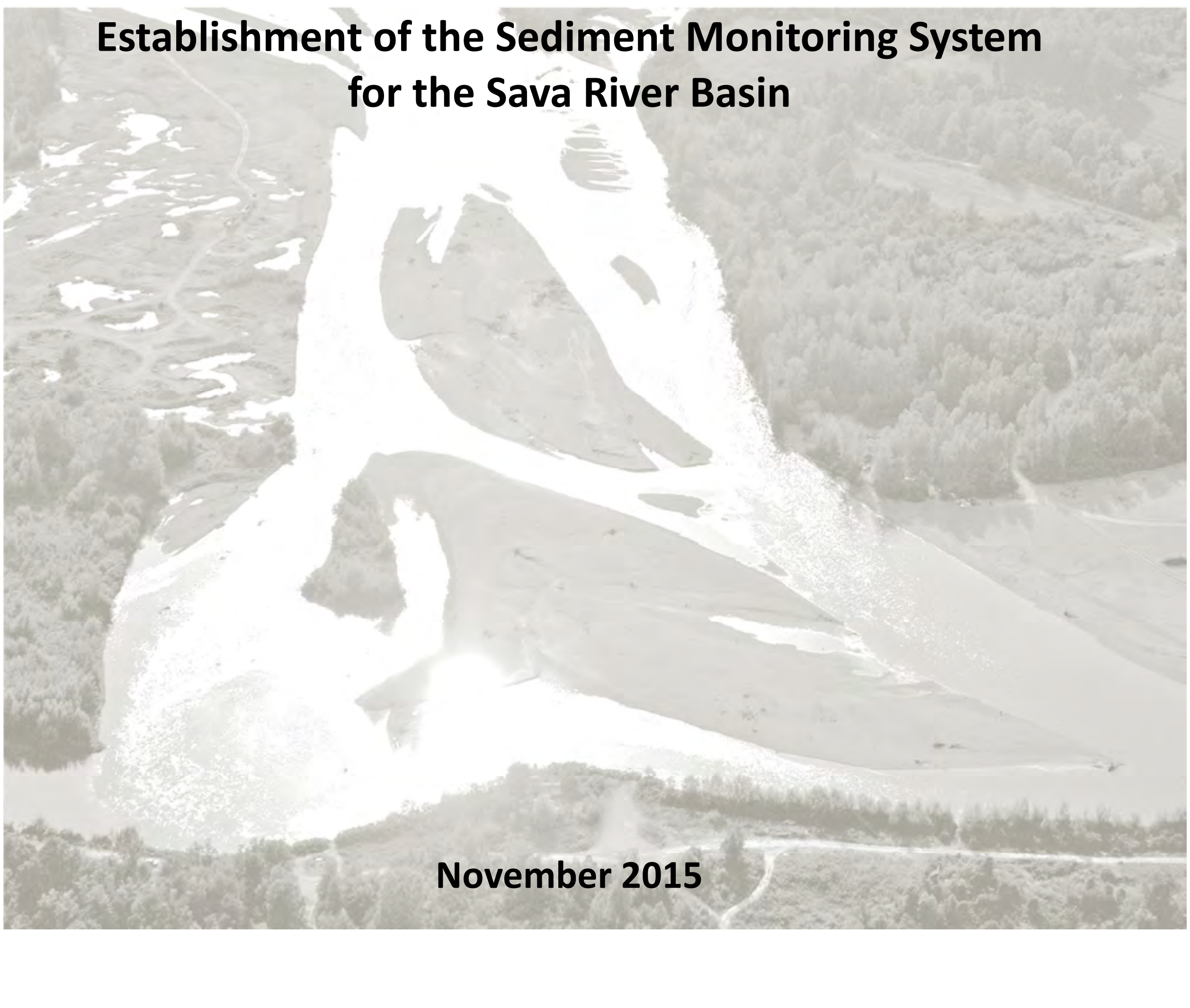
INTERNATIONAL SAVA RIVER BASIN COMMISSION

Towards Practical Guidance for Sustainable Sediment Management using the Sava River Basin as a Showcase



Establishment of the Sediment Monitoring System for the Sava River Basin

November 2015

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Photo at front page: Miroslav Jeremic_Drina river lower section

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Abbreviations

ADCP	Acoustic Doppler Current Profiler
AMPS	Analysis and Monitoring of Priority Substances
ARSO	Slovenian environment Agency
BA	Bosnia and Herzegovina
BiH	
BA RS	Bosnia and Herzegovina Republika Srpska
DHMZ	Meteorlogical and Hydrological Service (Croatia)
FASRB	Framework Agreement on the Sava River Basin
Fed BA	Federation of Bosnia and Herzegovina
FHMZFBIH	Federal Hydrometeorological Service
HESS	Hidroelektrarne na Spodnji Savi
HIS	Hydrological Information system
HPP	Hydropower plants
HR	Croatia
ISI	International sediment Initiative
ISO	International Standards
ISRBC	International Sava River Basin Commission
RHMZ	Republic hydrometeorological service of Serbia
RHMZRS	Republic Hydro-Meteorlogical Service of Republic of Srpska
RS	Serbia
SedNet	European Sediment Network
SEL	Savske elektrarne Ljubljana
SI	Slovenia
SRB	Sava River Basin
SSM	Sustaibale sediment management
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCS	Web Coverage Service
WFD	Water Framework Directive
WFS	Web Feature Services
WMO	World Meteorlogical Organization
WMS	Web Mapping Services

1. Introduction

The Sava River Basin is the major sub-basin of the Danube River, located in South Eastern Europe. The basin is shared by five countries: Slovenia, Croatia, Bosnia and Herzegovina, Montenegro and Serbia, while a negligible part of the basin area also extends to Albania.

Within the framework of a cooperative effort associating the UNESCO Venice Office (UVO), the International Sava river Basin Commission (ISRBC), the European Sediment Network (SedNet) and the UNESCO-IHP International sediment Initiative (ISI) ISRBC established the core expert group for the implementation of the project *Proposal of the Establishment of the Sediment Monitoring System for the Sava River Basin*. This project is also being developed in the frame of the Framework Agreement on the Sava River Basin (FASRB) ratified by BA, HR, RS and SI as well as the in application of the project “Towards Practical Guidance for Sustainable Sediment Management using Sava River as a Showcase” resulting in organizing the training course and Part I of the Guidance on Sustainable Sediment Management in the Sava River Basin (in October 2012-(http://www.savacommission.org/event_detail/8/22/273/4) and implementing the project Estimation of the Sediment Balance of the Sava River (in 2013-http://www.savacommission.org/project_detail/16/1).

On the Ministerial meeting held on July 6th 2015 in Brčko (BA-http://www.savacommission.org/event_detail/0/0/336/2) the Parties to the FASRB signed the Protocol on Sediment Management to the FASRB which affirms the need for efficient cooperation among the Parties and for promotion of sustainable sediment management (SSM) solutions.

The main objectives of the project have been:

- Establishment of strategic goals and specific objectives of the sediment monitoring and data exchange system;
- Review of existing sediment monitoring data;
- Review of technical international standards and technics of monitoring and assessment of their application in the Sava River Basin;
- Establishment of on-line free database on sediment taking into account the initial functionalities of Sava Geoportal implemented by ISRBC;

2. Glossary

Protocol on Sediment Management to the Framework Agreement on the Sava River Basin (2015) has the following definitions:

The Sava River Basin means the geographical area extended over the territories of the Parties, determined by the watershed limits of the Sava River and its tributaries, which comprises surface and ground waters, flowing into a common terminus.

FASRB means the Framework Agreement on the Sava River Basin, done at Kranjska Gora, Slovenia, on 3 December 2002, including amendments stipulated within the Agreement on Amendments to the Framework Agreement on the Sava River Basin and Protocol on Navigation Regime to the Framework Agreement on the Sava River Basin, done at Ljubljana on 2 April 2004.

Sava Commission means the International Sava River Basin Commission established by Article 15 of the FASRB.

Impact means any adverse or detrimental effect on the river environment resulting from a change in water or sediment regime, caused by human activity, and which change may affect life and property, safety of facilities, and the aquatic ecosystem concerned.

Main tributaries of the Sava River are defined in Annex I to this Protocol.

Water regime means quantity and quality conditions of the waters of the Sava River Basin in space and time influenced by human activities and/or natural changes.

Waterway means navigable part of Sava River and its main tributaries.

Sediment regime means quantity and quality conditions of the sediment of the Sava River Basin in space and time influenced by human activities and/or natural changes.

Sediment means solid material that is or can be transported by or deposited from water;

Sediment management means organized and coordinated sediment related activities provided in accordance with certain policies, plans and programmes to achieve main social, economic and environmental objectives.

Dredging is excavation of sediment and means an activity or operation usually carried out at least partly underwater with the purpose of gathering up bottom sediments and disposing of them at a different location.

Capital dredging means dredging in scope of creating new engineering works such as new waterways, new harbors, land reclamation and dredging allowed in accordance with national law.

Maintenance dredging means dredging for maintenance and improvement of the waterway to ensure safe navigation, or dredging for maintenance and improvement of water regime performed in accordance with national law.

Environmental remedial dredging means dredging of polluted sediments to solve environmental problems.

Pollution means the direct or indirect introduction, as a result of human activity, of substances into the environment which may be harmful to human health or the quality of aquatic ecosystems and terrestrial ecosystem direct depending on aquatic ecosystem.

Sava River Basin Management Plan means the plan developed in accordance with Article 12 of the FASRB.

International Glossary of Hydrology (WMO, 1992) has the following definitions:

Bed load *syn.* **bed sediment -** Sand, silt, gravel and rock detritus, mainly not in suspension, carried by a stream along its bed.

Bed-load discharge **-** Amount (weight, mass or volume) of bed load transported through a cross section of a stream per unit time.

Bed material **-** Sediment mixture of which the bed is composed. Bed material particles may be moved momentarily or during certain flow conditions.

Bed-material load **-** That part of the total sediment transport which consists of bed material and whose rate of movement is governed by the transporting capacity of the stream.

Monitoring **-** Continuous or frequent standardized measurement and observation of the environment, often used for warning and control.

Sediment concentration **-** Ratio of weight of dry solids to the weight of a water/sediment sample.

Sediment grading **-** Grading of the sediment carried by rivers according to particle size.

Sediment sampler *syn.* **silt sampler -** Sampling device for determining the concentration of sediment load.

Sediment yield *syn.* **total load -** Total sediment outflow from a watershed or past a given location in a specified period of time. It includes bed load as well as suspended load. Usually expressed in weight per unit of time.

Suspended sediment load **-** Sediment which remains in suspension in flowing water for a considerable period of time without contact with or settling on the streambed.

Wash load **-** Relatively fine material, in near-permanent suspension in a stream system, which is transported entirely through the system without deposition.

3. Establishment of strategic goals and specific objectives of the sediment monitoring and data exchange system

3.1. Sediment management as an integral part of river basin management

Every single river contains sediment as an important natural part of its flow. This sediment tends to settle down on the river ground. Erosion by flow hydraulics is working the other way. Usually over the year, sedimentation and erosion level each other out and the river is in dinamyc equilibrium.

Construction of any hydro installation on the river, for any purposes, faces sediment aspects. Many of them, sooner or later, suffer from severe sediment problems. Sedimentation or erosion is a sneaking problem. It is necessary to act before it is "suddenly" too late.

Any dam on a river profoundly changes the sediment balance. The reservoir usually traps most of the sediments. Only a part of the sediments is passed on. The downstream river is affected by erosion.

There are no examples of the fully fledged integration of sediment management into river-basin management yet (Brils, 2012).
The key issues related to sustainable sediment management are:

- Global change involves more than climate change;
- Important changes to the earth's surface occur as result of population growth, land clearance and land use change, infrastructure development and resource exploitation;
- Changing erosion and sediment dynamics have wide-ranging implications for food production, food security, water resource development and terrestrial and aquatic ecosystems;
- Need for improved sediment management in river basins, and resulting need for capacity building and improved education in the sediment field has appeared;
- Sediment monitoring programs and predictive capabilities for erosion and sediment dynamics should be improved. (www.irtces.org/isi and www.sednet.org)

3.2. Strategic goals of sediment monitoring

Sediment transport is the general term used for the transport of material (clay, silt, sand, gravels, and boulders) in rivers and streams. The transported material is called sediment load. Distinction is made between bed load and suspended load. The bed load characterizes grains rolling, sliding and saltating along the river bed while suspended load refers to smaller sediment grains maintained in suspension by turbulence. The total sediment discharge in a stream is the total volume of sediment particles in motion per unit time. It includes the sediment transport by bed load motion and by suspension as well as the wash load (Chanson and James, 1998).

Professional hydraulic engineers can apply the basic principles of river (fluvial) hydraulics to the most man-made channels and to some extent to grassed waterways. Fixed boundary hydraulics cannot predict the morphology changes of natural streams, because of the numerous interactions with the catchment, its hydrology and the sediment transport processes; indeed, the stream boundaries are movable (Chanson and James, 1998). It is recognized that movable boundary hydraulics is characterized by strong interactive processes between rainfall intensity and duration, water runoff, soil erosion resistance, topography of the stream and catchment, and stream discharge.

Sediments in water, such as clay, silt and algae can have many negative effects on aquatic life. Suspended materials reduce water clarity and can block light to aquatic plants, smother aquatic organisms, and carry contaminants and pathogens, such as lead, mercury, and bacteria. Suspended sediments can be caused by runoff from construction sites, agriculture, and logging sites; runoff from urban areas with paved and impermeable surfaces; eroding stream banks; bottom-dwelling fish and burrowing animals; excessive algae growth; high-velocity water, including storm water; and windy conditions in shallow-water areas (Reuther, 2009).

Thus, sediment transport and erosion/sedimentation monitoring is needed. It will provide an indication of temporal changes over a prolonged period, such as increase or decrease in concentrations of contaminants over time, changes in a river bed, and changes in the water capacity of the rivers, decrease of the water quality for agriculture or even for drinking water (Brils, 2008).

3.3. Purpose to establish a sediment monitoring system

Sediment is an essential, integral and dynamic part of any river basins. In natural and agricultural basins, sediment is derived from weathering and erosion of minerals, organic material and soils in upstream areas and from erosion of river banks and other in-stream sources. As surface water flow rates decline in lowland areas, transported sediment settles along the river bed and banks by sedimentation. This also occurs on floodplains during flooding, and is present as siltation of reservoirs and lakes (AMPS - Analysis and Monitoring of Priority Substances – Expert Group to the implementation of Water Framework Directive, 2004).

Often the natural sedimentation areas are severely restricted, because of embankments and the loss of flooding areas as a result of these embankments. Natural river hydrodynamics maintain a dynamic equilibrium, regulating small variations in water flow and sedimentation by suspension and resettlement.

Sediment forms a variety of habitats. Many aquatic species live in these sediments. Microbial processes cause regeneration of nutrients and important functioning of nutrient cycles for the whole water body. Sediment dynamics and gradients (wet-dry and fresh-salt) form favorable conditions for a large biodiversity, from the origin of the river to the coastal zone (Brils, 2008).

A healthy river needs sediment as a source of life. Sediment is also a resource for human needs. For millennia, mankind has utilized sediment in river systems as fertile farmland and as a source of construction material. Sediment acts as a potential sink for many hazardous chemicals. Since the industrial revolution, human-made chemicals have been emitted to surface waters. Due to their properties, many of these chemicals stick to sediment. Hence in areas with a long record of sedimentation, sediment cores reflect the history of the pollution in a given river basin. Where water quality is improving, the legacy of the past may still be present in sediments hidden at the bottom of rivers, behind dams, in lakes, estuaries, seas and on the floodplains of many European river basins. These sediments may become a secondary source of pollution when they are eroded due to flooding and channel bank erosion and transported further downstream (Reuther, 2009).

In order to protect surface water resources and optimize their use, soil loss must be controlled and minimized. This requires changes in land use and land management, which may also have an impact on water quality.

Control of the siltation rate in reservoirs and rivers requires that adequate data are available at the design stage. This, in turn, demands an understanding of sediment transport and appropriate methods for measuring sediment load and movement (Ongley, 1996). The measurement of sediment transport requires that many simplifying assumptions are made. This is largely because sediment transport is a dynamic phenomenon and measurement techniques cannot register the ever-changing conditions that exist in water bodies, particularly in river systems (Brils, 2008).

An effective monitoring program consists of the following steps:

- Choice of meaningful and attainable monitoring objectives,
- The development of a monitoring plan, and
- Design of a proper sampling strategy and method (Reuther, 2009).

To better evaluate and manage surface waters, controlling authorities need data on the chemical and biological status of sediments (Selander, 2011). Therefore one major goal of every sediment monitoring program is to measure, map, and document the distribution of concentration, mobility, and toxicity of pollutants and of possible cause and effects in sediments, to identify spatial and temporal trends. Other objectives are to investigate and consider implications for lake and river restoration options, or, more classically, to use sediment monitoring data for geochemical exploration or prospecting of minerals (Reuther, 2009).

3.4. Influences of sedimentation on the environmental system

Rivers play a major role in landscape evolution, transmitting signals of climactic or tectonic change across the landscape, controlling the timescale of response of the landscape to these changes (Selander, 2011).

Changes in the climatic regime of a catchment have direct impacts on the amount of water and sediment in the system. A cooler, wetter climate conductive to glaciation would see a decrease in channel discharge with an increase in sediment flux from glacial erosion into the system. Warm, wet climates will see an increase in stream discharge and in the amount of suspended and dissolved sediment produced by increased rates of chemical weathering. Dry climates would lead to a decrease in discharge, and a decrease in the amount of sediment moved by the system. Erosional and transport processes acting on rivers are ultimately responsible for the majority of sediment input to a river system (Ongley, 1996).

The effects of changes to erosion and sedimentation patterns will depend on whether the change results in an increase or decrease in sediment availability. Both effects have various physical and chemical consequences for water quality and aquatic ecosystem health. Sedimentation effects are usually local, but trans-boundary impacts may occur where major river systems form a common border.

The UNEP (2006) and Ongley (1996) present the following summary of some of these effects:

<u>Increased sedimentations lead basically to:</u>

- fill watercourses, storm drains and reservoirs leading to costly dredging and an increased risk for flooding;
- a decrease the water capacity in the rivers which influence badly on the navigation process;

- many toxic organic chemicals, heavy metals and nutrients are physically and/or chemically adsorbed by sediments, so that an increase of sediment can also lead to increased deposition of these toxic substances that result in further negative impacts on the water quality;
- a decrease in the amount of available sunlight which may in turn limit the production of algae and macro-phytes, increase water temperatures and reduce growth of natural vegetation;
- damage fish by irritating or scouring their gills and degrade fish habitats as gravel containing buried eggs becomes filled with fine particles, thus reducing available oxygen;
- a reducation of the success of visual predators and may also harm some benthic macro-invertebrates.

Decreased sedimentation:

- increased velocity of the water which may cause erosion downstream and cause damage to human settlements and ecosystems;
- if a decrease of sediment occurs, it can lead to degradation of an ecosystem by starving it of the elements needed to sustain production since sediments often carry a variety of minerals, nutrients, and organic matter.

3.5. Sediment monitoring system

The AMPS subgroup on sediment monitoring, under the EU Water Framework Directive, emphasized the following important plan for the sediment monitoring:

- Monitoring the progressive reduction or increase in the contamination of sediments;
- Demonstrate that there is no deterioration in sediment quality;
- Phasing out of the physicochemical properties of sediments, since it have an impact on the aquatic ecosystem;
- Controlling the geomorphological process within the river system including the operation in floodplains;
- Monitoring the changes regarding the quantity of sediments which have an impact on navigation and agriculture.

The AMPS revealed also that currently there is a wide range of approaches to sediment monitoring. Different authorities appear to organize their sediment monitoring in different ways because the different objectives are addressed.

Ongley (1996) reports that before starting a monitoring program, it is important to identify the appropriate methods for sediment measurements, such as:

1. Determining the particle size of the sediments can be a prerequisite for understanding the source, transportation and, in some cases, environmental impact of sediment;
2. Analysis of the sediment's composition helps to understand the variations in concentration of suspended sediment with water depth.
3. Measuring the discharges and taking a water sampling at intervals throughout a given event reflects the different periods when sediment may be more readily available than at other times. This is called the hysteresis effects.

Furthermore, Reuther (2009), AMPS group (2004) and Ongley (1996) confirmed that the sediment sampling is a major step for an effective monitoring program. Sediment samples should be collected at an appropriate frequency, taking into account the sedimentation rate and the hydrological conditions such as a flood event. The methods and equipment used for sampling suspended sediment are different from those used for deposited sediments. Also, sampling methods for measurements of the quantity of sediment in transport are different than for measurement of sediment quality. The reason for these differences reflects the fact that sediment quantity must include different sediment fractions which are unequally distributed in depth, whereas sediment quality focuses on the silt and clay fraction which is not depth-dependent.

4. Overview of river sediment transport processes

4.1. Sediment source areas

The term fluvial sediment is usually reserved for unconsolidated material found in rivers and streams. Sediment transport is a natural process of transporting solid particles from erosion sources to deposition or sedimentation areas. This process has been shaping landscape throughout geological time.

One important source of sediments is soil erosion. Geological soil erosion occurs as surface removal of farm, forest and other erodible soils in the form of sheet erosion, inter-rill and rill erosion, gully erosion or deflation, mainly caused by impacts of raindrops (splash erosion, rain erosion) and overland flow on bare soils or land without dense vegetation cover to protect soils. Accelerated erosion is the speeding up of erosive processes, either directly or indirectly, by the intervention of man, such as deforestation, overgrazing, construction sites etc.

Other important sediment sources are deposits of mass wasting phenomena, driven by gravity (rock falls, rock slides, landslides, debris flows, mud flows) exposed to fluvial processes of erosion, transportation and sedimentation. Subjects of these processes are fluvial sediments - solid particles and particles of rock material that have been transported from their sources and deposited elsewhere by flowing water.

Sediments in rivers can also occur from morphological changes of river channel in vertical and lateral direction (river bed and bank erosion) on the upstream river sections. These are natural morphological changes that can be exacerbated by the man intervention.

4.2. Physical properties

Sediment transport in rivers and streams involves two-phase flow of a water-sediment mixture. Most important physical properties of sediments as the solid phase can be divided into:

- properties of a single sediment particle: mass density of solid particles (the mass per unit volume), specific weight of solid particles (the solid weight per unit volume of solid), submerged specific weight of a particle (the difference between the specific weights of solid particles and water), specific gravity (the dimensionless ratio of the specific weight of a solid particle to the specific weight of a fluid at a standard reference temperature), sediment size (e.g. sieve diameter, fall diameter, nominal diameter etc.), sediment shape (different shape factors and indices, e.g. sphericity) and sediment roundness (different indices using the sharpness of the edges or corners of a particle classifying particles from angular to rounded);
- bulk properties of sediments: particle size frequency distribution (measured by wet or dry sieving equipment like mechanical shakers or sedimentation tubes and represented as a histogram or a cumulative curve) and corresponding particle-size parameters (mean, median, mode, sorting, skewness, kurtosis), angle of repose (usually given as the slope angle of a cone of submerged loose material under incipient sliding conditions), porosity (the volume of the voids per total volume), void ratio (the volume of voids per volume of solid), unit weight (the weight of solid and water in the voids per unit total volume), and dry unit weight (the weight of solid per unit total volume);

Most important physical properties of a water-sediment mixture are specific weight of a mixture (the total weight of solid and water in the voids per unit total volume), specific mass of a mixture (the total mass of solid and water in the voids per unit total volume), volumetric sediment concentration (the volume of solids over the total volume), dynamic viscosity of a mixture (function of the dynamic viscosity of water and the volumetric sediment concentration), and kinematic viscosity of a mixture (the dynamic viscosity of a mixture divided by the mass density of the same mixture).

4.3. Movement of fluvial sediments

When flow conditions exceed critical conditions, sediment particles on a streambed start to move. Once a sediment particle in a stream is in motion, the applied hydraulic load governs the way of its motion. Generally, there are two ways of motion:

- near or on the streambed, and
- in suspension.

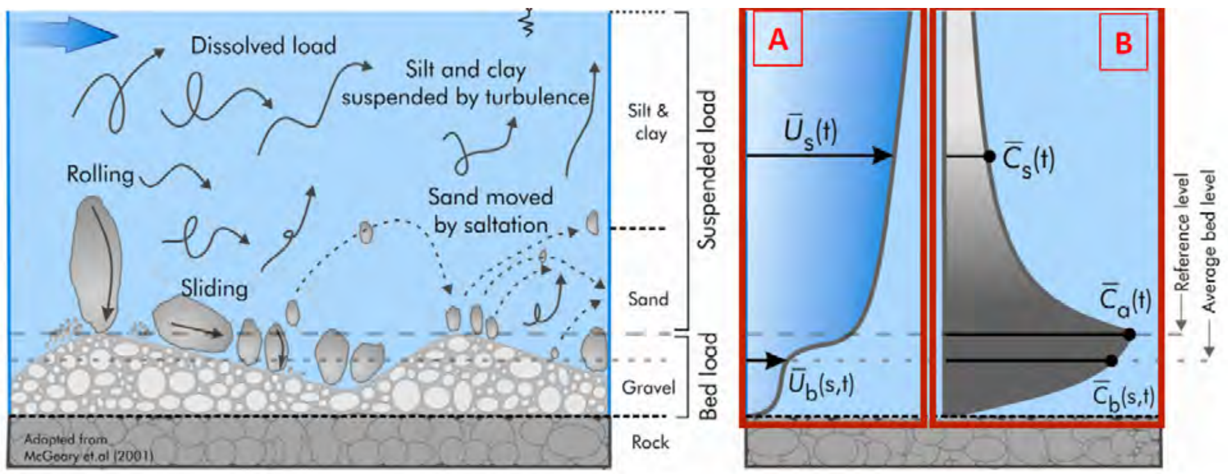


Figure 1: Movement of fluvial sediments and definition of sediment flux

Where sediment moves near or on the streambed is called bed load transport. Bed load can sometimes be divided into contact load composed of particles rolling, sliding or pushing, and saltating load composed of particles bouncing, hopping or jumping. The size of the particles that can be transported by saltation is usually correlated with the flow velocity and water density. The bed load, the amount of solid material carried on or near a streambed, usually amounts to less than 10 % of total sediment transported in large alluvial rivers. In mountain rivers and steep high-gradient streams, the major part of the total load may actually be bed load due to numerous mass-movement processes in the watershed and in-channel erosion of deposited fluvial sediments, e.g. in pools. Under fully developed sediment transport conditions there is steady exchange between bed load and suspended load.

Suspended load refers to sediment that stays in suspension for an appreciable length of time. In most natural streams, sediments are mainly transported as suspended load. Discharge-weighted total suspended solids concentrations range from practically 0 mg/l (clear water) during low flows in mountain environments to several kg/l during high flows in the form of hyper-concentrated flows, which typically occurs in tropical regions and in loess or volcanic ashes.

Based on the modes of sediment transport, total load is the sum of bed load and suspended load. Based on the source of material being transported, total load can also be classified as the sum of bed-material load and wash load. Wash load consists of fine materials that are finer than those found in the streambed. The amount of wash load depends mainly on the supply from the watersheds, not on the hydraulics of a stream. Consequently, it is difficult to predict wash load based on the hydraulic characteristics of a stream.

An important part of the lowland stream's load may also be dissolved load carried in solution. The proportion varies according to climate, the chemical nature of the rocks and the proportions of runoff contributing to the stream-flow in relation to the amount of groundwater flow. The quantity of dissolved solids in solution is given by the total concentration of dissolved material in water, measured by complete evaporation of a given quantity of water. The parameter is of use in any examination of the rate of chemical denudation and of the dissolved load of streams. Discharge-weighted total dissolved solids concentrations range from 5000 mg/l in arid saline environments to 5 mg/l in tropical rainforest regions.

4.4. Transport capacity of streams

The ability of a stream to transport sediment, as measured by the maximum quantity (mass or volume) of sediment that can be carried past a specific point in the stream in a given unit of time is called transport capacity. The transport capacity increases as the water discharge becomes greater or the stream gradient becomes steeper, and decreases, as the particle size of the sediment becomes larger. Stream transport capacity is a function of the bed width, since for a given water discharge and gradient the flow velocity near the streambed is smaller in a wide, shallow stream than in a narrow, deep one.

Sediment discharge ratio in a stream is the ratio between the sediment discharge and the water discharge. When defining the sediment discharge the total solid transport in a stream through its cross section is taken regardless of the way of sediment motion. Sediment-rating curve is than an empirical expression of the relationship between stream water discharge and stream sediment discharge at a given point. It is shown as an equation where the sediment discharge is defined as the water discharge multiplied by the mean sediment concentration, and can then be written as a potential function of the water discharge.

4.5. Stream aggradation and degradation

Sediment transport is a process interrelating erosion and sedimentation. When the rate of sediment supply from upstream is higher than a stream's sediment transport capacity, the streambed will start to aggrade at the rate defined by the difference between the rate of sediment supply and the sediment transport rate of the stream. The flow in the stream will be saturated with sediment, its transport capacity fully used. But if a stream's sediment transport capacity exceeds the rate of sediment supply from upstream, the balance of sediment load has to come from the channel itself. In this case, the channel starts to degrade.

4.6. Downstream fining in streams

Sediment transport is definitely selective in many ways and thus interrelated to sorting processes. Generally, sorting is defined as a process by which materials are graded according to one of their particular attributes, i.e. shape, size, density, etc. In sedimentology, the natural sorting of sediments by particle size is taken as a basis for classification into well sorted or poorly sorted deposits. Sediments that have been repeatedly reworked by marine waves or have travelled a long distance downstream in a fluvial system are usually well sorted into different-sized particles, because different particle sizes have different settling velocities. In general, sediments transported by glaciers and mass-movement are poorly sorted. Fluvial sediments tend to be well sorted.

Sorting processes in a stream can be observed in three directions: laterally (e.g. differences between coarser sediments in thalweg and finer sediments on a bar), vertically (e.g. differences between coarser armour layer and finer sublayers), and longitudinally (downstream decrease of mean sediment size due to decreasing flow competence).

Abrasion of fluvial sediments covers attrition processes during passive and active phase of sediment transport events, e.g. breakage, chipping, wearing, and grinding. Consequently, fluvial sediments change their particle size distribution as sediment particles are size-dependently reduced in size and their roundness generally increases. Only breakage events, more common in steep high-gradient streams or bedrock reaches, will increase angularity of sediment particles.

Downstream fining is a process in natural streams that describes an approximately exponential decrease in mean sediment size under ideal conditions. It covers sorting processes and fluvial abrasion, as well as in-situ processes like chemical or frost weathering of temporarily stored but exposed fluvial sediments, e.g. on a bar. Generally, sorting is the prevailing process responsible for fining; especially in specific situations like when a gravel-bed river suddenly turns into a sand-bed river. Abrasion is generally prevailing in steep high-gradient streams, where flow competence in high and sorting is thus less pronounced. The exponential decrease is often disrupted in sedimentary links, where fresh sediments from tributaries are laterally flowing into a stream. When sediment transport over longer reaches of a stream is to be modelled, sorting processes and fluvial abrasion of sediment particles should be therefore accounted for.

5. Review of technical international standards and techniques for sediment monitoring

5.1. International standards for sediment monitoring

The standards for sediment monitoring are developed in more details for the suspended sediments than for the bed-load sediments. The standards provide methods for determining the concentration, particle-size distribution, relative density of sediment, etc. The table below shows standards for suspended load and bed load monitoring, as well as standards for sediment quality monitoring.

Table 1: Specification of international standards for sediment monitoring

Standard	Standards of suspended load monitoring
ISO 4365:2005	**Liquid flow in open channels -- Sediment in streams and canals -- Determination of concentration -- Particle size distribution and relative density**
	Specifies methods for determining the concentration, particle-size distribution and relative density of sediment in streams and canals. The detailed methods of analysis are given for the following: determination of the suspended sediment concentration by evaporation and filtration, particle-size analysis of suspended sediment, determination of the bed-load and bed material sediment, determination of the relative density of sediment.
ISO/TS 24154:2005	**Hydrometry -- Measuring river velocity and discharge with acoustic Doppler profilers**
	Gives the principles of operation, construction, maintenance and application of acoustic Doppler profilers to the measurement of velocity and discharge, and discusses calibration and verification issues. It is applicable to open-channel flow measurements with an instrument mounted on a moving vessel.
ISO 13317-4:2014	**Determination of particle size distribution by gravitational liquid sedimentation methods -- Part 4: Balance method**
	Specifies the method for the determination of particle size distribution by the mass of particles settling under gravity in liquid. This method is based on a direct mass measurement and gives the mass distribution of equivalent spherical particle diameter. Typically, the gravitational liquid sedimentation method applies to samples in the 1 µm to 100 µm size range and where the sedimentation condition for particle Reynolds number less than 0.25 is satisfied.
ISO/TR 9212:2006	**Hydrometry -- Measurement of liquid flow in open channels** This standard has been revised by: ISO/TR 9212:2015
ISO 4365:2005	**Bed material sampling**
ISO 9195	**Sampling and analysis of gravel-bed material**

Standard	Standards of suspended load monitoring
	Reviews the current status of direct and indirect bedload-measurement techniques. The methods are mainly based on grain size distribution of the bedload, channel width, depth and velocity of flow. ISO/TR 9212:2006 outlines and explains several methods for direct and indirect measurement of bedload in streams, including various types of sampling devices.
ISO/TS 17892-4:2004	**Geotechnical investigation and testing -- Laboratory testing of soil -- Part 4: Determination of particle size distribution**
	Describes methods for the determination of the particle size distribution of soil samples. The particle size distribution provides a description of soil, based on a subdivision in discrete classes of particle sizes. The size of each class can be determined by sieving and/or sedimentation. For soils with less than 10 % fines, the sieving method is applicable. Soils with more than 10 % fines can be analysed by a combination of sieving and sedimentation.
ISO/TC 147/SC 2	**Water quality -- Determination of suspended solids -- Method by filtration through glass fibre filters (EN 872:2008)**
ISO5667-1 ISO5667-2	ISO 5667-1:2006 sets out the general principles for, and provides guidance on, the design of sampling programmes and sampling techniques for all aspects of sampling of water (including waste waters, sludges, effluents and bottom deposits).
ISO5667-3	ISO 5667-3:2012 establishes general requirements for sampling, preservation, handling, transport and storage of all water samples including those for biological analyses. It is not applicable to water samples intended for microbiological analyses as specified in ISO 19458, ecotoxicological assays, biological assays, and passive sampling as specified in the scope of ISO 5667-23. ISO 5667-3:2012 is particularly appropriate when spot or composite samples cannot be analysed on site and have to be transported to a laboratory for analysis.

5.2. Overview of techniques for sediment monitoring

5.2.1. Techniques for monitoring of suspended sediments

Grab samples

The simplest way of taking a sample of suspended sediment is to dip a bucket or other container into the stream preferably at a point where it will be well mixed. The sediment contained in a measured volume of water is filtered, dried and weighed. This gives a measure of the concentration of sediment and when combined with the rate of flow gives the rate of sediment discharge. A study of alternative sampling techniques showed that dip sampling in bottles generally gives concentrations about 25% lower than results obtained from more sophisticated techniques. For single samples taken by scooping a sample, a depth of 0.3 m below the surface is recommended as better than sampling at the surface. If the single sample can be taken at any chosen depth, 0.35-0.4 the depth of flow is recommended as giving the best estimate of average sediment concentration.

Figure 2: Suspended sediment sampling

Depth integrated samplers

Using the depth integrating samplers, water and sediment mixture can be sampled continuously while the sampler is moving at a constant transit rate along the vertical. If the ratio of intake velocity to ambient velocity is equal to 1, the volume of samples at each point will be proportional to the local velocity. The sediment concentration of the sample taken by the depth integration method is the discharge - weighted average concentration in the vertical. A typical sampler consists of a glass bottle inserted in a fish - shaped frame mounted on a rod when gauging small streams or suspended on a cable for larger streams. For the bottle to fill smoothly and evenly when below the surface it is necessary to have one nozzle or orifice for entry of water, and a second pipe through which the displaced air is ejected. The entry nozzle is usually designed with a slightly expanding cross - section behind the point of entry in order to reduce the risk of back pressure which could interfere with the flow into the bottle. In operation, the sampler is moved from the surface down to the bed and back up to the surface while sampling continuously. It is undesirable for any type of bottle sampler to continue to accept more inflow after the bottle is full as this can lead to an accumulation of sediment in the bottle. In some depth - integrating samplers the bottle is lifted out of the flow when or just before it is filled; other types of sampler may have some device to stop further sampling once the bottle is full.

Point - integrating samplers

The point - integrating sampler remains at a fixed point in the stream and samples continuously during the time it takes for the bottle to fill. Opening and closing the valves of the sampler are controlled from the surface electrically or by cables. Samples should be taken at a number of depths at each of several vertical sections.

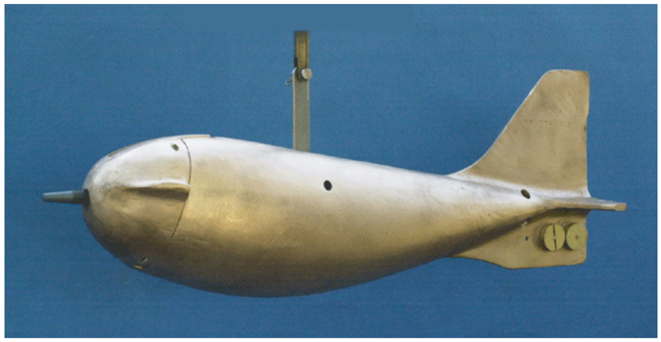


Figure 3: Point - integrating samplers

Pumping samplers

One of the characteristics of this type of sampler is its ability to collect samples at regular time intervals or in response to a rise or fall in stream flow at a definite point in the river. The entire variation in sediment concentration during a flash flood may be followed. Sufficient samples can be obtained automatically to define the variations in sediment concentration during a flood. However, all automatic pumping systems are vulnerable to pipe blockages and may also require efficient flushing systems. Portable pumping samplers may be used for taking point - integrated or depth - integrated samples at any point or vertical in a cross - section. Regulating the intake water velocity in order to be equal of that of the stream, the operator can obtain a sample that is representative of the sediment concentration at the point of measurement.

Photoelectric turbidity meter

The development of the photoelectric turbidity meter is based on the principle of attenuation of light transmitted through sediment - laden water. From light scattering theory, the photodensity (the ratio of intensity of the transmitted light and incoming light, I/Io) depends not only on the concentration but also on the particle size existing in the medium. It would be possible to establish a relationship between the sediment concentration and a photo - density reading only if the grain size were relatively constant. In operation, the instrument must be calibrated carefully to establish such a relationship. Determination of sediment concentration on the basis of the photoelectric effect can only be adopted in rivers where variation in grain size is very small and the concentration is fairly low.

Figure 4: Photoelectric turbidity meter

Acoustic Doppler Current Profiler (ADCP)

Acoustic current profilers were originally designed to measure 3 - D flow structure but they also record the intensity of the return echo. The latter is proportional to the number of backscatters present in the water column and can be used as a proxy for suspended sediment concentration. However, the software for such computation is limited, and considerable post - processing is needed to correct and normalize ADCP data for this use.

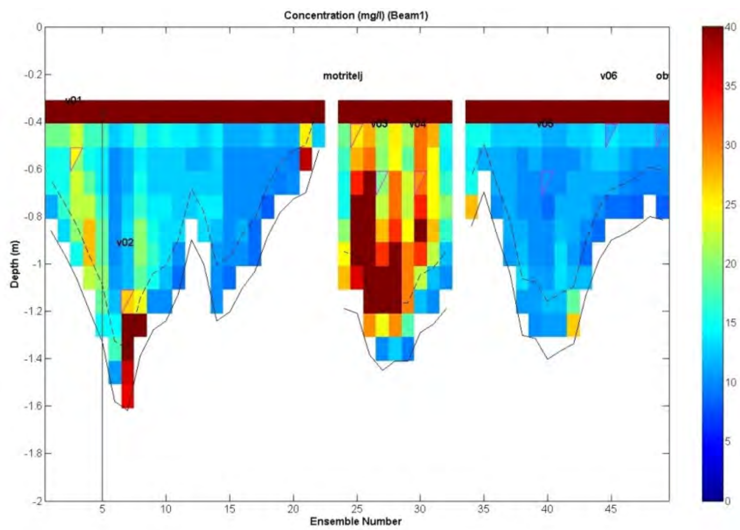


Figure 5: SSC spatial distribution (mg/l) on the hydrometric profile SAVA – PODSUSED (6/4/2012)

Other methods not commonly used for suspended sediment concentration measurements are optical backscatter, optical transmission, focused beam reflectance, laser diffraction, nuclear, spectral reflectance, digital optical, vibrating tube, differential pressure and impact sampler.

Table 2: Comparison of techniques for suspended sediment monitoring (after Wren et al., 2000).

Technology	Operation principles	Advantages	Disadvantages
Acoustic	Sound backscattered from sediment is used to determine size distribution and concentration.	Good spatial and temporal resolution, measures over wide vertical range, nonintrusive.	Backscattered acoustic signal is difficult to translate, signal attenuation at high particle concentration.
Bottle sampling	Water - sediment sample is taken isokinetically by submerging container in stream and is later analysed.	Accepted, time - tested technique, allows determination of concentration and size distribution, most other techniques are calibrated against bottle samplers.	Poor temporal resolution, flow intrusive, requires laboratory analysis to extract data, requires on - site personnel.
Pump sampling	Water - sediment sample is pumped from stream and later analysed.	Accepted, time - tested technique, allows determination of concentration and size distribution.	Poor temporal resolution, flow intrusive, requires laboratory analysis, does not usually sample isokinetically.

Focused beam reflectance	Time of reflection of laser incident on sediment particles is measured.	No particle size dependency, wide particle size and concentration measuring range.	Expensive, flow intrusive, point measurement only.
Laser diffraction	Refraction angle of laser incident on sediment particles is measured.	No particle - size dependency.	Unreliable, expensive, flow intrusive, point measurement only, limited particle - size range.
Nuclear	Backscatter or transmission of gamma or X - rays through water - sediment samples is measured.	Low power consumption, wide particle size and concentration measuring range.	Low sensitivity, radioactive source decay, regulations, flow intrusive, point measurement only.
Optical	Backscatter or transmission of visible or infrared light through water - sediment sample is measured.	Simple, good temporal resolution, allows remote deployment and data logging, relative inexpensive.	Exhibits strong particle - size dependency, flow intrusive, point measurement only, instrument fouling.
Remote spectral reflectance	Light reflected and scattered from body of water is remotely measured.	Able to measure over broad areas.	Poor resolution, poor applicability in fluvial environment, particle - size dependency.

5.2.2. Techniques for monitoring of bed load sediments

Basket - type sampler

A basket - type sampler is generally adopted for sampling coarse bedload material such as gravel and pebbles. Metal or nylon mesh is put on the side and top of a metal frame. The mesh should pass the suspended material, but retain the sediment moving along the bed. Loosely woven iron rings or other elastic materials may be put at the bottom to deal with variations in bed surface.

The average sampling efficiency of a basket - type sampler calibrated in the laboratory is reportedly about 45 per cent, although this may vary from 20 to 70 per cent.

The problems with bedload samplers are:

- The sampler disturbs the flow and changes the hydraulic conditions at the entry into the sampler.
- The sampler has to be resting on the streambed and tends to dig in as scour occurs round it.
- To remain stable on the bed it has to be heavy, and this restricts the use to lowering from bridges or purpose - built gantries.
- A sampler needs to rest on a reasonably smooth bed and not perch on large stones or boulders.

Pressure - difference - type sampler

Pressure - difference - type samplers are designed to produce a pressure drop at the exit of the sampler, sufficient to overcome energy losses, to ensure an entrance velocity equal to that of the undisturbed stream. A perforated diaphragm with a sampler body forces the flow to drop its sediment into the retaining chamber and to leave through the upper exit.

Figure 6: Bed load sampling

Pan or tray - type sampler

There are various types of this sampler, here are some:

- Flat pan divided into compartments by transverse vertical strips of sheet metal which were intended to trap the moving material.
- Flat wedge - shaped pan container pointing upstream, thus forming an upward slope on the top of the container. The bedload material moves up the slope and falls into the container through a slot entrance in the top.

This type of sampling method is used primarily to obtain the total amount of bed load in a flood period, since it is not easy to remove or replace the traps during floods. The top of the inner container may be adjusted to make it even with the riverbed. The height of deposition in the trap can be recorded and the sampled material can be extracted from the trap using a submerged slurry pump.

Slot or pit - type sampler

Concrete troughs or trenches are constructed across the. The slot is divided into sections fitted with gates. Sediment falling into the open slot is carried laterally to a sump in the riverbank. After continuous sieving and weighing, the sediment is returned to the river downstream of the trap by a conveyor belt. The measurement of bed load using this type of installation is reliable and accurate. However, it is adaptable mainly for relatively small rivers and particularly for experimental studies or the calibration of samplers.

Dune tracking method

The dune tracking method of bed load involves measuring the rate of bed material movement in dune shaped forms in the direction of flow. It is generally difficult to measure the bed load in an alluvial river that consists mainly of fine sands by means of existing measuring methods.

The dune tracking method has the advantage that only hydrographic surveying techniques are employed. With this method, a sounding system should be established which permits the recording of bottom profiles along pre - fixed courses in a river reach. Bed load rate can be estimated from the propagation of dunes, calculated by successive surveys. The accuracy of the dune tracking methods relies on the accurate determination of the bed elevation and positioning of the measuring points.

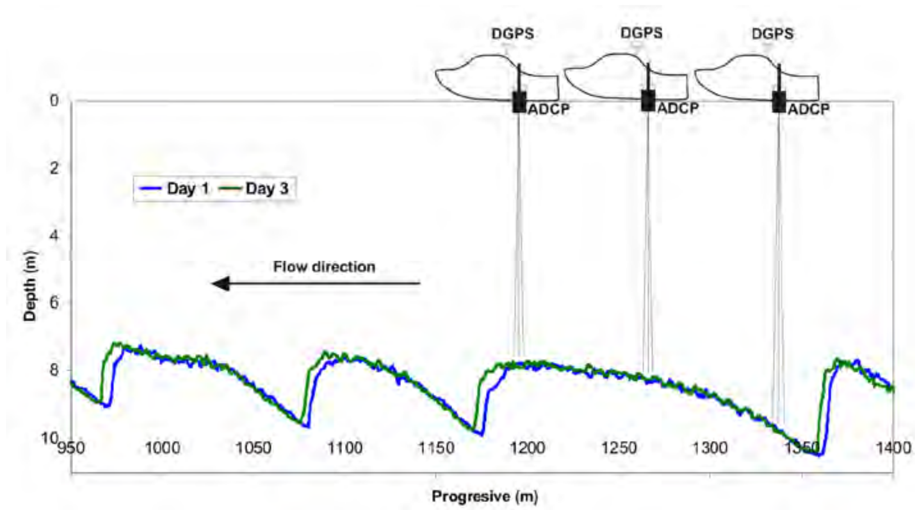


Figure 7: Dune tracking method

Tracer method

The tracer method is based on the detection of the sediment movement by tracers. This method is feasible for measuring bed material discharge and sediment dispersion. The procedures and techniques involved are the selection and labelling of the sediment tracer particles, the method of introducing the tracer into the flow system, and the method of detection. Field data collection includes tracing labelled particles, sampling the bed material and measuring hydraulic elements in the river reach under investigation. Four labelling methods are available for use with the tracer method. The fluorescent tracer, radioactive tracer and stable isotope tracer can all be used in rivers where the bed material is composed of relatively coarse particles such as gravel and sand. However, only the radioactive tracer seems to be suitable for use in places where the bed material is composed mainly of fine sand, silt and clay. In all cases, the labelled particles should have the same hydraulic behaviour after labelling as before and should resist leaching, abrasion and decay of their traceability.

Figure 8: Colouring particles for tracking of river bed sediments

Sediment sampling

Sediment samplers could be divided roughly into 2 different techniques:

- grab sampling which collects surface and near surface sediments
- coring which collects a column of the subsurface sediment and could be required to establish the historical pattern of the contamination.

In all grab and core operations, a slow approach to the river bed should be ensured to avoid the creation of "bow wave" that disturbs the sediment-water interface prior to sampling. In some circumstances, it would be, also, possible to have the samples collected by divers using either glass or Teflon beakers.

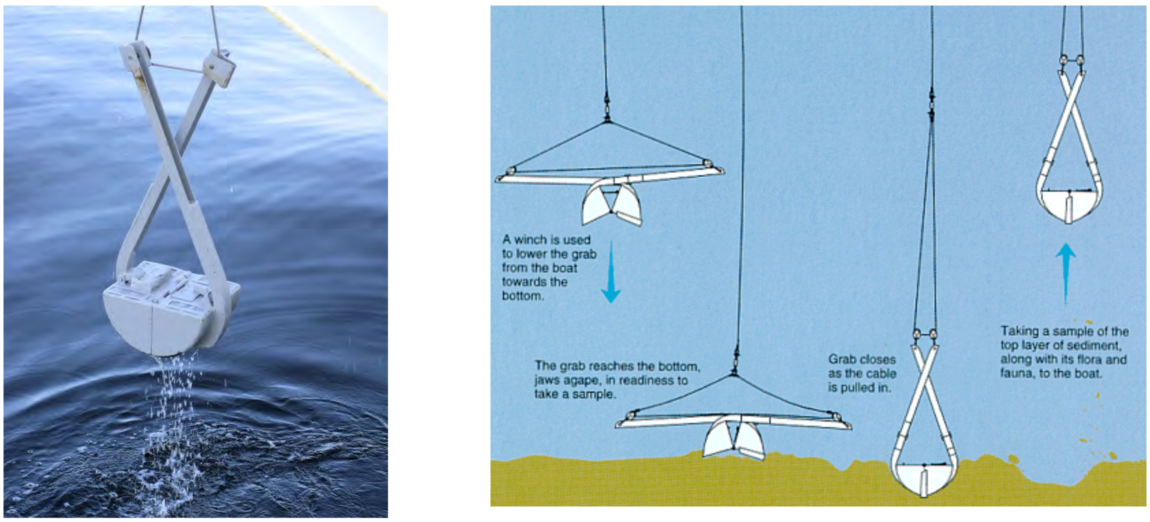


Figure 9: Sampling of river bed sediments by grab sampler

5.2.3. *Monitoring of siltation in reservoirs and morphological changes*

Monitoring of siltation in reservoirs and morphological changes in rivers is usually performed by hydrographic survey of a channel bed. The surveys are usually made from a boat by using single-beam or multi-beam sonar. The location of a boat/sonar and vertical elevation is gained by RTK-GPS so the 3D absolute coordinates of a channel bottom can be produced. A comparison of repeated hydrographic surveys shows the changes of sedimentation in reservoirs or morphological changes of the river bed.

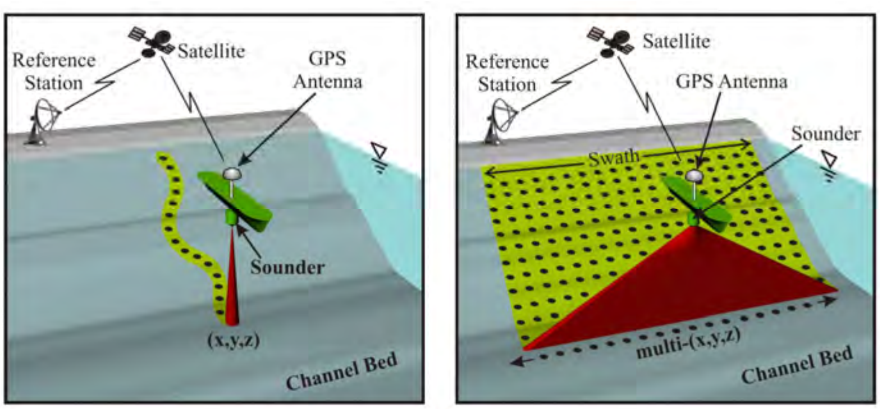


Figure 10: Single-beam and multi-beam hydrographic surveys

5.2.4. Density of sediment monitoring network

Design of sediment monitoring networks is based on the minimum density principle (a) either by measurement of the erosion, transport and deposition of the sediment within the country, (b) or by measurement the total sediment discharge into the sea. An optimum network would contain a sediment station at the mouth of each important river discharging into the sea. Streamflow records must be collected at all stations where sediment transport is measured. Therefore, the sediment transport monitoring stations should be so located that they can function as components of the minimum streamflow networks.

The Guide to Hydrological Practices (Vol. I) 4th ed. (1981) recommends that sediment transport be measured of the following percentages of the stations in the minimum network of stream gauges – considering the European conditions:

- Arid regions/Mediterranean regions: 30 per cent
- Humid temperate 15 per cent.

These percentages can serve as guides in establishing a minimum network. Considering the minimum density of hydrometric (stream gauging) stations the following minimum density is required:

- Flat regions of temperate or Mediterranean zones: 1000-2500 km^2/station
- Mountainous regions of temperate or Mediterranean zones: 300-1000 km^2/station
- Arid zones (without great deserts): 5000-20000 km^2/station

From the two aspects one can conclude that under European normal conditions the minimum sediment monitoring network-density is between

a. 1000-3000 km^2/station for normal conditions
b. 3000-10000 km^2/station for extraordinary conditions

The density of suspended monitoring network in 2000 was presented in the WMO report: “WMO - Regional Association VI - Working Group On Hydrology, Sediment Transport Survey, July 2000”. The density of stations for 29 analysed countries was from 23552 km^2/station for Russia to 358 km^2/station for France (Annex – Table 4). The report shows the introduction of sediment monitoring and the length of monitoring (Annex - 5) for suspended sediment (in Bayern Germany starts in 1923 and lasts for 76 years), bed load (in Ukraine starts in 1932 and lasts for 67 years) and bed material (in Russia starts in 1936 and lasts for 63 years). Largest number of stations in 1999 was 1560 in France. The table (Table 5**Error! Reference source not found.**) also shows the frequency of sampling, characterizes the sampling (separated, jointly, combined methodology) and informs the reader about standardization and international co-operations. Annex-Table 6**Error! Reference source not found.** shows instruments used in the network, summarizes the data processes on concentration, and characterizes the form of international co-operations.

5.3. General conclusion on international standards and techniques

From the previous analysis of sediment status on SRB it has been realized that we need harmonization and standardization of a measurement based methodology to have comparable results on entire river basin.

The general conclusions on the international standards and techniques for sediment monitoring with regard to the SRB are:

- The novel acoustic techniques allow more detailed and cheaper monitoring of suspended sediment concentration than traditional methods. The acoustic technique requires calibration of measurements by direct sediment sampling. So a combination of ADCP measurements and laboratory analysis is necessity and is recommended method for obtaining a reliable relationship between discharge and suspended sediment concentration.
- The modern international standards for the sediment monitoring are already utilised in the SRB (mainly in Slovenia and Croatia). The implementation of the same measurement techniques and standards is recommended for the all SRB countries.
- The sampling of the river bed sediments is a cheap method and can be periodically performed in the Sava River on several locations.
- Monitoring of siltation in reservoirs and morphological changes are performed by the state agencies. The establishment of periodical hydrographic surveys would be beneficial.

6. Review of existing sediment monitoring data, standards and technics is SRB

6.1. Institutions responsible for sediment monitoring in SRB countries

6.1.1. Slovenia

Sediment transport: Hydrologic monitoring, including monitoring of sediment transport, is performed by the Slovenian Environment Agency (ARSO). The results of the regular hydrologic monitoring are published by the Slovenian Environment Agency (ARSO) in annual reports and the results of additional measurement, performed during flood events, are published in special reports. More details on monitoring can be found on http://www.arso.gov.si/. Detailed data on surface water condition are available on-line: water level (m), discharge (m^3/s), temperature (°C), discharge decile class (-) for automatic gauging stations (http://www.arso.gov.si/en/water/data/stanje_voda.html). Archive hydrologic data are also available on-line: daily values and extremes for all rivers and gauging stations can be downloaded as CSV (comma separated values) or as *.xls files to be used in Excel spreadsheet for a selected calendar year (http://vode.arso.gov.si/hidarhiv/pov_arhiv_tab.php) – for selected gauging stations (Veliko Širje on the Savinja River, Suha on the Sora River, and Hrastnik on the Sava River) and years of operation also daily values of suspended loads (g/m^3).

Sediment quality: Water quality monitoring is performed by the Slovenian Environment Agency (ARSO).

Reservoir sedimentation: Monitoring of reservoir sedimentation is an obligation of HPP owners (SEL - Savske elektrarne Ljubljana and HESS – Hidroelektrarne na Spodnji Savi).

Dredging: For dredging of fluvial (river) sediments concessions for dredging are issued according to the Water Act (ZV-1 from 2002, articles 136 - 149) as a stand-alone legislation act in alignment with the Water Management Plans. In practice, dredging was allowed if water contributions were paid to the state. Example for the Sava River: "Decree on the concession for the removal of alluvial deposits from the Sava River in the area of Litija Municipality at the removal sites for which the final operating permit has been obtained" (2004). Also, occasional dredging is performed by NPP Krško in the Sava River reach upstream of the Krško weir (to assure safe water intake for cooling purposes).

Survey of river cross-sections: Survey of cross sections on water gauging stations is performed by the Slovenian Environment Agency (ARSO).

6.1.2. Croatia

Sediment transport: Sediment monitoring in Croatia is a task of the Hydrological and Meteorological Service, Hydrology Department (DHMZ). All hydrological parameters, including sediment data, are being stored in hydrological database (Hydrological Information System 2000) developed by Hydrological and Meteorological Service, Hydrology Department. Annual overview on sediment data is published in the Hydrological yearbooks. More details on monitoring can be found on www.dhmz.htnet.hr.

Sediment quality: Water quality monitoring is performed by Croatian Waters. DHMZ is responsible only for particle size distribution of suspended and bed load at some hydrological gauging stations.

Reservoir sedimentation: Monitoring of reservoir sedimentation is obligation of HPP owners and Croatian Waters and is done by DHMZ.

Dredging: Croatian Waters are responsible for dredging.

Survey of river cross-sections: Croatian Waters and Agency for inland waterways (Agencija za vodne putove) are responsible for surveys of the Sava riverbed, while DHMZ is monitoring morphological changes at the locations of hydrological gauging stations.

6.1.3. Bosnia and Herzegovina

The right bank of the Sava in Bosnia and Herzegovina belongs to Federation of Bosnia and Herzegovina, Republic Srpska, and Brcko District.

Sediment transport: Water monitoring is carried out by hydrometeorological services of 2 entities (FHMZFBIH and RHMZRS), but sediment transport is presently not done in this frame.

Sediment quality: Water quality monitoring in Republic Srpska is performed by Javna ustanova Vode Srpske and Agencija za vodno podrucje rijeke Save in Federation BA. Sediment quality investigations were performed only through a few projects – NATO SfP DSS for river Bosnia and JICA Hot spots in BA.

Reservoir sedimentation: Monitoring of reservoir sedimentation is obligation of reservoir owners, performed recently only by JP "Spreca", for reservoir "Modrac".

Dredging: Javna ustanova Vode Srpske in Republic Srpska and Agencija za vodno područje rijeke Save in Federation BA are responsible for dredging.

Survey of river cross-sections: Responsible institution is not defined.

6.1.4. Serbia

Sediment transport: Sediment monitoring is still present in the Program of the Republic hydrometeorological service of Serbia (RHMZ), but presently not executed.

Sediment quality: Ministry of agriculture and environmental protection, Agency for Environmental Protection is responsible for sediment quality monitoring.

Reservoir sedimentation: Electric Power Industry of Serbia is responsible for monitoring of sedimentation of HPP reservoirs of on Drina River (HPP Bajina Basta and HPP Zvornik).

Dredging: Ministry of agriculture and environmental protection, Republic directorate for water is responsible for dredging.

Survey of river cross-sections: Ministry of Construction, Transport and Infrastructure, Directorate for Inland Waterways is responsible for survey of the Sava riverbed.

6.2. Review of monitoring network, standards, techniques and practices in SRB countries

6.2.1. Slovenia

(a) Suspended sediment transport

Monitoring network: The number of monitoring sites for suspended load is far from being optimal. Suspended load monitoring was interrupted for some years, and will be re-established in the course of 2015 through the execution of the program BOBER (started in 2010) at 9 monitoring stations in the Republic of Slovenia - is presently done on only 3 rivers in the SRB: the Sava River (gauging station Hrastnik), the Sora River (g.s. Suha) and the Savinja River (g.s. Veliko Širje I). Suspended sediment is not monitored on any other 1st order tributaries of the Sava River (Ljubljanica, Krka, Sotla/Sutla and Kolpa/Kupa).

Sampling method: Measurements are done continuously using turbidity meters (HACH LANGE Solitax Turbidity and Suspended solids highline sc devices are foreseen to be installed in 2015 at 9 gauging stations, 3 of them in the SRB – the project called BOBER).

Sampling/measurement schedule: Measurements are continuous; the data transfer from the measuring sites to the database will be done continuously.

Laboratory analysis: Sediment concentration is obtained through conventional filtration method.

Processing: The usual method for discharge measurements in gauging stations is nowadays the application of Acoustic Doppler Current Profilers (h-ADCPs). Knowing the profile of sediment concentration and discharge (measured at the same time) sediment transport rate (kg/s) through profile is calculated and finally summed up to an annual profile sediment load (kg/year).

Analyses: Suspended load data is gathered on daily, monthly and annual basis. Annual overview of daily suspended load concentrations (kg/m^3) and daily transportation rates (kg/s) is freely available on the web in the ARSO hydrologic archive (http://vode.arso.gov.si/hidarhiv/pov_arhiv_tab.php).

(b) Bedload measurements do not exist.

(c) Sediment quality monitoring

Monitoring network: at 6 water bodies – river reaches (2 reaches at the Sava Dolinka River, 2 sites at tributaries of the Lower Sava River (Krka, Sotla/Sutla Rivers), and 2 sites at the Lower Sava River (Vrhovo-Boštanj, border cross section at Jesenice na Dolenjskem)

Standard: For sampling of river sediments standards SIST ISO 5667 - 12 & ISO 5667 - 15 are used. For the chemical analysis of sediments the wet sieved fraction < 63 µm is used.

Sampling schedule: Primary substances in sediments are sampled 4 to 12 times a year.

(d) Reservoir sedimentation measurements

Sedimentation is monitored in reservoirs of HPP Moste on the Sava Dolinka River, HPP Mavčiče and HPP Vrhovo on the Sava River.

(e) Dredging data

Data on dredging are collected on a few locations: Hrušica in the Sava Dolinka River upstream of the HPP Moste, cross section Hotič upstream of Litija on the Sava River, reservoir upstream of the weir for cooling water intake for the Nuclear Power Plant Krško on the Sava River.

(f) River cross sections: In water gauging stations on a regular basis (on average four times a year), occasionally using ADCP on a boat (in existing HPP reservoirs). A new Krško gauging station downstream of the new HPP Krško will be built (will be part of ARSO state hydrologic monitoring). A new gauging station Čatež II will be built (with h-ADCP) after HPP Mokrice will be finished.

6.2.2. Croatia

(a) Suspended sediment transport

Monitoring network: Suspended sediment is monitored on 10 gauging stations in SRB (4 stations on the Sava River and 6 stations on the tributaries).

Sampling method: Grab samples (dipping a bucket/container in the river), point or depth integrating samplers are used. These types of measurement are used according to ISO 4365:2005 standards. ISO 4363:2002 standards are followed for profile mean suspended sediment concentration and mean particle size distribution measurements.

Sampling/measurement schedule: Point samples at all gauging stations are taken once a day. Profile measurements of sediment concentration and sediment load, at 3 stations on the Sava River, are done periodically.

Laboratory analysis: Sediment concentration is obtained through standard vaporization and filtration methods.

Processing: The usual methods for discharge measurements are Acoustic Doppler Current Profiler (ADCP) or hydrometric current meter. ADCP is also used in suspended sediment concentration measurement. Knowing the profile sediment concentration and discharge (measured at the same time) sediment transport (kg/s) through profile is calculated.

Analyses: Suspended load data is gathered on daily, monthly and annual basis and its correlation with water levels, discharges, and grain size distribution of the material is derived. Annual overview of daily suspended load concentration and transportation rates is published in the Hydrological yearbooks. Periodic profile measurements of concentrations and transportation rates and grain size distribution of material are published in annual reports and studies.

(b) Bedload measurements do not exist.

(c) Sediment quality monitoring

Monitoring network: Monitoring is done by Croatian Waters on seven locations as part of the general plan for water quality monitoring (according to WFD requirements)

Standard: The chemical analysis of sediments includes total nitrogen, total phosphorus, cadmium, nickel, lead, mercury, mineral oil, polychlorinated biphenyls, organochlorine pesticides, alachlor, triazine pesticides, pentachlorobenzene. As there are no standards for the assessment of the sediment quality, the content of substances are compared between different streams. Besides the regular monitoring, periodic chemical analyses are performed by different institutions on a project-to-project basis.

Sampling schedule: Besides the regular monitoring, periodic chemical analyses are performed by different institutions on a project-to-project basis.

(d) Reservoir sedimentation measurements

Only in the reservoir upstream of the Novska lake in order to control intake of sediment load into the lake.

(e) Dredging data.

Available in Croatian waters.

(f) River cross sections

Available in Croatian Waters, Agency for inland waterways and DHMZ (only cross sections of gauge stations).

6.2.3. Bosnia and Herzegovina

(a) Suspended sediment transport

As stated before, regular suspended sediment monitoring is not performed by hydrometeorological services (FHMZFBIH and RHMZRS). Occasional monitoring of sediment is conducted for individual projects, like “The Sava River waterway design - monitoring on the Sava River” and “HPP Vranduk project – monitoring on the River Bosna”.

(b) Bedload measurements do not exist.

(c) Sediment quality monitoring – only occasionally, through specific projects (Miljacka, Bosna)

Monitoring network: Regular monitoring doesn't exist. Sediment quality measurements were only conducted within "Sava River Basin project: Sustainable usage, management and protection of resources". Samples were collected four times (08/2005, 11/2005, 05/2006, 10/2006) after drought and rain periods

(d) Reservoir sedimentation measurements – performed only for reservoir Modrac, as mentioned before

(e) Dredging data – do not exist

(f) River cross sections – in course, for the implementation of Flood Directive

6.2.4. Serbia

(a) Suspended sediment transport

In the past, RHMZ did regular suspended sediment monitoring on a number of gauging stations in SRB. Monitoring was done on the Sava River, at Sremska Mitrovica (1958-1980), Sabac (1958-2002), and Beograd (1958-1998), as well as on large tributaries: the Drina (Badovinci, 1990-2001) and the Kolubara River (Drazevac, 1958-2002). Instruments and methodology should be updated.

Institute Jaroslav Cerni conducted yearly programs of the Iron Gate 1 reservoir monitoring, between 1974 and 2014. These encompassed daily monitoring of suspended sediment transport at Beograd and Sremska Mitrovica on the Sava River.

(b) Bedload measurements do not exist.

(c) Sediment quality monitoring

Monitoring network**:** River sediments are analysed at 4 locations on the Sava River (Jamena, Sremska Mitrovica, Šabac, Ostružnica) and many locations on the Drina, Lim, Kolubara and Topčiderka Rivers.

Standard is set in by-law.

Sampling schedule is not set.

(d) Reservoir sedimentation measurements: occasionally, in Bajina Bašta and Zvornik reservoirs on the Drina river. Include sampling of bed material in reservoirs and survey of the riverbed within reservoir space

(e) Dredging data: Only data on water permissions for individual dredging fields are stored in a database. Actually dredged quantities are not available.

(f) River cross sections: Sava riverbed was surveyed in 2004 and 2009.

6.3. General conclusions on the sediment monitoring and assessment

The general conclusions on the sediment monitoring and assessment in SRB are:

- Only suspended sediment is monitored, while bedload measurements are not present anymore;
- Regular monitoring of suspended sediment is currently present only in Slovenia and Croatia;
- Suspended sediment sampling and measurement methodologies are different in Slovenia and Croatia;
- Sediment quality measurements according the Water Framework Directive (2000/60/EC) are done in Slovenia, Croatia and Serbia;
- Data on reservoir sedimentation are not collected on a regular basis;
- Data on dredging are not publically available in all countries.

7. Proposal of future sediment monitoring system in the SRB

7.1. Basic considerations

It is in the interest of all SRB countries to establish a coordinated sediment monitoring system in the Sava River basin, as stipulated in Art. 6 of the Protocol on Sediment Management to FASRB. Data gathered on the future sediment monitoring network will be used for preparation and implementation of the SRB Sediment management plan.

Future sediment monitoring network should cover the whole SRB, i.e. all river basins larger than 1000 km2. However, monitoring of sediment on the Sava River main course is crucial and should be established as the first phase of the future SRB monitoring network development. Besides the monitoring along the Sava, sediment should be monitored at profiles established on the lowest sections of its main tributaries to get the clear picture on their role in the Sava River sediment balance.

Sediment monitoring in SRB should be based on coordinated national monitoring programs, having a common or at least comparable methodology, instruments and techniques.

"Sediment monitoring" referred to in this report is focussed only on determination of sediment quantities in SRB. Namely, sediment quality monitoring in SRB countries is already in place or will began soon, as a part of WFD (Water Framework Directive, 2000/60/EC) compliant monitoring of status of water bodies.

7.2. Data to be collected

Future sediment monitoring system in the SRB should include:

1. **Continuous suspended sediment monitoring**
   a. Turbidity measurements (with turbidity meters), with periodic calibration by sediment sampling, C_{point}
   b. Daily sampling of suspended sediment at specified point of the monitoring profile, C_{pov}
2. **Periodic suspended sediment monitoring**
   a. ADCP measurements of suspended sediment concentration from backscatter intensity, C_{prof}
   b. Sampling of suspended sediment across the monitoring profile, to determine the average profile suspended sediment concentration, C_{prof}
   c. Determination of grain-size curve
   d. Bed material sampling
3. **Periodic monitoring of reservoir sedimentation and river bed changes**
   a. Survey of cross-sections within reservoirs (every 6 years)
   b. Survey of river cross-sections (every 6 years)

As suspended sediment plays the dominant role in the morphological processes on the Sava River and in lower courses of its tributaries, system for monitoring of suspended sediment should be established as soon as possible. Two SRB countries (Slovenia and Croatia) already monitor suspended sediment transport in the Sava River and its tributaries, while other countries (Bosnia and Herzegovina and Serbia) will need to re-establish monitoring.

Bed load monitoring is not envisaged for the first phase, as it is very costly and difficult. Also, the first phase is dedicated to preparation of data for the sediment balance of the Sava River itself, where bed load has comparably small role in comparison to suspended load. In the later phases of development, when monitoring will be expanded to large mountainous tributaries, bed load data will be needed also.

Bed material sampling should be done, not only on some locations, but all along the Sava river main course.

Data on reservoir sedimentation are very important to balance the sediments in the SRB. In the first phase, dedicated to the Sava River main course, surveys of cross sections within reservoirs should be done only in Slovenia. Eventually, these data will be needed for reservoirs on all Sava tributaries.

Data on cross sections of the Sava riverbed and dredging data should also be collected from navigation and water management agencies

7.3. Methodology of data collection

7.3.1. Suspended sediment load

Variations of suspended sediment load in the Sava River and its large tributaries are very frequent, and depend on hydro-meteorological conditions and other circumstances.

As suspended sediment load is a product of water flow and suspended sediment concentration (SSC), measurements of these components should have at least a comparable accuracy. Presently, water flow on almost all gauge stations in the SRB is measured using contemporary devices which provide continuous data. It is expected that in the further enhancement of flow monitoring network all gauges will provide continuous data on water flow.

To obtain more reliable data on suspended sediment load, especially during high flows, SSC data should also be continuously collected. Discrete SSC values (provided by taking sediment sample once a day) are not sufficient for flood events, when the transport is very intensive and variable in time. On the other hand, taking a few samples per day may be very costly and overburden the national hydro-meteorological services.

Instead of traditional data collection methods requiring routine collection and analysis of water samples, there is a number of promising surrogate technologies to continuously monitor suspended sediment. There are commercially available instruments operating on bulk optic (turbidity), laser optic, pressure difference, and acoustic backscatter principles. These instruments are permanently developing, and differ a lot in terms of cost, reliability, robustness, accuracy, sample volume, susceptibility to biological fouling, and suitable range of mass concentration and particle size distribution.

Turbidity meters are proposed for SRB monitoring, as widely used all around the world in sediment monitoring programs, and also in some parts of the SRB (Slovenia). They provide reliable data where the point measurements can be reliably correlated to the river's mean cross section concentration value, effects of biological fouling can be minimized, and concentrations remain below the sensor's upper measurement limit.

Turbidity meters can be installed in gauge stations along the Sava River and lower sections of its tributaries, at reasonable cost (approximately 5000$ per unit). Individual, site specific field calibrations are needed to make a correlation between point SSC and turbidity, and moreover between point SSC and cross-sectional average SSC.

This is the reason why point sediment sampling and cross sectional measurements should be (re)established at all sediment monitoring profiles in the SRB. These measurements should continue until the above mentioned correlations became reliable and cover the whole range of flows.

Point or depth integrating samplers should be used following ISO 4365:2005 standards. ISO 4363:2002 standards should be followed for profile mean SSC and mean particle size distribution measurements.

Acoustic Doppler profilers may be used for occasional cross sectional suspended sediment measurements at gauge stations. ADCPs are currently in use in Slovenia, Croatia and Serbia for flow measurements. The same measurements can be used to derive suspended sediment concentrations, as the acoustic backscatter to measure.

Presently, knowledge in the Sava countries on possible use of ADCP in suspended sediment measurements is very limited (available only in Croatia). Common field exercises, where standard techniques and ADCP are used in parallel for suspended sediment transport measurement, and help of the ADCP manufacturers will be needed to enhance it.

Daily data on suspended sediment concentrations and transport should be collected, and printed in the Hydrological yearbooks of ISRBC. Monthly and yearly suspended sediment quantities will be derived also.

7.3.2. Bed sediment sampling

Sampling of riverbed material should be obligatory part in all cross sectional measurements. However, it might be of interest for all countries to do the sampling campaign along the Sava River every 6 years, in the time of riverbed survey. Sampling campaigns are also to be performed after large floods.

Standard grab samplers should be used, and ISO 4365:2005 standard followed.

7.3.3. Survey of cross sections

Survey of river cross sections will be done as a part of flow/sediment measurement in gauge stations. However, a survey campaign along the whole course of the Sava River should be done every 6 years. Navigation and water management agencies should determine the distance between cross sections to be surveyed. Cross sections should be surveyed using single beam echo-sounder, eventually combined with multi beam echo-sounding on some locations.

7.4. Monitoring profiles

The future sediment monitoring network in the SRB is presented in the following table.

Table 3: Future SRB sediment monitoring profiles

SRB country/ entity		River	Sediment monitoring profile	Rationale of proposal
Slovenia		Sora	Suha	Operating
		Sava	Hrastnik	Operating
		Savinja	Veliko Širje I	Operating
		Sava	One for each Hydro power plant (HPP)	New, operational monitoring to be performed by the HPPs owners on the lower Sava River (HESS)- – Savske elektrarne (SEL): HPP Vrhovo & HESS: HPP Boštanj, HPP Arto-Blanca, HPP Krško, HPP Brežice, HPP Mokrice.
Croatia		Sava	Jesenice na Dolenjskem	New, SI-CR common measurements
		Krapina	Kupljenovo	Operating
		Sava	Podsused	Operating
		Sava	Rugvica	Operating
		Kupa	Farkašić	New
		Sava	Crnac	New
		Una	Dobretin	New
		Una	Hrvatska Kostajnica	Should be re-activated (operated till 1991)
		Sava	Jasenovac	Operating
		Sava	Stara Gradiška	Should be re-activated (operated till 1991)
		Sava	Davor (Sl. Kobas)	New
		Sava	Slavonski Šamac	New
		Sava	Slavonski Brod	Operating
		Sava	Gunja	New, CR-RS common measurements
Bosnia and Herzegov	Fed BA	Una	Kralje*	New
	BA RS	Una	Novi Grad – nizvodno	New

SRB country/ entity		River	Sediment monitoring profile	Rationale of proposal
ina	Fed BA	Vrbas	Jajce-Kozluk*	New
	BA RS	Vrbas	Razboj	New
	Fed BA	Bosna	Maglaj*	New
	BA RS	Bosna	Modriča	New
	Fed BA	Drina	Goražde	New
	BA RS	Drina	Janja**	New
	BA RS	Sava	Rača**	New
Serbia		Sava	Jamena	New
		Drina	Badovinci or Radalj	Should be re-activated (operated till 2001)
		Sava	Sremska Mitrovica	Should be re-activated (operated till 1980)
		Sava	Sabac	Should be re-activated (operated till 2002)
		Kolubara	Drazevac	Should be re-activated (operated till 2002)
		Sava	Beograd	Should be re-activated (operated till 1998)

(*) Upstream profiles on tributaries in BA should be incorporated in the SRB monitoring network in the next phase

(**) BA profiles on the common BA RS sectors of the Drina and the Sava River may not be needed, since there are nearby stations in Serbia.

8. Establishment of on-line free database on sediment

8.1. Legal background

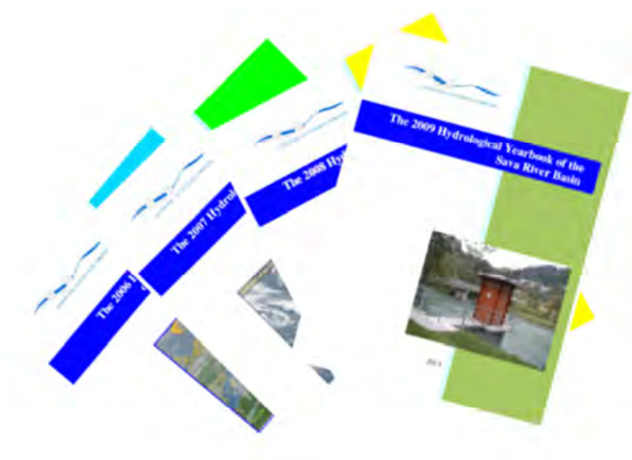
The legal background to exchange hydrological and meteorological data and information in the Sava River Basin has been established by the:

- Framework Agreement on the Sava River Basin signed and ratified by Bosnia and Herzegovina, Croatia, Serbia and Slovenia;
- WMO Resolution 25 (Cg-XIII) - Exchange of Hydrological Data and Products and Resolution 40 (Cg‑XII) - Policy and Practice for the Exchange of Meteorological and Related Data and Products, the World Meteorological Organization adopted by the World Meteorological Organization Congress;
- The Convention on Cooperation for the Protection and Sustainable use of the Danube River signed by the Danube riparian Countries, including the Sava River Basin countries;
- Policy on the Exchange of Hydrological and Meteorological data and Information in the Sava River Basin signed by the national hydrometeorological services in Slovenia, Croatia, Bosnia and Herzegovina (both entities), Serbia and Montenegro and 2 water agencies in Serbia and Bosnia and Herzegovina.

8.2. Existing sediment data exchange system

At the Sava River Basin level the data on hydrological data including sediment are available in the Hydrological Yearbooks. The first HY for the Sava River Basin has been developed for the year 2006 which is the first one for the whole basin since 1986. Until now the 2006, 2007, 2008, 2009, 2010 and 2011 issues accessible on the ISRBC web-site (http://www.savacommission.org) in pdf format. Starting with the 2007 issue, data for Montenegro included.

Until now only data for gauging stations Veliko Širje and Suha in Slovenia and Podused, Jasenovac, Slavonski Brod and Kupljenovo in Croatia are available.



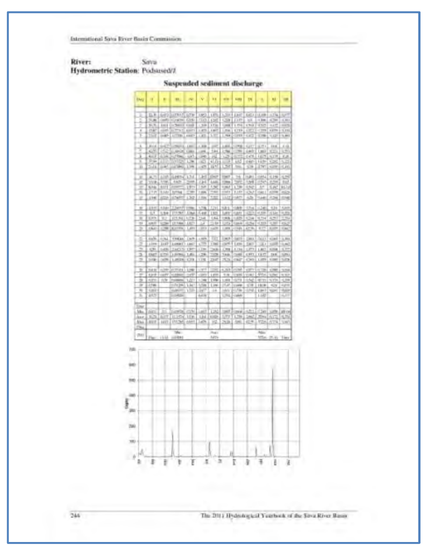


Figure 11: The Hydrological Yearbooks

8.3. Establishment of web-based application for processed data

Hydrological Information System of the International Sava River Basin Commission (Sava HIS) provides a tool for collecting storing, analysing and reporting a sufficiently high quality data hydrological and meteorological data, including sediment data.

Hydrometeorological data collected by Sava HIS system are based on and contain position of the gauging stations. Such data with spatial component can be visualized on a map as a point object with related hydrometeorological attribute data. Therefore, the SavaHIS web-based application for processed data is integrated with SavaGIS Geoportal in order to combine datasets and functionalities of SavaGIS platform. The institutions should prepare the processed datasets for upload into central SavaHIS database under authorized part of application. The processed datasets are data prepared by institutions or ISRBC which is ready for Hydrological Yearbook formatting in the SavaHIS application.

The metadata management is based on GeoNetwork software which is ISO TC211 and OGC compliant. The parties shall provide metadata via editor or by web services registration.

The implementation of SavaHIS as integrated module of the SavaGIS web application gives the data management based on GeoServer software which implements OGC standards for publishing spatial data:

- Web Mapping Services (WMS),
- Web Feature Services (WFS) and
- Web Coverage Service (WCS).

Sava GIS Geoportal is expanded and enriched with new layer group called Hydrological and Meteorological data where layers are placed related to Sava HIS:

- Layer for hydrological data
- Layer for meteorological data

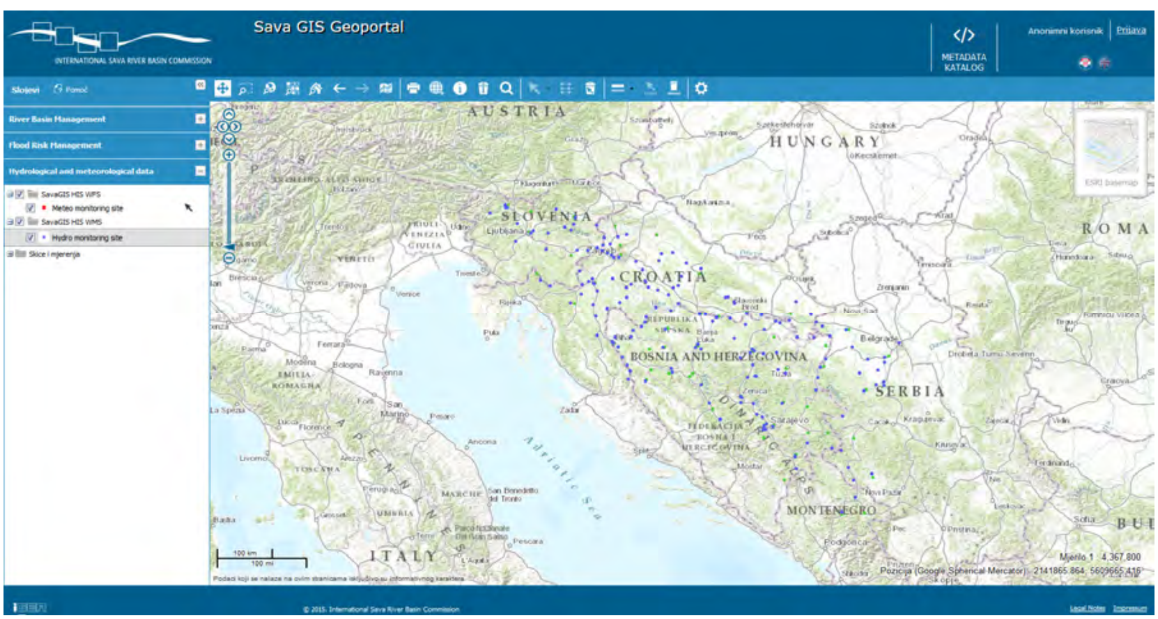


Figure 12: SavaGIS Geoportal with enriched SavaHIS layer group

Selecting individual gauging station on a map will be possible to see descriptive data about the station and get processed hydro meteorological datasets related to selected station. Most functionality of SavaGIS Geoportal can be applied to Sava HIS layers and data, but also can be restricted according to requirements of Sava Commission or according to user right defined by administrator.

Mentioned layers will show only processed data (official and verified data by the competent institutions delivered to Sava HIS system) visible and available for public and registered users, but only registered user will have permission to download data. User rights and permissions will be regulated through administration module.

In Sava HIS system the processed datasets will be collected via web interface. The processed datasets cover daily time series from historical data (Year books), monthly/yearly time series and statistical data which shall be loaded into central Sava HIS database via web interface following the default template.

The workflow of datasets upload and validation is following:

- Each institution that delivers the processed dataset shall upload the data via web interface under login session.
- The middleware application then:
    - reads data formats,
    - makes data conversion mapping according to Sava HIS database model and
    - stores data into central Sava GIS database.

For metadata management of Sava HIS is implemented the GeoNetwork solution which is also used for Sava GIS system. GeoNetwork is an OpenSource catalogue application for spatial datasets management and can be used for metadata search and editing. GeoNetwork is powerful, OpenSource solution based on International and Open Standards for services and protocols (ISO TC211 and OGC standards).

Metadata part will contain the functionalities of metadata entry and provision by manual editing or by web services registration. The users will search registered metadata and overview the description of hydrologic and meteorological data of interest.

The Sava HIS and Sava GIS are accessed via savahis.org and savagis.org.

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Annex

Table 4: Density of suspended sediment monitoring network

DENSITY OF SUSPENDED SEDIMENT MONITORING NETWORK

Country	Area, km^2	Station	Density km^2/station
Armenia	29 800	-	-
Austria	83 856	20	4 192
Azerbaijan	86 600	46	4 330
Belgium	30 519	0	0
Bulgaria	110 993	106	1 047
Czech Republic	78 864	20	3 893
Estonia	45 100	2	22 750
Finland	338 145	85	3 978
France	551 700	1 540	358
Germany (Federal network)*	349 520	69	5 065
Hungary	93 030	25	3 721
Iceland	103 000	25	4 120
Ireland	70 283	0	0
Latvia	64 600	5	12 420
Lithuania	65 200	3	21 733
Macedonia (FYR)	25 715	18	1 428
Moldova	33 700	20	1 685
The Netherlands	41 548	-	-
Norway	323 878	14	23 134
Poland	312 683	14	22 334
Portugal	92 389	0	0
Romania	237 500	478	496
Russia	17 075 40	725	23 552
Slovakia	49 007	25	1 960
Slovenia	20 251	11	1 841
Sweden	449 464	46	9 782
Switzerland	41 293	86	480
Turkey	779 452	195	3 997
Yugoslavia	102 173	28	3 649
* Germany	349 520	104	3 360
(Provincies, in addition)		173	2 020

Table 5: Network statistics of sediment monitoring station in various countries

		Date of introduction			Length of period			Stations (99)			Frequency			Cost	Standardization			Int. co-operation		
		SS	BL	BM	SS	BL	BM	SS	BL	BM	SS	BL	BM	1000 US	SS	BL	BM	SS	BL	BM
1.	Albania																			
2.	Armenia	46	46	46	48	48	48	47	28	28	10-20	10-20	10-20	50	-	-	-	-	-	-
3.	Austria	34	99	-	65	1	-	20	1	-	54	-	-	-	x	-	-	-	-	-
4.	Azerbaijan	0	-	0	30	-	30	46	-	46	12-15	-	2	-	x	-	x	-	-	-
5.	Belorus																			
6.	Belgium	no sediment monitoring																		
7.	Bosnia-Herzegovina																			
8.	Bulgaria	51			49			106			25-60									
9.	Croatia																			
10.	Cyprus																			
11.	Czech Republic	99	-	99	1	-	1	20	-	20	12	-	2	88	x	-	-	-	-	-
12.	Denmark																			
13.	Estonia	78	-	-	22	-	-	2	-	-	12	-	-	-	x	-	-	no	-	-
14.	Finland	62	-	-	28	-	-	85	-	-	4-12	-	-	8	x	-	-	x	-	-
15.	France	69	-	-	31	-	-	1540	-	-	12	-	-	-	x	-	-	-	-	-
16.	Georgia																			
17.	Germany*	65	80	76	35	20	24	69	65	-	365	1106		?	x	x	x	x	x	-
18.	Greece																			
19.	Hungary	52	52	-	48	22	-	25	4	4	5-10	1-3	1-3	81	x	-	-	x	-	-
20.	Iceland	63	-	-	37	-	-	25	-	-	6-12	-	-	88	x	-	-	x	-	-
21.	Ireland	no sediment monitoring							-			-		-	-	-	-	-	-	-
22.	Israel																			
23.	Italy																			
24.	Jordan																			
25.	Kazahstan																			
26.	Latvia	65	75	76	35	25	24	5	1	1	35-20	3-5	3-5	3,3	x	x	x	x	x	x
27.	Lebanon																			
28.	Lithuania	69	-	-	34	-	-	3	-	-	6-10	-	-	2,8	x	-	-	-	-	-
29.	Luxembourg																			
30.	Macedonia	61	-	-	38	-	-	18	-	-	365	-	-	9,8	x	-	-	no	-	-

		Date of introduction			Length of period			Stations (99)			Frequency			Cost	Standardization			Int. co-operation		
		SS	BL	BM	SS	BL	BM	SS	BL	BM	SS	BL	BM	1000 US	SS	BL	BM	SS	BL	BM
31.	Malta																			
32.	Moldova	57	76	-	42	23	-	20	1	-	4-12	1-2	-	25	x	x	-	-	-	-
33.	Monaco																			
34.	Netherlands	80	80	51	20	20	50	-	-	-	-	-	-	177	x	x	x	x	x	-
35.	Norway	68	68	-	32	32	-	14	3	-	120-365	20-50	-	135	x	-	-	-	-	-
36.	Poland	37	-	-	53	-	-	14	0	0	8	-	-	5	x	-	-	-	-	-
37.	Portugal	78	-	78	16	-	12	0	0	0	5-10	-	4-8	-	x	-	x	-	-	-
38.	Romania	60	70	70	39	22	29	478	15	65	25-30	3-6	2-4	-	x	x	x	-	-	-
39.	Russia	36	-	36	63	-	63	725	-	230	365	-	-	-	x	-	x	x	-	x
40.	Slovakia	92	-	-	8	-	-	25	-	-	365	-	-	10(?)	-	-	-	x	-	-
41.	Slovenia	55	-	-	44	-	-	6-11	-	-	4-8	-	-	30	x	x	x	-	-	-
42.	Spain																			
43.	Sweden	65	-	-	35	-	-	46	-	-	-	-	-	-	x	-	-	-	-	-
44.	Switzerland	62	89	89	38	11	11	86	80	80	104	-	-	36	x	x	x	x	x	-
45.	Syria																			
46.	Turkey	62	-	-	38	-	-	195	-	-	5-12	-	-	130	x	-	-	-	-	-
47.	Ukraine	32	32	-	67	67	-	115	119	-	6-12	1-2	-	-	x	x	-	-	-	-
48.	UK																			
49.	Yugoslavia	60	-	-	40	-	-	28	-	-	4-6	-	-	15	x	-	-	x	-	-
Germany (Lands) addition																				
	Baden Würtenberg	97	-	-	2	-	-	18	-	-	36	-	-	-	x	-	-	x	-	-
	Saarland	94	-	-	6	-	-	2	-	-	6-12	-	-	-	x	-	-	x	-	-
	Mecklenburg/Vorpomer	96	-	-	5	-	-	12	-	-	6-12	-	-	-	-	-	-	-	-	-
	Brandenburg	98	-	-	2	-	-	4	-	-	6-10	-	-	-	x	-	-	-	-	-
	Sachsen-Anhalt	94	-	94	6	-	6	4	-	31	12	-	1	-	-	-	-	-	-	
	Thüringen	98	-	-	-	-	-	64	-	-	2	-	-	167	x	-	-	-	-	-
	Bayern	23	-	-	76	-	-	-	-	-	-	-	-	-	x	-	-	x	-	-

Table 6: Evaluation of sampling techniques and processing of sediment monitoring in various countries

		SS sampling	BL sampling	BM sampling	Processing	Remarks
1.	Albania					
2.	Armenia	-				
3.	Austria	milk bottle; turbidity	ultrasonic; monitor		filtering, drying	
4.	Azerbaijan	Delft bottle; pumping	-	disturbed	filtering, drying	WQ jointly
5.	Belorus					
6.	Belgium					
7.	Bosnia-Herzegovina					
8.	Bulgaria					
9.	Croatia					
10.	Cyprus					
11.	Czech Republic	other		scraping	filtering, drying	WQ, SS, BM all together
12.	Denmark					
13.	Estonia	milk bottle, pump/filtration			filtering, drying	
14.	Finland	other: Ruttner s., filtration			filtering	WQ jointly
15.	France	milk bottle, turbidity			filtering	
16.	Georgia					
17.	Germany*	pump/filter bucket	video, tracing bedload sampler	scraping, grab boring	filter, drying	
18.	Greece					
19.	Hungary	milk bottle, pumping	video, tracer sampler, hydrophone	scraping (harang)	drying	
20.	Iceland	milk bottle			filter/drying sedigraph	WQ jointly
21.	Ireland					
22.	Israel					
23.	Italy					
24.	Jordan					
25.	Kazahstan					
26.	Latvia	Delft bottle	sampler	disturbed (scraping)	drying	in 1999 stopped, WQ jointly
27.	Lebanon					
28.	Lithuania	milk bottle, pump/filter			filterint/drying	
29.	Luxembourg					
30.	Macedonia	bucket, plastic, bathometer	bin		filtering/drying	

		SS sampling	BL sampling	BM sampling	Processing	Remarks
31.	Malta					
32.	Moldova	milk bottle, other	other		filtering, drying	
33.	Monaco	turbidimetry.	trap, echo-sounder	grabs	settling tube	
34.	Netherlands					
35.	Norway	ISCO samplers	bed load samplers	grabs, scraping	filtering, drying, ignition, laser coulter	SS jointly WQ, BL jointly WQ
36.	Poland	milk bottle			filtering, drying	
37.	Portugal	Delft bottle		grabs	filtering	
38.	Romania	milk bottle	settler, trap	grabs, scraping core sampling	filtering, drying	
39.	Russia	Delft bottle, pumping, special	special device	undisturbed, boring	filtering, drying	
40.	Slovakia	Delft bottle			filtering, drying	
41.	Slovenia	milk bottle, turbidimetry			filtering, drying	
42.	Spain					
43.	Sweden	Ruttner sample			filtering	combined monitoring
44.	Switzerland	Swiss bottle, turbidity	trap, hydrophone	seraping, line probe		WQ jointly
45.	Syria					
45.	Macedonia					
46.	Turkey	milk bottle			filtering, drying	
47.	Ukraine	milk bottle, pump/filter			filtering, drying	
48.	UK					
49.	Yugoslavia	vacuum, bathometer		scraping, boring	filtering	
Germany (Lands) addition						
Baden Würtenberg		pump/filter			filtering	WQ jointly
Saarland		other			drying	
Mecklenburg/Vorpomer		centrifuge (50-60 l)				
Brandenburg		pump/filter				WQ jointly
Sachsen-Anhalt		pumping		scraping	drying	
Thüringen		pump/filtering			filtering, drying	
Bayern		other			filtering	WQ jointly

Sediment monitoring for the Sava River Basin

This product is based on national information provided by the Parties to the FASRB (SI, HR, BA, RS) and ME.
Shuttle Radar Topography Mission (SRTM-3) from USGS Seamless Data Distribution System was used as topographic layer.
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