



Meteorological and Hydrological Service -Hydrology Department

# Sediment status Croatia

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Practical training course on sustainable sediment management with the Sava River Basin as a showcase 15.-18.10.2012, Zagreb, Hotel Panorama









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### **Presentation contents**

#### 1. Overview of the Croatian part of the Sava River Basin

• Sava River Basin - General

Flood protection schemes (historic and existing) Major water management structures River Sava waterway project

- Sediment balance throughout the river system
- River Sava morphological changes
- 2. Sediment monitoring
  - Monitoring of suspended sediment concentration
  - Monitoring of bed load transport
  - Evaluation of sediment quantity





# OVERVIEW OF THE CROATIAN PART OF THE SAVA BASIN

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SVEUČILIŠTE U ZAGREBU GRAĐEVINSKI FAKULTET ZAVOD ZA HIDROTEHNIKU



Meteorological and Hydrological Service HYDROLOGY DEPARTMENT

### 1. Sava River Basin - General



### **Rivers in Sava Basin - Hydrology data**

	Površina sliva		Duljina				Površina	Karakteristični protoci				
Vodotok	Ukupna	U RH	Ukupna	U RH	Granica	stanica	sliva	Q <sub>min</sub>	Q <sub>min,sr</sub>	Q <sub>sr</sub>	Q <sub>max,sr</sub>	$Q_{max}$
	kn	n <sup>2</sup>		km			km²			m³/s		
Sava	95.419	25.770	946	510	313	Županja	62.891	226	311	1.134	3.038	4.130
Sutla	590	133	92	89	73	Zelenjak	455	0,342	0,859	7,31	129	250
Krapina	1.244	1.244	65	65	-	Kupljenovo	1.150	0,200	1,12	12,0	153	368
Česma	2.890	2.890	96	96	-	Čazma	2.877	0,066	0,679	14,1	91,9	153
llo∨a s Pakrom	1.816	1.816	96	96	-	Veliko Vukovje	995	0,130	0,390	6,99	68,0	151
Orlja∨a	1.616	1.616	97	97	-	Pleternica	745	0,111	0,560	5,12	60,0	117
Bosut	2.913	2.375	132	81	-	Nijemci	1.670			12,2		
Kupa	10.236	8.412	294	294	100	Farkašić	8.902	16,9	30,5	201	1.207	1.776
Dobra	1.354	1.354	104	104	-	Donje Stative	1.313	1,65	2,45	34,8	241	372
Korana	2.297	2.049	134	134	23	Velemerić	1.258	0,611	3,31	28,8	320	492
Mrežnica	980	980	63	63	-	Mrzlo Polje	975	0,223	1,85	26,6	256	373
Glina	1.418	967	100	100	18	Glina	1.145	0,939	2,91	18,2	174	350
Sunja	482	482	77	77	-	Sunja	225	0,001	0,325	2,91	87,0	141
Una	9.368	1.686	212	116	101	Hrvatska Kostainica	8.876	25,1	44,7	221	1.110	1.521

(from Water Management Strategy, Croatian Waters, 2009)

#### **Sava River Basin - Altitude**







#### Longitudinal profile of River Sava

### Sava Basin - Average annual precipitation

#### Precipitation (mm)





(from ISRBC Sava River Basin Analysis Report, Sept 2009)

#### **Surface erosion in Croatia**



(from Water Management Strategy, Croatian Waters, 2009)







### **1a. Flood protection**



### **Historical flood prone areas**

Historical 100-year flood prone areas



(Croatian Waters for ISRBC Sava River Basin Analysis Report, Sept 2009)

### Historical flooding in Zagreb

- In the 1950-ies the city of Zagreb spread
- Areas beyond the banks became more and more populated
- System of dikes was constructed only partially, was inadequate, inconsistent and vulnerable
- Flood in October 1964:
  - around 6,000 hectares of the immediate urban area were flooded
  - settlements of Zaprešić, Samobor, Dugo Selo, and Velika Gorica
  - 17 human lives were lost
  - material damage was extensive
  - 150,000 people were evacuated
  - >10,000 people lost their homes



### **Existing flood protection**

- Only large towns are flood protected Zagreb, Sisak and Karlovac (Zagreb 1000-year flood).
- Upstream of Zagreb levees are partially constructed → frequent flooding.
- Downstream reaches from Zagreb till Serbia have lower flood protection, as Middle Posavlje System is not finished and levees overtop.

#### Middle Posavlje flood protection scheme



(from Water Management Strategy, Croatian Waters, 2009)

### **1b. Major structures**

- Major structures
- River structures





#### Major structures – Sava River Basin



(from Water Management Strategy, Croatian Waters, 2009)

#### **River structures - Downstream reach**

#### Embankments and groynes along the left river bank



### 1c. Sava River waterway project

- The River Sava had been navigable up to upstream of Zagreb.
- Current activities are two project to upgrade fairway to class IV or Class Va from Belgrade to Sisak (two-way navigation where possible).





## 2. Sediment balance in the river system

#### Surface erosion in Croatia by River Basins



(from Water Management Strategy, Croatian Waters, 2009)





#### Sava Podsused - Total load and bed load

#### Bed load = 3% of Total load



#### **Suspended load material**

#### River Sava - upstream/downstream of Zagreb



#### **Bed load material**

#### **River Sava - Slovenia**

#### **River Kupa - Karlovac**





### **Production of sediments in the Sava Basin**

#### Annual volume of soil surface erosion, estimated by Gavrilović method

	Station	F [km2]	Wg [m3/y]	Gg [m3/y]	Wg/F [m3/y/km2]	Gg/F [m3/y/km2]	Wg/F*F [m3/y]	Gg/F*F [m3/y]	Wg/F Avg [m3/y/km2]	Gg/F Avg [m3/y/km2]	F1 [km2]	Wg1 [m3/y]	Gg1 [m3/y]
	Kupa	5,330	1,941,940	752,670	364	141	1,940,120	751,530			8,412	3,916,035	1,439,737
es t	Bregana	90	109,500	52,560	1,220	580	109,800	52,200	166	171	100	46,553	17,115
igh	Sunja	220	55,720	17,730	253	81	55,720	17,730	400	171	482	224,385	82,496
R jpu	Una	1,654	1,289,933	426,928	780	258	1,289,933	426,928			1,686	784,883	288,563
tr	Σ	7,294				Σ	3,395,573	1,248,388		Σ	10,680	4,971,856	1,827,911
	Sutla	140	35,310	20,000	252	143	35,310	20,000	329		133	43,759	16,378
S	Krapina	1,053	402,400	179,560	382	171	402,400	179,560			1,244	409,293	153,188
ft arie	Lonja	4,201	1,237,180	397,950	294	95	1,237,180	397,950		) 123	5,297	1,742,784	652,281
Le	V.Strug	222	108,000	52,200	486	235	108,000	52,200			200	65,803	24,628
trip	Orljava	688	291,210	126,575	423	184	291,210	126,575			1,616	531,686	198,997
	Σ	6,304				Σ	2,074,100	776,285		Σ	8,490	2,793,323	1,045,473
Other		6,600							200	74	6,600	1,320,000	488,400
Sava Basin		25,770							200	74	25,770	9,085,179	3,361,784

basic source: "Erozija i nanos sliva rijeke Save" (1969)



year

Year

Hydrometric station	Up to 1982	1983- 2006	Ratio until 1982 / beyond 1983							
Annual suspe	ended load trans	port SLT (1000 t	/year)							
Krapina - Kupljenovo		110.6								
Kupa - Hrvatsko	28.8	5.7	5.05							
Sava - Slavonski Brod	3842	1118	3.44							
Mean suspended sediment concentration SSC (g/m <sup>3</sup> )										
Krapina - Kupljenovo		45.7								
Kupa - Hrvatsko	7.38	1.98	3.73							
Sava - Slavonski Brod	39.8	14.2	2.80							
Mea	Mean annual discharge Q (m <sup>3</sup> /s)									
Krapina - Kupljenovo		10.9								
Kupa - Hrvatsko	22.2	18.1	1.22							
Sava - Slavonski Brod	1016	857	1.19							

## 3. River Sava morphological changes

#### **3a. Vertical river bed changes**

- A decrease of the water levels and the river bed has been observed along the whole length of the Sava River.
- At several gauging stations (1975-1985 and 1990-1999) measurements show an average decrease of levels ranging between 1.5 m and 2.2 m.





#### **Case A. Downstream reach**

- measurement of mean and low water levels over a period of 40 years
- the lowering of water and bottom levels amounted to approximately 2 m or about 5 cm/year
- for the river Sava and entire water management such a decrease is quite serious issue

#### **Case B. Upstream reach (River Sava, GS Podsused)**



### Case C. Upstream reach (River Sava, GS Zagreb)

#### Water levels at GS Zagreb 1925-2010

H<sub>REL</sub> [cm]

Mean annual recorded stages for GS ZAGREB



#### Discharges at GS Zagreb 1925-2010



#### Mean annual discharge of the Sava river at Zagreb 1926-1995



Annual precipitation for the period 1926-1995.



(from Šegota and Filipčić 2007)

#### 1. Problem:

thermal power plant (TE-TO Zagreb) shut down due to the low Sava River and discontinued supply of cooling water

#### 1. Solution:

construction of submerged weir for the water level increase

#### 2. Problem

Jankomir spillway function disrupted (1900 m3/s → 2350 m3/s)

### 2. Solution

none

#### Case D. Flood event 19.9.2010.

<b>SAVA - Podsused GS, rkm 714, "0"= 119,134 m a.s.l.</b>										
Date	Stage (cm)	Stage (m a.s.l.)	V <sub>mean</sub> V <sub>max</sub> (m <sup>-1</sup> ) (m <sup>-1</sup> )		Discharge (m³s <sup>.1</sup> )					
22.8.2005	181	120,94	2,62	4,16	1175					
2.6.2006	98	120,11	2,32	3,45	861					
12.12.2008	268	121,81	2,90	4,09	1512					
10.2.2009	86	119,99	2,46	3,57	934					
19.9.2010	526	124,39	2,09	4,88	3117					
10.12.2010	368	122,81	1,71	3,99	2116					
28.10.2011	49	119,62	2,50	3,71	769					

S	SAVA - Zagreb GS, rkm 702,8 "0"= 112,26 m a.s.l.										
Date	Stage (cm)	Stage (m a.s.l.)	V <sub>mean</sub> (ms <sup>-1</sup> )	V <sub>max</sub> (ms <sup>-1</sup> )	Discharge (m³s⁻¹)						
22.8.2005	172	113,98	1,97	3,55	1231						
23.8.2005	175	114,01	1,92	3,56	1215						
12.12.2008	281	115,07	1,93	3,67	1686						
10.2.2009	112	113,38	2,01	3,39	977						
26.2.2010	21	112,47	2,04	3,03	746						
19.9.2010	454	116,8	2,40	4,77	2723						
20.9.2010	460	116,86	2,34	4,06	2854						
27.10.2011	162	113,88	2,35	3,41	1105						

#### Jakuševac bridge in Zagreb





H (m n.m)

"0" = 112,26 m n.m



#### **3b. Lateral river changes**







# Possible causes for general and continuous river bed erosion

- Sediment dredging from the River Sava
  - In the 1970 a major highway Zagreb-Belgrade was constructed. The gravel and sand for construction was extracted from the Sava river bed.
  - Since the 1970 there has been non controlled dredging.
- The supply of sediment from the upper Sava has practically dried up due to:
  - construction of hydro-power plants in Slovenia
  - the damming up of tributaries to the Sava
- A "natural" contribution to the erosion?
  - the natural behaviour of alluvial rivers?

## Summary

### Summary for the River Sava in Croatia

- River bed degradation is continuous and very serious issue for the general water management on the River Sava.
- Study of the sediment production on the tributaries (1969) of the Sava River is out dated.
- 3. No study on the sediment transport on the tributaries.
- No monitoring on the sediment transport on the tributaries (exept one on R.Kupa and one on R.Krapina)
- 4. Limited data on the suspended load transport.
- 5. Very limited data on the bed load transport.









Meteorological and Hydrological Service HYDROLOGY DEPARTMENT

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## **SEDIMENT MONITORING**

## **2.1 Introduction**

Basic parameters of the river load regime researched at the Hydrological and Meteorological Service are:

- Daily suspended load concentration [g/m<sup>3</sup>]
- Daily load transportation rate through the river cross-section [t/day]
- Grain size distribution of the river load (suspended and bed load)
- Periodical measurements of cross-section concentrations and transportation rates of suspended load
- This means gathering information on daily, monthly and annual transportation of suspended and bed load, its correlation with water levels, discharges, and grain size distribution of the materijal. These and other hydrological parameters have been obtained by analysis of long-term measurements saved in a hydrological database (*HIS2000*) developed at the Hydrological and Meteorological Service, Hydrology Department.
- Annual overview of daily suspended load concentration and transportation rates is published in the Hydrological yearbooks.
- Periodical measurements of cross-section concentrations and transportation rates of suspended load, and grain size distribution of material are published in studies prepared for individual clients.





### **SSM Network - Croatia**







### Sava – SSM network







## **2.2 Sediment monitoring**

River	SAVA	SAVA	SAVA	SAVA	SAVA
Station	Podsused	Rugvica	Jasenovac	St. Gradiška	SI. Brod
L (rkm)	675,4	636,3	500,5	453,4	360
Established	1885	1878	1878	1817	1855
SLM BLT	1979-2012 1967-1986	1978-2012	1978-2012	1963-1991	1960-2012
F (km²)	12316	12730	38953	40262	50858
Q (m³/s)	300	309	751	775	978
H (m a.s.l.)	119,134	95,612	86,82	85,467	81,8





### **Methodology for SSC**

ISO 4365:2005 Liquid flow in open channels -- Sediment canals



GRADEVINSKI FAKIII TE

### Laboratory





GRAĐEVINSKI FAKULTET

DHMZ

### Results

Η

Stanica: PODS Vodobi: SAVA

-188 -198 -200 -200 -196 12111 -178 -174 -174 -136 -92 -94 -117 -125 -125 -131

1222224

Statem 

20 170 117 -94 -09 -77 -100 -113 -115 -178 -173 -167 -167 -173

3. -204 -85 287 287

-14 -34 -100 -117

-123 -125 -126 -136 -136

-144 -150 -155 -160 -160 -160 -160 -160 -160 -170 -46 -42 -07 -111 -184 -144 -129 -149

-48 -30 -108 -125 -135 -138 -138 -114 -110 -97 -142 -175 -177 -182 -182 -182 -185 -186 -014 -014 -028 -027

-127 -133 -145 -157

-173 -176 -189 -189 -139 -140 -192 -195 -195

29. -201 -129 -3 17. 14. -213 -150 19 91.

2101 .....

-20 -73



#### SLUŽBA ZA HIDROLOGIJU HIDROLOŠKI GODIŠNJAK ZA 2010. GODINU

#### SLIVNO PODRUČJE SAVA



Ο

178 185 194 245 344 140 134 120 138 197

100 . 19 1143 90 2010

105 59,5 59,6 91,6 52,3 99,6 52,9 99,6 50,0 252 252 105

86,1 78,2 78,3 78,0 155

104 272 818



Godišnja suma: 2069200







ZAVOD ZA HIDROTEHNIKU



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SAVA - PODSUSED ŽIČARA, KONCENTRACIJE (g/m3), 2010



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### Profile measurements of SS (ISO 4363:2002)

- ISO 4363:2002 for the measurement of cross-sectional mean suspended sediment mass concentration and mean particle size distribution.
- For routine measurements in periods of stable or slowly varied flow.





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### **Empirical relations**





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## **Methodology for BL**



### **2.3 Sediment balance for SS**











## 2.4 Sediment quantity



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### **Transport capacity**







## **Grain size distribution of BL**

#### **ISO 4365:2005 -- Determination of concentration, particle size**

#### distribution and relative density



Oznaka uzorka	Oznaka	ŜLJUNAK [%]	PIJESAK [%]	PRAH [%]	GLINA [%]	Cu	Cc	d10	d <sub>so</sub>	d <sub>eo</sub>	d <sub>srednje</sub>	USC prema ASTM 2000.	R.N.
20 m		70,19	26,24	3,57		50,22	2,17	0,19	6,67	16,59	8,12	GW s pijeskom i org. prim.	93-31/08
36 m		73,61	23,43	2,95		44,73	2,98	0,23	7,38	17,45	9,10	GW spijeskom	93-32/08
52 m		87,72	10,31	1,97		11,45	3,38	1,14	11,23	18,82	11,61	GP	93-33/08





### **Particle size distribution of SL**







# Thank you



