generated by the intermediate runoff of the Araks and Arhuryan basins. The total area of the Araks basin catchment is 102,000 km^2 (22,600 km^2 of which are in Armenia). At the border of the Republic, the Araks river has a basin catchment of 11630 $km^{2.}$ possessing a full-flowing river and original hydrological characteristics. The Araks river is characterized by a violent flood regime during spring, which is specific to mountainous rivers. The Araks is an uliginous river used mainly for irrigation. The use of transboundary waters is being made under the principle of equity. The runoff of transboundary waters is characterized by a spatial misdistribution. It is evident that runoff varies from 0 (Ararat valley) to 900 mm (Geghama and Vardenis mountainous zones).

The evaluation of rivers potential as an irrigation source needs to be estimated within-year distribution by months and seasons. The rivers of basin are characterized according to the following phases: spring flood, summer-autumn and winter. The spring flood is the main phase of the rivers runoff in the Republic, which represent 30-90% of the annual runoff flow. For the rivers with groundwater recharge, the runoff is 30-40% in average (for Gavarget – 32% of the annual flow). Most of them are surface fed (Dzknaget, Voghdji, Argichi rivers) and spring flood is 70-80% of the annual runoff in high mountains' rivers as the Mantash and Gegharot rivers and in other small rivers.

In the majority of the Republic's rivers, the maximum outlet flow can be observed during the spring floods. Maximum water consumption is usually observed in May, especially in the first part of the month. The volume of the maximum outlet is bigger per 2 to 4 times than the average volume of annual runoff, but for small rivers it can be increased up to 10 to 12 times.

Most of the rivers of the Araks basin present a well-marked phase of low water-levels throughout the summer-autumn and winter periods. During those phases, rivers are mainly fed with groundwater (in winter completely). In winter, rivers exclusively rely on groundwater recharge. Minimum water flows (0,51-1,26 m^3/sec) are observed mainly in winter. For flow regularization purposes, a reservoir for the spring runoff is being constructed; and its waters will be used for irrigation. The water users of the river are the agriculture, industry, urban water-supply and hydro-electricity sectors. Armenia has a universal river basin management principle for water resources and water supply which is coordinated with riparian countries at an intergovernmental level.

Keywords: Araks River Basin, regularities of spatial-temporal distribution, aaverage height of drainage basin, height of runoff layer.

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International Research Collaboration as a Tool for Water Resource Management in the Lake Chad Basin

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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.

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Water Balance of the Alluvial Aquifer Shared between Bulgaria, Greece and Turkey

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The paper stresses the role of soil moisture content and groundwater evapotranspiration in the water balance of the transboundary aquifer shared between Bulgaria, Greece and Turkey. This is alluvial aquifer N56 (Svilegrad/Stambolo/Orestiada) according to the Transboundary Aquifers Inventory in South-Eastern Europe.

The information base includes data on soil moisture content from an Agrometeorological Network and data on groundwater levels from observational wells at the National Hydrogeological Network (National Institute of Meteorology and Hydrology, Bulgaria).

Average annual cycles of balance components are presented on a monthly basis for the study area. In addition, both multi-annual and a dry year water balance are presented.

In Bulgaria, more than 70% of the yearly precipitation sums are spent on evapotranspiration. A typical feature of the water balance elements is their seasonality. The potential evapotranspiration reaches its maximum in July and August, and groundwater recharge occurs during winter. The water reserves stored both in topsoil and shallow aquifers (if any) are highly variable.

Long-term agrometeorological observations in Bulgaria show that soil moisture varies over a 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 the cold season, reaching maximal values (of field capacity) in March. From the onset of the new growing season, water reserves in the soil gradually decrease. The most severe reduction of soil moisture content occurs in July and August (according to the increased demand of water used by plants) after which soil moisture may reach wilting point. In the case of shallow aquifers, plant transpiration occurs partly from groundwater.

Rainfall over the study area is about 600 mm/yr. Potential evapotranspiration is high (780 mm) and real evapotranspiration, which is limited by water availability, is about 530 mm. The inter-annual water balance (on a monthly basis) is presented for the transboundary aquifer. Regional groundwater recharge is estimated taking soil water balance computation into account. Groundwater recharge and groundwater evaporation are important balance elements. In general, the role of soil moisture variability in the water balance is the most important for temperate climates (Lawrence et al., 2007).

Droughts have increased in frequency over the last decades and have harmful impacts on the ecosystem. Previous studies have focused on either agrometeorological drought (soil moisture content) or groundwater issues (lowering of water table or decrease of spring discharge). Winter droughts diminish soil water reserves and reduce groundwater recharge, and summer droughts have a direct negative impact on crops.

Keywords: water balance, soil moisture, shallow groundwater, unconfined aquifer.

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Development of a Hydrological Transboundary Model for the Lower Jordan Valley, Israel, Palestine and Jordan

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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.ufz.de/smart), where all water resources (groundwater, surface runoff and wastewater) will be quantitatively and qualitatively evaluated.

One major topic of SMART is the generation of a borderless numerical transboundary 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. Within these sub-projects, natural resources on local catchment scales were evaluated. The results lead to a better understanding of the processes, which are important and necessary for the implementation in the transboundary model. Concerning the quantification of the system, different models were linked in the sub-projects: a numerical flow-model for the groundwater passage and a new hydrological model (JAMS). JAMS was successfully applied in the local study areas of Wadi al Arab (Jordan) and Wadi Qilt (Israel/Palestine), which are selected because of their particular climate conditions. Wadi al Arab is situated in the north of Jordan and represents a semiarid catchment area. Wadi Qilt is characterised by a strong variation between semiarid and arid climate conditions. The region of mountains around Jerusalem is shaped from semiarid conditions. In contrast, the main part of the catchment area, the Judean desert, represents an arid catchment area.

JAMS calculates temporal aggregated and spatial distributed hydrological variables (runoff, recharge). The challenges of the investigation were the adoption and parameterisation of JAMS onto the semiarid and arid conditions. The presentation and calculation of the hydrological procedures occur one-dimensional for infinite points in space. The mentioned input data for JAMS are spatially organized in hydrological response units (HRU), which lead to a spatially discriminated output. The model is based on different input parameters: slope, aspect, altitude, soil type and the vegetation, which is the base of differentiation of the catchment into HRUs. The resulting mesh of HRUs is the fundamental part to link the hydrological with the groundwater flow model. The advantage is that JAMS' mesh is not static and can be adapted to the geometry of the flow model mesh. The resulting important advantage is: HRUs individually define groundwater recharge (GWR) and that boundary condition can be directly linked via interface between both model spaces.

In the study areas Wadi Qilt and Wadi Al Arab, the monthly groundwater recharge was calculated for the time period January 1980 - December 2008. The simulation adduced 45 mm/yr for Wadi al Arab and 89 mm/yr for Wadi Qilt. Analysis of the spatial distribution of the GWR shows, that under the specific conditions, land use and slope are the controlling input parameters for recharge. In contrast, soil type and aspect show a small variation on the groundwater recharge. In the second phase of SMART the hydrological model JAMS will be adapted and upscaled onto the mesh of the transboundary 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.

Keywords: hydrological model, groundwater recharge, JAMS, IWRM, SMART, linkage of 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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In hydrogeology it is often assumed that prior to anthropogenic influences (such as clearing of vegetation or groundwater pumping) the groundwater system is in a state of hydrodynamic equilibrium. This typical assumption does not consider the role that changes in boundary conditions induced by changes in climate over geological time may have on the recharge/discharge balance. Indeed, a complicating factor is that current hydrogeological responses may be a reflection of paleo-perturbations, most notably recharge from an ancient climate. How to reconcile modern hydraulic information with recharge information is therefore a challenge. This is compounded in a large regional groundwater system whose hydraulic behaviour may reflect a complex mixture of both current and past conditions.

In this paper we examine the role that a change in recharge from the Pleistocene to Holocene transition may have on the distribution of hydraulic heads in a large regional scale aquifer system (with an inherent large hydraulic response time constant). Many of the parameters used in this generic model (such as hydraulic conductivity and size) are based on field measurements from the Great Artesian Basin. The model was run throughout the Pleistocene using a recharge rate of 2.8 mm/year until a steady state was reached. The recharge rate was then changed to zero to reflect more arid conditions during the Holocene. An important output from the model is the hydraulic 'time constant', which is defined as the time required to reach a steady state after an earlier hydrodynamic perturbation. This time constant is estimated from the simulated discharge rate. The time constant obtained from the model is on the order of 50 ky, which is longer than the present interglacial phase, i.e., 10 ky and thus the hydrodynamic system is a transient one which is still responding to the paleo-perturbation due to recharge. The time constant from the numerical simulation is compared with analytical solutions for the time constant. This comparison highlights the importance of the unconfined portion in the hydrodynamic response of large sedimentary aquifers. Furthermore, we present time constants for other large sedimentary aquifers. This shows that extremely large time scales are required for hydraulic perturbations to reach a new equilibrium, often much longer than the intermediate period between natural hydroclimatic perturbation. This suggests that large regional scale aquifer systems, such as the Great Artesian Basin, are rarely expected to be in steady state with respect to their hydraulic behaviour.

Keywords: Great Artesian Basin, Time Constant, Paleo-climate.

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The North West Sahara Aquifer System: the Complex Management of a Strategic Transboundary Resource

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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. Consequently, its exploitation has increased exponentially in the last decades, causing serious hydrogeological problems and worries for the future. Supported by the scientific community, many national and international organizations, and mainly the "Observatoire du Sahara et du Sahel" (OSS), 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 in the Tunisian NWSAS region are presented, focusing on the current exploitation and state of the art definition and the estimation of the consequences of different withdrawal scenarios at mid and long terms and at local and regional scales.

Keywords: NWSAS, Tunisia, arid regions, artesianism, overexploitation.

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New Scientific Information on the Southwest Part of the Gondo Plain (Burkina Faso)

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The Gondo Plain lies between Mali and Burkina Faso. Its area is 36,000 km², with 6,000 km² in Burkina Faso and 30,000 km² in Mali. 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: Find water resources to provide drinking water supply to Ouahigouya Town and assess the exploitation possibility of the deep aquifer for rural water supply.

The combination of remote sensing, geology, geophysics (electromagnetism and resistivity methods), 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);
- to identify and characterize the different aquifers and their relationships;
- 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;
- 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.

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.

Keywords: Gondo Plain, Aquifers, Geophysics, Trial water drilling, Isotopic chemistry, Piezometric depression.

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Regional Features of Sustainable Use of Fresh Groundwater in Europe (on the Specific Example of Belarus)

Oleg V. Shershneyov[1]

Freshwater resources are one of the major constituents to successful development of economy for all regions of the world. The majority of total surface water extraction, as a rule, provides needs of agriculture and industry. But of greater importance are the fresh groundwater resources. Because, as a source of domestic and potable water supply, they have some advantages over surface ones. It is, as a rule, characterized with a higher quality and better protection from pollution and evaporation.

For Europe, the character of specific groundwater discharge values is primarily governed by the type of hydrogeologic structure. Artesian basins of platforms, hydrogeological massifs, old and young mountain-fold areas are characterized by different conditions for groundwater resource generation, groundwater storage, specific discharge values and distribution, and the effect of groundwater runoff generation factors. In all hydrogeological structural elements, over 90 % of the total runoff is generated in the upper hydrodynamic zone.

In Europe about 18 % of the total water abstraction is from groundwater and proportion of their abstraction varies from country to country. The use of aquifers depends on annual recharge and quality of surface water.

The water secure yields for more than 260 fresh groundwater reservoirs were certified from Belarus in 2008. The water yield resources, estimated for these reservoirs, totalized about 6.66 mln. m^3/day. Total natural fresh groundwater resources are estimated to 43.6 mln. m^3/day. The basic water-bearing strata containing fresh groundwater, which using for water supply belong to Quarternary, Paleogene-Neogene and Cretaceous periods.

In Belarus during 1995–2008 groundwater abstraction accounts about 54–60 % of total abstraction. The overall groundwater withdrawal is 1.8 mln. m^3/day or 4.2 % of natural fresh groundwater resources, more of them (90%) used for households and drinking water supply. The average use of water for drinking per capita is about 180 l/day which is higher than for the majority of European countries (120–150 l/day/per capita). Fresh groundwater abstraction varies from regions of Belarus. The major groundwater abstraction, (over 320 mln. m^3/year), falls on the Minsk region.

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At the present time, the major factors influencing the condition of fresh groundwater of Belarus, are: agriculture (melioration, applying fertilizers, cattle-breeding wastes); communal-household and industry; exploration and prospecting of minerals; over-exploitation; radioactive pollution. Most of them are typical practically for any industrial region of the modern world. And they are cause by hydrodynamic and hydrochemical changes of water regimes.

Anthropogenic contamination takes effect with the highest intensity in groundwater and inter-stratum water-carrying complexes of Quaternary period. It leads to introducing of technogenic chemical elements and compounds (nitrates, nitrites, chlorides, sulfates, mineral oil products, heavy metals, etc.) not peculiar to natural fresh water and transformation of their natural chemical composition. Such features, for example, takes place within industrial cities (Minsk, Gomel, Mozir) and territories of oil deposits exploration (Rechitsa and Svetlogorsk regions). The most serious pollution of groundwater (depth 3-6 meters) in rural areas is caused by nitrates.

Safe yield depletion occurs, when groundwater withdrawal, exceeding estimated safe yield. The over-exploitation can cause quick water level decline during exploitation and reduce groundwater quality in a case of salt water intrusion in the underground (e.g. in the cities Soligorsk and Polotsk).

Special kind of pollution of fresh groundwater within south-eastern part of Belarus belongs to radioactive contamination. In groundwater, radioisotopes can get results of infiltration of atmospheric precipitation or in the water of the river. Nowadays, the concentrations of radioisotopes in fresh groundwater are much lower, than in rivers and practically never exceed the standards of limited permit of concentration.

Keywords: Natural fresh groundwater resources, Water quality, Drinking water, Freshwater consumption, Groundwater contamination

The Muskau Arch Geopark (Poland, Germany): an Opportunity of Transboundary Water Environment Protection and Monitoring

Sylwia Skoczyńska-Gajda

The Muskau Arch Geopark (MAG) is situated within the border zone between Poland and Germany. Presently, the efforts to create this transboundary Geopark are still ongoing. 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. The present MAG's landscape has been influenced by the natural, glaciotectonic processes (the Muskau Arch is a frontal morraine) and mining activity as well. Lignites of Miocene age have been mined here since the second part of XIX century for seventies of the XX century. 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'. 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 Ł knica 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. 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. Because of the unique natural values, the area of post-mining lakes within the MAG, should be protected by a uniform (transboundary) nature conservation law.

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. The Muskau Arch Geopark – situated on the borderland of the two countries – gives also an opportunity of designing the representative, unified ground- and surface water monitoring system.

Keywords: Muskau Arch Geopark, Anthropogenic lakeland, Transboundary groundwater bodies.

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Transboundary Aquifers - Ramsheh Plain Technical and Social Analysis

M.Torfeh[1], K. Aghili[2] and E. Paykhasteh[3]

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Nowadays, in addition to the aspects of of surface and ground-water availability, geographical distribution, ownership, political and geographical boundaries; the development and use of management methods and tools are among the head-on challenges.

Transboundary aquifers, located along political borders, are on one hand concerned with issues that have direct effects on their preservation and sustainability. On the other hand, they 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 a provincial management model.

The Ramsheh plain, located in the Isfahan province, is nourished by the Izadkhast river of the Fars province, especially in thesouthern flank of the Morvarid mountion. The Gavkhoni wetland located in North – Eastof the area is considered to be a drainage of the plain.

Based on traditional water rights, the Izadkhast river has been used by Ramsheh inhabitants for agriculture and recharge of the plain. In addition, its flow has turned water- mills which date back to about 250 years.

In recent years, the construction of the 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, dealing with social problems and their historical evolution.

With the use of a GMS model (Groundwater Modeling System) and based on geological data and measurements of piezometers, the loss incurred by cutting off the water infiltrating into the Ramsheh aquifer (in terms of the construction of the Izadkhast dam) and its consequent effects on stake-holders, is evaluated.

Keywords: Ramsheh- Esfandaran, aquifer, Gavkhuni wetland, Izadkhast dam.

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Climate and Land Use Change Impacts on Groundwater Quality in the Beninese Coastal Basin of the Transboundary Aquifer System Benin-Nigeria-Togo

V.S. Henri Totin[1], Abdoukarim Alassane[2], Moussa Boukari[3], Serigne Faye[4] and Michel Boko[5]


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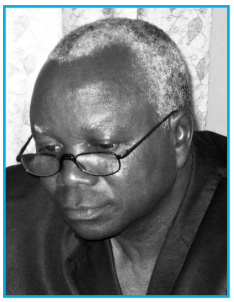
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The coastal hydrogeological basin of Benin covers 12,377 km^2 in the part of the transboundary aquifer system shared by Benin, Nigeria and Togo. Groundwater is the main water supply source for approximately an estimated 4 million inhabitants. Population rapid growth with the rate of 4.5% induces extension of human settlement which interaction with climate variability affects water quality. This study aims to analyze groundwater quality under climate variability; land use and land cover change effects on the physicochemical and bacteriological quality of drinking water in the coastal sedimentary basin of Benin.

Seasonal analysis of 40 dug-wells, boreholes and spring water sampling, land use and land cover diachronic analysis help to emphasize environmental change impacts on groundwater physicochemical and bacteriological quality. Furthermore, binary diagram method is used to interpreted geochemical process of drinking water mineralization depending on hydroclimatic variability and human settlements state. Water quality is also appreciated from the quality standards of World Health Organization (WHO) like Maximal Allowable Concentration and Maximum Allowable Value.

This study shows that drinking water pollution in the coastal sedimentary basin of Benin is emphasizing the chemical and bacterial concentration. Groundwater quality degradation is more caused by bacteria (total coliforms, faecal coliforms, Escherichia coli, faecal streptococcus beyond WHO standard) than by mineralization (nitrogen, calcium, chloride, sodium, sulphate, carbonates, etc.). Binary diagram (Cl vs Na, SO_4 vs Ca, Cl vs Na / Cl, Cl vs NO_3, etc.) helps to highlight rainfall and evaporation variability and land use change effects on groundwater mineralization linked to induced recharge from inadequate sanitation facilities in the human settlement and sea water intrusion on the coastal aquifers.

Groundwater quality seasonal change characterized in step with climate variability and land use change help to propose transboundary aquifers management based of national hydrogeological basin approach like in Benin.

Keywords: Groundwater, quality degradation, climate, land use, binary diagram, management.

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Environmental Risks of the Kyrgyz Republic and Central Asia

A.K. Tynybekov

The region of Central Asia suffers from ecological disasters on a vast scale with many more occurrences expected. The extent of anthropogenic factors of influence on environment degradation directly impacts the scale of the damage. Furthermore, the more extensive the territory impacted is, the greater the ecological threats are , even encroaching upon adjacent states. The regions of the Tien-Shan mountain range are among those areas especially endangered by ecological threats. Using advanced methods of measurement, scientists have investigated numerous issues: water ecosystems, the impact of radioactive wastes on the environment, pollution of rivers, the hydro-power energy systems, and glacial degradation.

Keywords: environmental issues, anthropogenic, hydro power station, Central Asia, Aral Sea, Kyrgyz Republic, Issyk-Kul Lake.

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Water Balancing and Power Generation Using Topographical Advantage: Hidden Potentials between Transboundary Aquifers

P.N. Vidhale

Great potentials are hidden across the transboundary aquifer regions between neighbouring countries. However, these potentials are interlocked by the boundary disputes. If anyhow we could open the interlocks of such disputes, tremendous potentials will be available at the disposal of mankind on Earth. In an ancient time, boundaries were formed because of natural obstacles like high hill ranges, water barrier rivers and the costal limits if those are considered (boundaries formed because of high hill ranges and the rivers flowing through it). Consequently, there are sudden and drastic changes in topography, silt gradients of lands and tremendous changes in hydrodynamic current which have high potential to satisfy man's need like water for drinking, water for irrigation, mainly for the generation of hydroelectric power that will become the prime and an ecofriendly source of electricity. Thus, the down flow stream sprinkled the lower altitude region and at the same time, produced power will illuminated the higher altitude. Beneficiaries will be the whole neighbourhood of the water resource.

Every continent has a similar type of topographical landscape. To the extreme end, high ranges of mountains are there, and the 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 is spread on different altitudes. Nature distributes the potable water (3 %) in the form of precipitation. Water at particular height acquires certain static quantity of potential energy because of its 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 by the conduit. Same water with the same quantity can be reused for 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 and water rich zones. One of the regions in Himalayan Transboundary aquifer location is challengeable for giving the new directions for the use of transboundary aquifers.

Keywords: Transboundary locations, Aquifer hidden potential, Interlock, Boundary dispute, continental topography, precipitation, water potential at different altitude, water transport , energy, advantage of global warming, global warming rate reduction, Indian sub-continent.

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Nanosafety as a New Direction of Transboundary Biomonitoring

V.A. Zolotarev

Cooperation in transboundary water resources management becomes an essential element to meet human and environmental needs. Many transboundary aquifers are contaminated with a number of nanomaterials and other pollutants. We intend to develop this project in collaboration with the EU NanoSafety Cluster. Entering the information age requires integrative methodology that employs a holistic view of the multiple risks related to the water management. International standardization and automation is needful for sharing data and information, a universal biological monitoring system should use species with a cosmopolitan distribution. By undulating their flagella, nanoflagellates generate local water currents to propel themselves through their aquatic environments and to collect bacteria and nanoparticles on the walls of their collars. Testing with microorganisms are the most cost-effective and less likely to antagonize animal rights activists. Several advantages of using microperiphyton communities for the development of standard online biosensors of pollutional stress and implementation of information technology are discussed. Also simplified methods for training, education and technical assistance needs are available. Holistic approach and early warning are essential for effective monitoring programs. The project 'Automated Biomonitoring International Network' (ABIN) using microscale online biosensors, multispecies online 'eco-sensors' (MES), based on ubiquitous microbial organisms is suggested.

Keywords: Automated information systems, Nanoflagellates as sensors, Global environmental standards, Nanotoxicity testing, ABIN.

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Origin of Salinity of Water Resources: Climatic and Anthropogenic Impacts (Western Morocco)

Lahcen Zouhri[1], Christian Gorini[2], Benoit Deffontaines[3] and Mohamed Dakki[3]

The southern part of the Rharb basin is represented by the Mamora basin. Thanks to its hydraulic potentialities, the groundwater of the Mamora basin supplies not only Rabat (the capital of Morocco) and Kenitra cities, but also the economic city of the country, Casablanca, as well as the industrial and agricultural sectors. Along with this heavy solicitation, 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 mineralization related to saltwater intrusion, the hydraulic gradient and the water-aquifer interaction. Hydrochemical correlations which have been carried out in the coastal area showed contamination by seawater. The analysis and the interpretation of wells highlight salt benches which may explain the mineralization of water in the zone far from the coast. The seawater intrusion and the identification of the Pre-Rifean complex were identified by electrical and seismic methods.

Keywords: hydrochemical evolution, saltwater, correlation, interaction, geophysics.

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