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

Estimation of Sediment Balance for the Sava River

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1. Introduction

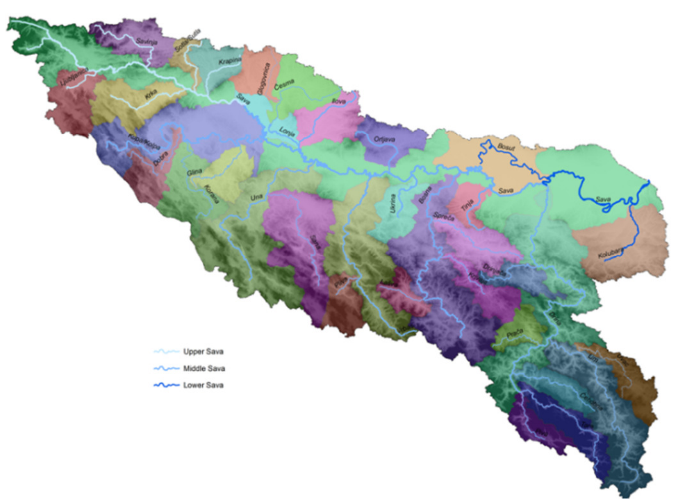
The Sava River Basin is shared by five countries: Slovenia, Croatia, Bosnia and Herzegovina, Montenegro and Serbia, while a negligible part of the basin area also extends to Albania.

Slovenia, Croatia, Bosnia and Herzegovina, and Serbia are Parties of the Framework Agreement on the Sava River Basin (FASRB). The implementation body of the FASRB is the International Sava River Basin Commission (ISRBC) which is responsible for development of joint plans and programs regarding the sustainable water management among others.

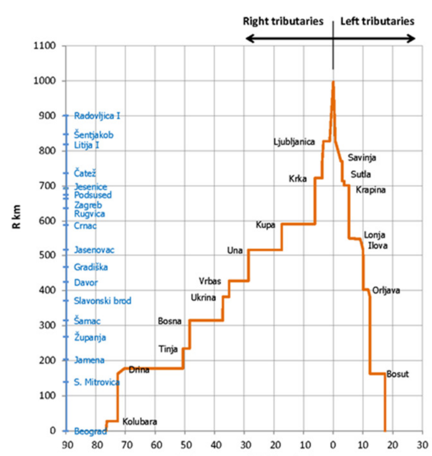
ISRBC has developed the Protocol on Sediment Management to the FASRB which affirms the need for efficient cooperation among the Parties and for promotion of sustainable sediment management (SSM) solutions. To respond to the above mentioned needs, a project *Towards Practical Guidance for Sustainable Sediment Management using the Sava River Basin as a Showcase* has been launched upon the initiative of UNESCO Venice Office, together with the UNESCO International Sediment Initiative (ISI), European Sediment Network (SedNet) and the International Sava River Basin Commission (ISRBC) aiming to develop and validate a practical guidance on how to achieve a SSM Plan on the river-basin scale, using the Sava River Basin as a showcase. The project *Estimation of Sediment Balance for the Sava River (BALSES)* has been implemented by the core expert group which has analysed the sediment balance for the main Sava River course, considering the input from the main tributaries, and thus to form a basis for sustainable transboundary sediment and water management.

2. Overview of the Sava River Basin and its main rivers

Total area of the Sava River Basin is 97,713 km^2. High mountains dominate in the upper part of the basin. The southern middle part is hilly and mountainous, while the northern middle and lower part of the Sava River Basin are characterized by low mountains and flat plains. River network in the Sava River Basin is well developed, but the basin is very asymmetric.



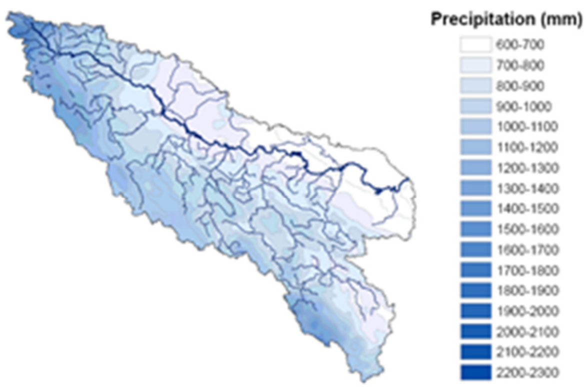
Sub-basins of the Sava River Basin

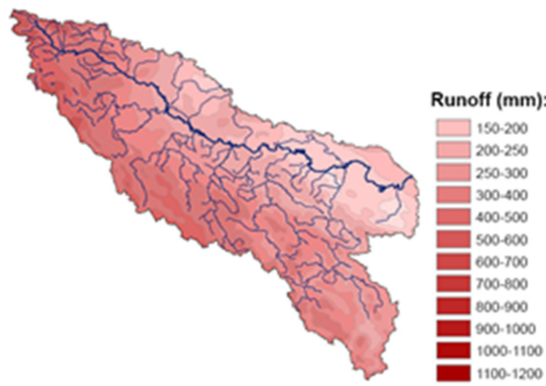


Schematic presentation of the basin

The very important geological characteristic of the Sava River Basin, influencing the regime of water and sediment, is the presence of the karst phenomena. The terrain mostly consists from very thick layers of limestone while in the rest of the basin prevail sandstone, marls, claystones, intrusive and extrusive igneous rocks and metamorphic rocks.

The Sava River Basin has in general moderate climate, with clearly distinctive cold and hot seasons. Average annual rainfall was estimated at about 1,100 mm but precipitation amount is very variable.





Mean annual precipitation in the Sava River Basin

Mean annual runoff in the Sava River Basin

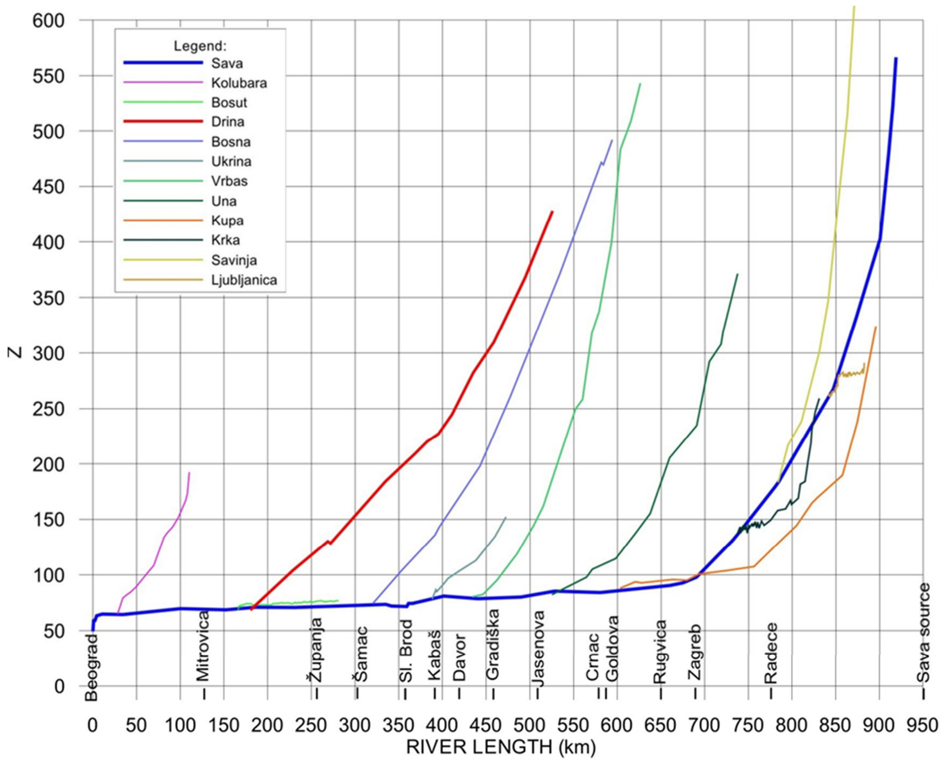
Floods usually appear in the spring and in the autumn. Spring floods are the result of snow melting while autumn floods are caused by heavy rainfall.

The total length of the Sava River is cca 945 km and can be divided into 3 sections:

- Upper Sava, between the confluence of Sava Dolinka and Sava Bohinjka and Rugvica
- Middle Sava, between Rugvica and the mouth of the Drina River
- Lower Sava, downstream of the mouth of the Drina River.

Near Rugvica is also a rather sharp transition from a gravel-bed river (at the Upper Sava) to a sand-bed river (at the Middle Sava). The mean sediment diameter from the Sava source to the knickpoint close to Rugvica is of the order of several tens of mm. Riverbed material on the Middle and Lower Sava is finer (sand and find gravel), having D50% mainly bellow 12 mm.

The most important right tributaries are: Ljubljanica, Krka, Kolpa/Kupa, Una, Vrbas, Ukrina, Bosna, Drina and Kolubara Rivers, while the main left tributaries are Savinja, Sotla/Sutla, Krapina, Lonja, Orljava and Bosut Rivers.



Schematic longitudinal profiles of the Sava River and some of its main tributaries

3. Sediment monitoring and assessment

In most cases, sediment monitoring on the river basin level comprises regular field surveys, aerial mapping and aerial photography of soil erosion, stream bank erosion, landslides, mechanical movement and regular measurements of suspended and bed load, reservoir sedimentation and sediment quality.

On the stations that play an important role in controlling sediment yield, the following measurements should be taken:

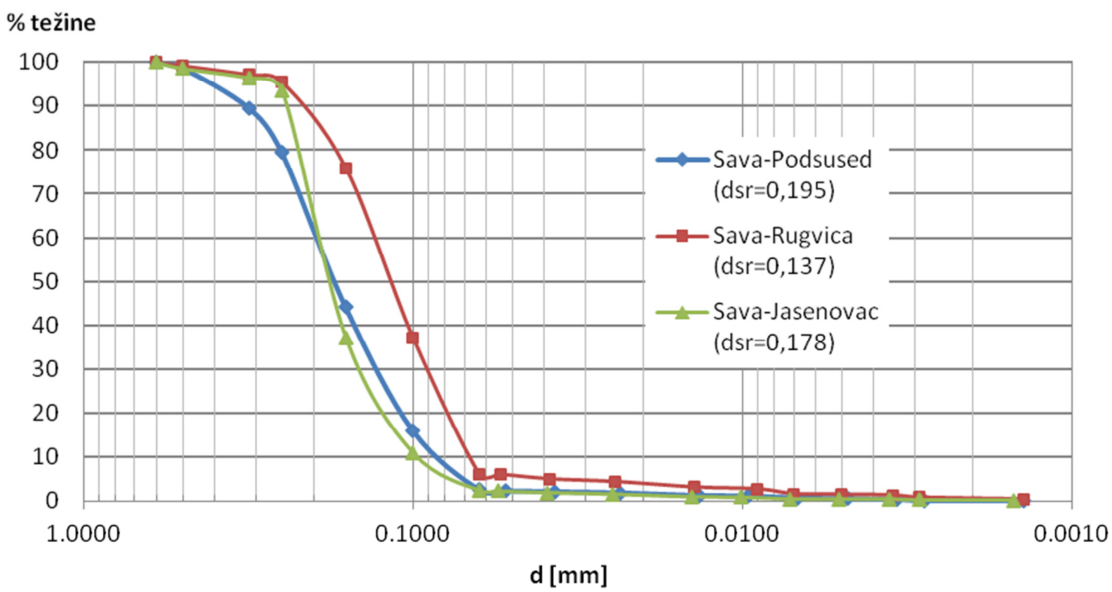
1. Regularly: suspended sediment concentration and suspended load , size gradation of suspended sediment and bed material.
2. Occasionally: bedload measurements.

Slovenia: sediment monitoring is performed by the Slovenia Environment Agency (ARSO). Monitoring was modernized in the last decade and is today in accordance with the Water Framework Directive. *Suspended sediment measurements* are part of hydrologic monitoring but the number of monitoring sites for suspended load is far from being optimal. *Sediment quality monitoring* comprises sampling of primary substances in accordance with SIST ISO 5667 - 12 and ISO 5667 – 15. *Reservoir sedimentation measurements* are performed on the hydro power plants mainly while *bedload measurements* and *soil erosion surveys* are currently non-existent in Slovenia.

Croatia: Parameters of the sediment load regime are monitored by the Hydrological and Meteorological Service, Hydrology Department (DHMZ).

Suspended sediment measurements are part of a regular hydrologic monitoring system and include:

- Point measurements of sediment concentration on daily basis at 10 gauging stations in total on Sava River Basin (4 stations on the Sava River and 6 stations on the tributaries)
- Calculation of sediment load on the Sava River gauging stations on daily basis from the point sampling
- Profile measurements of sediment concentration and sediment load, at 3 stations on the Sava River, periodically
- Grain-size distribution of suspended load on 3 stations on the Sava River, periodically.



Sediment weight distribution of suspended load from 2011 sampling in Croatia

Sediment quality monitoring in the Sava Basin is conducted by Croatian Waters. *Reservoir sedimentation measurements* have been performed on a reservoir upstream of the Novska lake only in order to control intake of sediment load into the lake. *Bedload measurements* and *soil erosion surveys* are currently non-existent in Croatia.

Bosnia and Herzegovina: Systematic monitoring of sediment does not exist. In the BA-Republic of Srpska the soil erosion map which will provide data on erosion process is under development. Sediment quality measurements were only conducted within “Sava River Basin project: Sustainable usage, management and protection of resources” in year 2005 and 2006 and the NATO project Science for Peace, Development of Decision Support System for Reducing Risk form Environmental Pollution in the Bosna River, 2012-2014.

Serbia: Present scope of sediment monitoring in RS is not sufficient – only partial investigations of sediment parameters for different purposes. Sediment monitoring is envisaged in Program of Republic hydrometeorological service of Serbia (RHMZ), but instruments/methodology should be updated. *Suspended sediment measurements* are done on Sremska Mitrovica and Beograd profiles by Jaroslav Cerni Institute (IJC) (in the scope of the monitoring of the Iron Gate reservoir sedimentation), providing basis for suspended sediment balance on monthly and yearly basis. *Bedload measurements* were previously conducted only for individual studies and projects, as well as the bed material sampling along the Sava River and in reservoirs on the Drina River. *Sediment quality* was monitored by the RHMZ by sampling of river and reservoir sediment in the Sava River Basin till 2010, when this became the regular task of the Agency for Environmental Protection. *Soil erosion surveys* were performed for individual studies and projects and comprised estimation of sediment yield based on erosion maps. *Reservoir sedimentation* is monitored in Bajina Bašta and Zvornik reservoirs.

H - water level (cm)
Q - discharge (m^3/s)
SSC - suspended sediment concentration (g/m^3)
LT - load transport rate (t/day; t/month; total t/annualy)
Prof. SSC - Integrated SSC measurement in the river cross section
SL - Suspended load particle size distribution; BL - Bed load size distribution

Country	STREAM	Code	Monitoring site	Position (Gauss-Kruger)	Monitoring variable	Op. period	Institution	Daily		Occas.	Granulometry	
								SSC	LT	Prof. SSC	SL	BL
SLOVENIA	SAVA - main channel	3420	Radovljica I	Y 5436120; X 5133220	H,Q,SSC,LT	1953-	ARSO	x	x			
		3570	Šentjakob	Y 5468075; X 5104515	H,Q,SSC,LT	1955-1994	ARSO	x				
		3725	Hrastnik	Y 5507381; X 5108630	H,Q,SSC,LT	1993-	ARSO	x	x			
		3740	Radeče	Y 5514390; X 5103055	H,Q,SSC,LT	1955-1993	ARSO	x				
	SORA	4200	Suha I	Y 5448320; X 5113319	H,Q,SSC,LT	1953-	ARSO	x	x			
	SAVINJA	6200	Laško I	Y 5518410; X 5112230	H,Q,SSC,LT	1953-	ARSO					
	SAVINJA	6210	Veliko Širje I	Y 5515244; X 5105337	H,Q,SSC,LT	1955-	ARSO	x	x			
	SOTLA	4740	Rakovec I	Y 5555070; X 5086540	H,Q,SSC,LT	1965-	ARSO			x		
CROATIA	SAVA - main channel	3087	Podsused	Y 5565652; X 5074098	H,Q,SSC,LT	1979-	DHMZ	x	x	x	x	x
		3096	Rugvica	Y 5595979; X 5067325	H,Q,SSC,LT	1978-	DHMZ	x	x	x	x	x
		3219	Jasenovac	Y 4614661; X 5014177	H,Q,SSC,LT	1978-	DHMZ	x	x	x	x	x
		3098	Slavonski Brod	Y 6500781; X 5000950	H,Q,SSC,LT	1960-	DHMZ	x	x			
	KRAPINA	3054	Kupljenovo	Y 5563758; X 5088155	H,Q,SSC,LT	1980-	DHMZ	x	x			
	KUPA	4016	Hrvatsko	Y 5477111; X 5043087	H,Q,SSC,LT	1963-	DHMZ	x	x			
	ILOVA	3185	Munije	Y 6445034; X 5058159	H,Q,SSC,LT	1979-	DHMZ	x	x			
	BIJELA	3171	Badljevina	Y 6437061; X 5040307	H,Q,SSC,LT	1984-	DHMZ	x	x			
	BJELOVARSKA R.	3188	Bjelovar	Y 6411531; X 5083507	H,Q,SSC,LT	1979-	DHMZ	x	x			
	Reserv. NOVSKA	3151	Novska g. step.	Y 6424413; X 5023989	H,Q,SSC,LT	1980-	DHMZ	x	x			
B&H	SAVA - main channel	No actual monitoring site*										
	Tributaries	No actual monitoring site*										
SERBIA	SAVA - main channel		Sremska Mitrovica	Y 7388292; X 4981825	H,Q,SSC,LT	1974-	IJC	x	x	x	x	x
			Beograd	Y 7453377; X 4961362	H,Q,SSC,LT	1986-	IJC	x	x	x	x	x
			Sremska Mitrovica	Y 7390175; X 4981125	H,Q,SSC,LT	1958-1980	RHMZ					
			Sabac	Y 7397450; X 4959150	H	1958-2002	RHMZ					
			Beograd	Y 7456875; X 4963650	H	1958-1998	RHMZ	x	x	x	x	x
	DRINA		Mihaljevici	Y 7369129; X 4896888	H,Q,SSC,LT	1991-2002	RHMZ	x	x			
	DRINA		Radalj	Y 7352975; X 4921075	H,Q,SSC,LT	1984-2002	RHMZ	x	x			
	DRINA		Badovinci	Y 7369845; X 4961554	H,Q,SSC,LT	1990-2001	RHMZ	x	x			
	KOLUBARA		Slovac	Y 7427150; X 4910975	H,Q,SSC,LT	1958-1992	RHMZ	x	x			
	KOLUBARA		Beli Brod	Y 7436750; X 4914330	H,Q,SSC,LT	1986-2001	RHMZ	x	x			
	KOLUBARA		Drazevac	Y 7438150; X 4939050	H,Q,SSC,LT	1958-2002	RHMZ	x	x			

* B&H only occasionally measurements of SSC, BL (Drina, upstream of Višegrad, period 1989/1990) in order to define reference conditions before HEPP Višegrad has been buildt, and very rare measurements on the River Bosna and some tributaries of the Sava River in B&H.

Network of sediment monitoring stations in the Sava River Basin

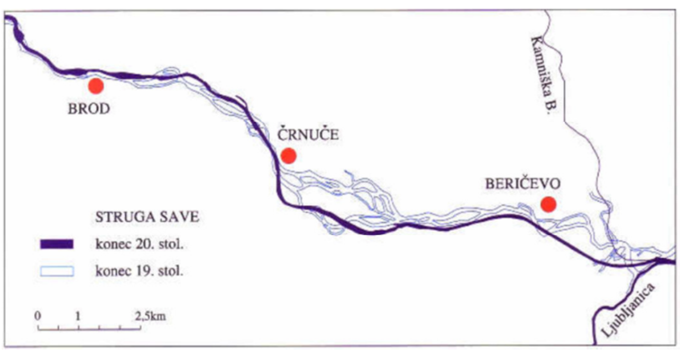
The boundaries and names shown and designations used on this map do not imply official endorsment or acceptance by the ISRBC.

4. Sava River channel evolution in time

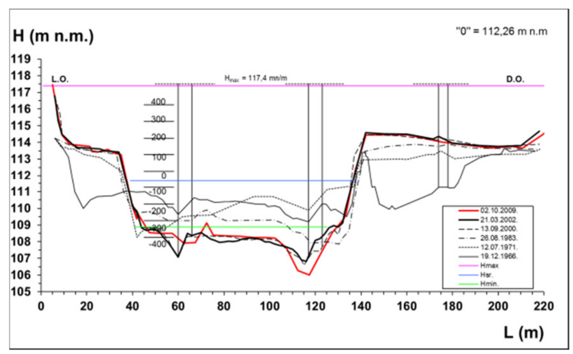
The Sava River is a typical large alluvial river, flowing mostly in its own alluvial deposits. Only in its upper course in Slovenia it has cut its channel into the mountains or hills. Elsewhere, the river flows on plains where it has deposited large amounts of coarse and fine-grained sediments, and where different river terraces and wide alluvial floodplains, formed in the past (since the last glacialization) could be observed. Generally speaking, the Sava River is a large meandering river in almost its entire course. Part of its river dynamics is e.g. a permanent river channel shifting caused by river erosion of cut banks and deposition on point bars. A wide river corridor contains oxbow lakes, semi-active meanders and parallel channels.

The changes of an alluvial river can be put into three categories:

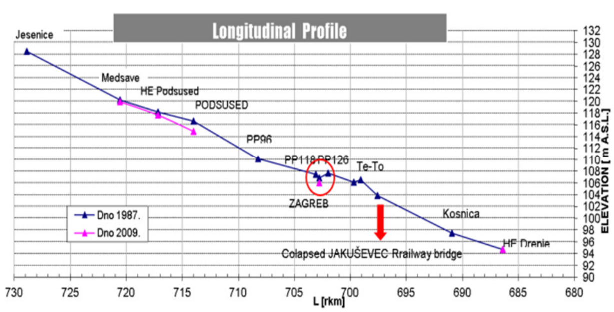
- Planform pattern (cascade, step-pool, rapids, riffle-pool, braided, wandering, single thread sinuous (meandering), anastomosing)
- Channel evolution (braid bars, scroll bars, point bars, islands, meanders, oxbow lakes, bed forms)
- Longitudinal profile evolution (degradation, incision, forming of fluvial terraces, bedrock erosion, aggradation)



The Sava River changes from the end of the 19th century to the end of the 20th century upstream of the confluence with the Ljubljanica River and Kamniška Bistrica River



The morphological changes of the cross section of the hydrological station Zagreb on the Sava River in period 1966-2009



The Sava River longitudinal profile in the reach between rkm 685 and 730

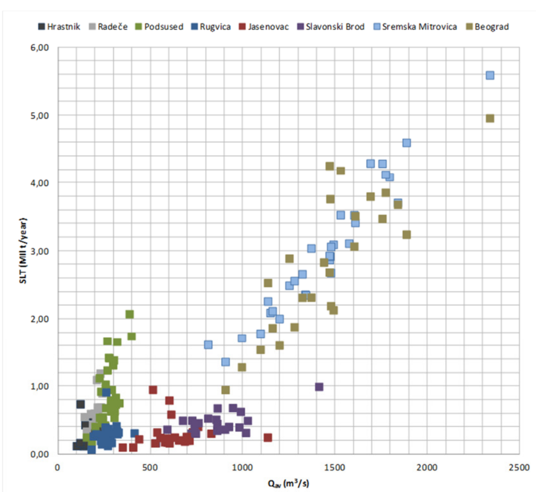
The railway bridge Jakuševac in Mičevac on the Sava River that collapsed on March 30, 2009

5. Estimation of the Sava River sediment balance

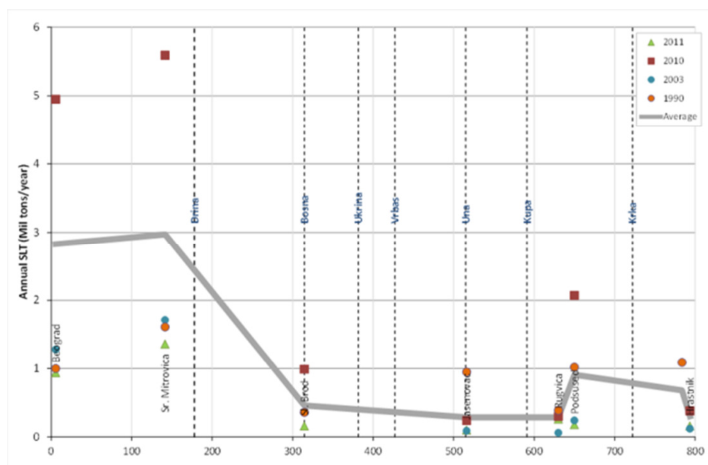
The Sava River and downstream reaches of its tributaries are typical alluvial courses whose channels are incised into their own sediment, with a permanent exchange of sediment particles between the riverbed and the suspension. Coarse particles of sediment (gravel, coarse and medium sand) move along the riverbed, as *bed load*, while finer fractions (fine sand, silt and clay) are suspended in water, and move as *suspended load*. A portion of suspended sediment is in permanent exchange with the riverbed material, and takes part in morphological processes (bed-material load); the finest particles pass by without any interaction with the bottom of the river (wash-load).

5.1. Suspended sediment balance along the Sava River

The basic assumption is that suspended load transport along the Sava River should increase in the downstream direction, because of the increase of the catchment area and inflow from tributaries. But according to available data this cannot be confirmed. There are significant discrepancies between data. The fact that yearly suspended sediment transport is very similar on the Upper and Middle Sava, brings the question about the role of large tributaries along the middle course of the Sava River in the sediment balance. On the other hand, there is unusual increase of the annual suspended sediment load on the Lower Sava (5-10 times higher than on Middle Sava), which can be the result of significant differences in sediment measurement technology.



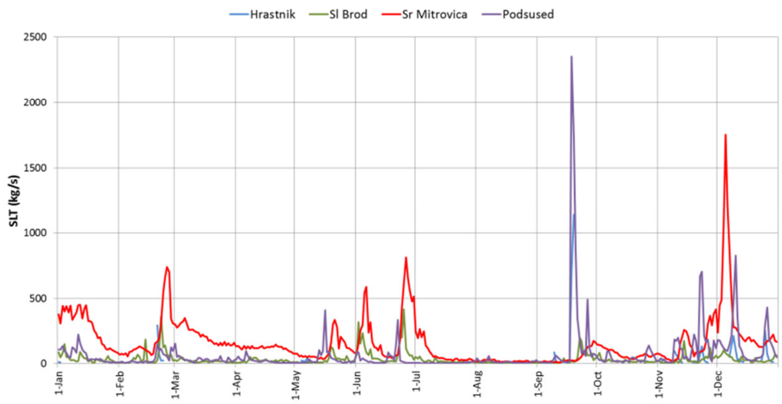
Correlation between the annual river flow and suspended load transport along the Sava River



Longitudinal presentation of the annual suspended sediment transport along the Sava River

Seasonal variability of suspended transport shows that sediment transport varies within the year, mainly corresponding to the meteorological conditions and hydrology. On the Upper Sava, sediment transport in spring is low, because the river flow is originating from snow melt. On the Middle and Lower Sava the highest monthly sediment quantities appear in spring. Along the whole river, high sediment transport also appears at the end of fall, when high river flows originate from intensive rains.

The floods have a very important role in the sediment transport on rivers, because high flows initiate sediment motion and carry large quantities of suspended and bed load as it was a case in year 2010.



Suspended sediment transport along the Sava River in 2010

5.2. Other components of sediment balance along the Sava River

Bed load has a relatively small share in the total sediment transport, but it has an important role in morphological processes. Data on the composition of the Sava riverbed are rare. The only systematic bottom sediment sampling along the Sava River was done more than 50 years ago. A downstream trend of sediment size decrease was noticed, but with a number of local variations related to the impact of tributaries and morphology along the river. *Intensive dredging* which mainly affect bed load balance is present along the Sava River channel but data on dredging are not gathered systematically. *Reservoirs* have the important role in the sediment balance because of retention. In the Sava River Basin the reservoirs are built only on tributaries, affecting both bed load and suspended load. The run-off- river hydropower plants on the Upper Sava affect mainly bed load. There is a general lack of data on reservoir siltation processes within the Sava River Basin.

6. Gaps and data uncertainties

Specific data uncertainties for the Sava River Basin are derived from following reasons:

- Suspended sediment and bed load measurements
  - different sampling techniques and changing techniques during time
  - different frequency of measurements
  - different duration of time series in the long-term measurements
  - complete lack of measurements
  - changing of the gauging station location during time (upstream/downstream of tributary)
- Monitoring of sediment quality
  - monitoring of different parameters by countries
  - different frequency of monitoring
  - complete lack of monitoring
- The period of measurements and monitoring with regard to the construction of large structures and other impacts on watershed and in the river channel

7. Main conclusions with the proposal of future activities

Issue	Conclusions
Sediment monitoring and assessment	• Insufficient and decreasing number of sediment monitoring sites, • Limited availability of suspended load data, • Low sediment monitoring on the tributaries, • Very limited data on bed load, • No unique sampling and measurement of suspended load and bed load methodology agreed between countries, • Lack of measurement equipment and the need for update, especially for continuous monitoring and during high flood events, • Sediment quality measurements according the Water Framework Directive (2000/60/EC).
Estimation of Sava River Sediment balance	• The size and highly heterogeneous natural characteristics of the Sava River Basin significantly affect the inflow of water and sediment. • Significant tributaries bring large sediment load and have a major influence on the hydrologic, hydraulic and sediment regimes of the recipient. • The heterogeneity of geomorphological and morphological conditions along the course of the Sava River also effects sediment transport and deposition processes. • The controlled regime of the Iron Gate 1 reservoirs' backwater levels is the most important artificial influence on the sediment transport and deposition processes in the Lower Sava. • Excavation of material from the Sava riverbed is a relatively important component of these processes, even though the effects of dredging are generally local and depend on the location of the excavation field. • River training structures and HPP play a significant role in riverbed formation along some stretches of the Sava.
Proposal for further joint activities	• The currently monitored sediment-balance related parameters in all hydrologic stations along the Sava River main channel and in its major tributaries should be connected to a joint Sediment Database, available on-line for free. • The effort towards the harmonisation of monitored sediment data by applying the same technical international standards should be made. • The monitoring network should be made denser with additional new hydrologic stations to be taken into operation in the years to come. • The sediment monitoring should integrate regular cross-section measurements in selected cross sections along the Sava River main channel and the main tributaries. • A numerical modelling of sediment transport in the Sava River main channel based on reliable sediment data to validate the model should be performed.