DEVELOPMENT OF A FLOOD FORECASTING AND EARLY WARNING SYSTEM ON SAVA RIVER BASIN

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Summary: *The project "Flood forecasting and warning system for the Sava River Basin" is for sure one of the most important project implemented among countries that share Sava River basin, regarding flood protection and mitigation of the flood effects. The main goal of the project is the creation of the common prognostic platform where all data necessary for flood forecasting are accessible in real time. Measured meteorological and hydrological data together with the prognostic hydrological, hydraulic and weather prediction model outputs provided by Sava River countries enables quality hydrological forecasts and synchronized action in case of emergency situations. For Serbia, the most downstream country, this tool is providing necessary information for fast and adequate decision making and timely issuing of warnings on floods from Sava River.*

Keywords: *Sava River, Sava-FFWS, flooding*

1. INTRODUCTION

Initiative for the project "Flood forecasting and warning system for the Sava River Basin" originates from the National Hydrometeorological Services in the Sava River basin since the first decade of the 21st century. It was planed that the project is going to be coordinated by The International Sava River Basin Commission. The legal framework for the project would be the Framework Agreement on the Sava River Basin and the Protocol on the Protection from Floods of the Sava Commission, which are two key

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documents for the cooperation of the countries in the Sava River Basin. One of the objectives of the Protocol is the establishment of the sustainable flood protection system in Sava River Basin. With the approval of the Western Balkans Investment Framework that the World Bank will finance this project, the realization of this plan has started.
The project started in June 2016 and will end in December 2018. Total budget for the project is 1.5 million euros. Project beneficiaries are Slovenia, Croatia, Bosnia and Herzegovina, Montenegro and Serbia. The World Bank selected a consortium comprising Deltares along with Royal HaskoningDHV, Eptisa, the Hydro-Engineering Institute of Sarajevo and Mihailo Anđelić.
The main goals in the project are the establishment of a unique prognostic platform Sava-FFWS (Sava Flood Forecasting and Warning System), better coordination, exchange and harmonization of the data and information between countries, preparedness and assessment of necessary action for decision makers in the area of flood risks. The platform Sava-FFWS is based on the Delft-FEWS platform [1], which has already been applied to several river catchments all around the world. The basic principle of the Sava-FFWS platform is the creation of an environment for data management and forecasting, allowing the integration of a wide range of external data and models. Sava-FFWS enables the integration of meteorological, hydrological and hydraulic models into one common platform. In this way, relevant data and information becomes available to all decision-making institutions in all five countries. Countries retain autonomy in terms of monitoring, modeling and forecasting, developing their own prognostic models and additional activities in the field of flood forecasting.
The Republic of Serbia was particularly interested in the establishment of this system as the most downstream country on the Sava River Basin and especially after the catastrophic floods in the Kolubara Basin in May 2014. This platform is an added value to existing flood forecasting systems already running in Operational Hydrological Department in Republic Hydrometeorological Service of Serbia.
The implementation of this prognostic platform together with well-trained staff will improve preparedness and optimize mitigation on extreme hydrometeorological situations. During the project, the knowledge and observations of local experts were actively used in order to obtain a functional and efficient environment. In this way, better co-ordination in the exchange of data and forecasts was achieved with respect to regional specifics.

2. DATA AVAILABLE IN SAVA-FFWS

The Sava River basin with the total area of 97,700 km^2 is shared by six Sava countries: Bosnia and Herzegovina (BA), Croatia (HR), Montenegro (ME), Serbia (RS), Slovenia (SI) and Albania. The largest area of the basin is in Bosnia and Herzegovina and Croatia, while Albania has the smallest share of 179 km^2 (Table 1). Main tributaries of Sava River from upstream to downstream are: Ljubljanica, Savinja, Krka, Sutla, Krapina, Kupa, Cesma, Una, Vrbas, Bosna, Drina and Kolubara (Figure 1).
Hydrological and meteorological data necessary for the operational functioning of the platform in real-time are measured, collected and controlled by numerous institutions within the Sava countries. Hydrological informational system for Sava River Basin (Sava HIS) has been created during 2015 and it supports Sava countries in collection and

dissemination of hydrologic and meteorological data, information and knowledge about the water resources [3].

The number of measuring locations vary by country and it is presented in Table 1. The near real-time data are harvested from the Sava-HIS every hour. They can be visualized in Sava-FFWS GUI or to be used for the creation of the initial state of the hydrological models before the forecast simulations.

Table 1: Percentage of the basin area per country [2] with number of hydrological and meteorological stations

Country	Basin area per country (km^2)	Percentage of basin area per country (%)	Number of the meteorological stations	Number of the hydrological stations
Slovenia	11,734	12.01	95	21
Croatia	25,373	25.97	49	127
Bosnia-Herzegovina	38,349	39.25	65	98
Serbia	15,147	15.50	14	28
Montenegro	6,929	7.09	5	13

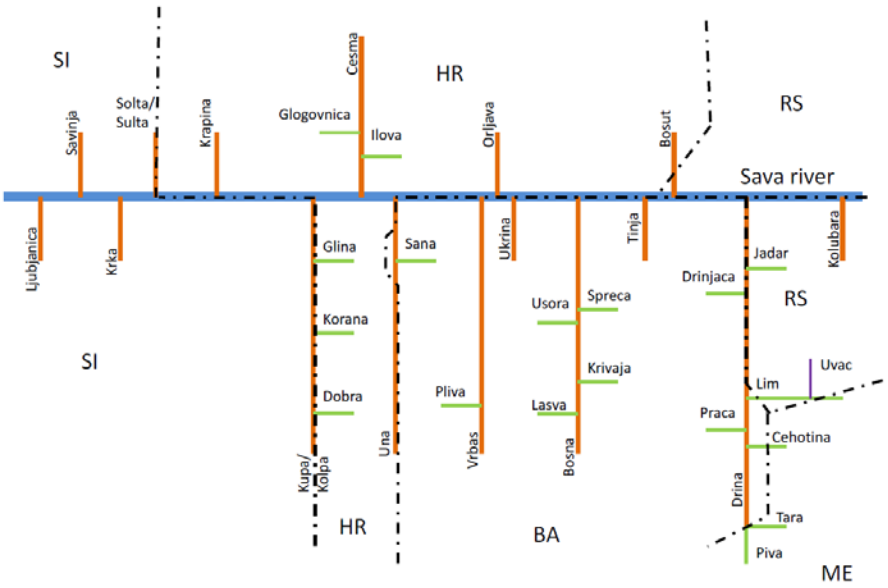

Figure 1: Schematic overview of the Sava River and its main tributaries, including schematically the borders between the five riparian countries: SI-Slovenia, HR-Croatia, BA-Bosnia and Herzegovina, ME-Montenegro and RS-Serbia

Outputs from different numerical weather prediction models (NWP) are also provided by relevant organizations directly to the Sava-FFWS platform. Those spatially distributed

data are used as input to various hydrological and hydraulic models integrated to the platform. They all contain information about precipitation, temperature and potential evapotranspiration for the following three to ten days (Table 3).

Table 3: NWP model outputs integrated to Sava-FFWS platform with forecast length and available runs per day

Country	NWP model	Forecast length (h)	Forecast per day
Slovenia	Aladin 8 km	72	2
Croatia	Aladin 8 km	72	2
Bosnia-Herzegovina	WRF NMM 4 km	72	2
Serbia	ECMWF single	240	2
	ECMWF ensemble	240	2
	NMM B 4 km	72	2
	WRF NMM 4km	72	2
Montenegro	WRF NMM 3 km	72	2
	WRF NMM 1km	72	2

3. AVAILABLE HYDROLOGICAL AND HYDRAULIC MODELS IN SAVA-FFWS

On Sava-FFWS platform several different hydrological and hydraulic models are integrated. In combination with nine NWP models there are 44 model chains created with those hydrological and hydraulic models (Table 4).

Table 4: Combinations of the hydrological/hydraulic/NWP model per country

	Hydrological model	Hydraulic model	NMM B (RS)	WRF NMM (RS)	WRF NMM (BA)	WRF NMM (MNE) 1km	WRF NMM (MNE) 3km
BA/RS/ME	Wflow Sava		x	x			x
BA/RS/ME	HEC-HMS Sava	HEC-RAS Sava	x	x			x
HR	Mike NAM	Mike 11					
BA	Mike NAM Una	Mike 11 Una					
BA	HBV Light Bosna		x	x	x		x
BA	HEC-HMS Sava	HEC-RAS Bosna	x	x			x
BA	HEC-HMS Sava	HEC-RAS	x	x			x
BA	Mike NAM Vrbas	Mike 11 Vrbas	x	x	x		x
RS	HEC-HMS Kolubara	HEC-RAS Kolubara	x	x			x
RS	HBV: Jadar, Kolubara, Tamnava, Ub, Ljig		x	x			x

	Hydrological model	Hydraulic model	Aladin (SI) + ECMWF	Aladin (HR) + ECMWF	ECMWF	ECMWF ensemble
BA/RS/ME	Wflow Sava		x			x
BA/RS/ME	HEC-HMS Sava	HEC-RAS Sava	x			x
HR	Mike NAM	Mike 11		x		
BA	Mike NAM Una	Mike 11 Una		x		
BA	HBV Light Bosna		x			x
BA	HEC-HMS Sava	HEC-RAS Bosna	x			x
BA	HEC-HMS Sava	HEC-RAS	x			x
BA	Mike NAM Vrbas	Mike 11 Vrbas	x			x
RS	HEC-HMS Kolubara	HEC-RAS Kolubara	x			x
RS	HBV: Jadar, Kolubara, Tamnava, Ub, Ljig		x			x

HEC-HMS Sava [4] and Wflow Sava [5] are hydrological models that covers Sava River basin from Croatia to Serbia. In Croatia Mike NAM [6] transforms precipitation to runoff for Sava River and for Una and Vrbas River basins in Bosnia and Herzegovina. In Bosnia and Herzegovina there is HBV-Light [7] model for river Bosna. In Serbia there are HEC-HMS models for Kolubara and five SMHI/HBV models for Kolubara subbasins.
HEC-RAS Sava [8] hydraulic model covers Sava River from Slovenia to Serbia, while HEC-RAS Bosna, HEC-RAS Kolubara and HEC-RAS Bosnia and Herzegovina (for rivers Bosna, Drina, Sana, Una, Usora and Vrbas) are covering subbasins of the Sava River. In Croatia there is Mike 11 [9] model set for Sava and for Una and Vrbas in Bosnia and Herzegovina. The output from these models are water level and the river discharge.
The start time of every workflow is precisely defined and mostly depend on the end time of th
e NWP model run.

4. FLOOD WAVE ON SAVA RIVER IN MARCH 2018

In February 2018 Sava-FFWS platform version 1.0 has been released. Institutions in Sava countries responsible for the hydrological forecasting started the six months test period. At the beginning of March 2018 unusually high air temperatures has caused sudden snowmelt at all altitudes on Sava River basin. In combination with the additional water coming from the rainfall a water level started to rise on all Sava river tributaries. At the Crnac profile (HR) the flood wave has started to be visible from March 8th (Figure 2). The question was shall the water level on Sava River in Serbia exceed first or second warning level in the following days?

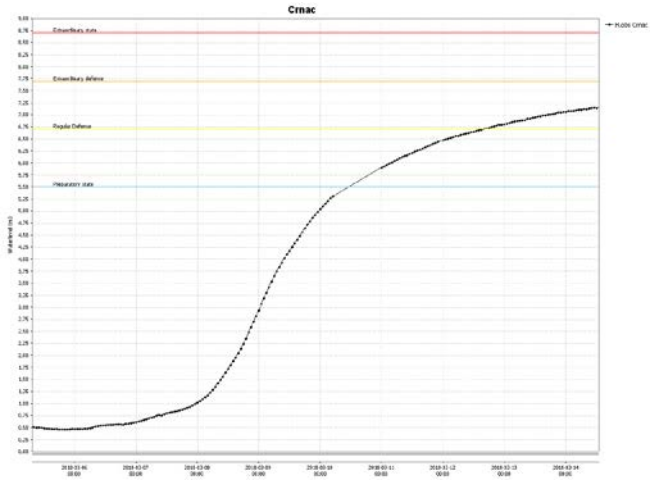

Figure 2. Flood wave at location Crnac in Croatia for period from March 5th till March 14th (created in Sava-FFWS)

For the river profiles on Sava River in Serbia: Jamena, Sremska Mitrovica and Šabac there are two hydrological and one hydraulic model available in Sava-FFWS to forecast discharge for the following three to ten days. The HEC-HMS Sava is calibrated using several flood waves on Sava River and thus we find him the most relevant forecasting model. The other hydrological model is giving very low discharge values in this moment and thus need to be recalibrated using longer time series of precipitation and temperature data. Official forecasts created by forecasters from upstream countries are also available on the Sava-FFWS. That information is giving a good overview what is going to happen on downstream Sava River locations in following days.

For the days from March 16th till March 19th NWP models are forecasting rainfall in amounts from 30 to 60 mm in average on Sava River subcatchments. With those amounts of rain, it is expected that water level on Sava River in Serbia will continue to rise. Discharge values gained with HEC-HMS Sava model on March 15th using various NWP forecasts (Table 5) indicates that the discharge will continue to rise in several days but the first warning level will not be reached (Figure 3). The final forecast indicates that the water-level will exceed the first warning level on profile Sremska Mitrovica on March 17th (Table 6).

Table 5: Forecasted discharge on river profile Sremska Mitrovica using HEC-HMS Sava and available NWP models

Datum:	15.mar	16.mar	17.mar	18.mar	19.mar	20.mar	21.mar	22.mar	23.mar	24.mar
ECMWF	3690	3987	4222	4565	4902	5371	5668	5608	5369	5106
ECMWF eps 50%	3690	3985	4323	4643	4759	4838	4904	4848	4707	4526
NMMB (RS)	3690	3989	4230							
WRF NMM (RS)	3690	3984	4210							
WRF NMM (ME)	3690	3984								

Table 6: Final discharge and water level using information from Sava-FFWS (yellow color indicates exceedance of the first warning level)

Datum:	15.mar	16.mar	17.mar	18.mar	19.mar	20.mar	21.mar	22.mar	23.mar	24.mar
Final Q (m^3/s):	3690	3987	4220	4604	4831	5105	5286	5228	5038	4816
Final H (cm):	605	639	663	695	713	732	744	740	728	712

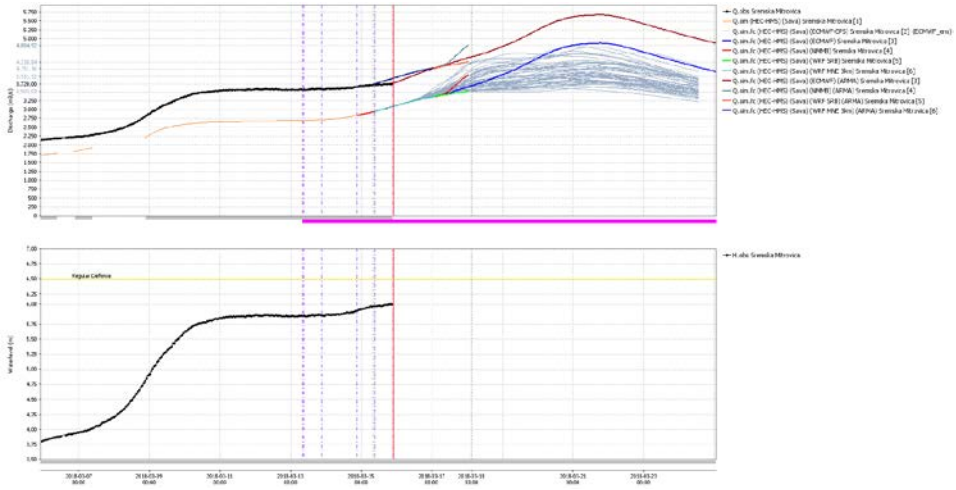

Figure 3. Observed water level and discharge together with the forecasted discharge from simulations with various NWP models

CONCLUSION

Sava-HIS is providing a good way to visualize and analyze time series of the observed data. On the other hand, Sava-FFWS is offering possibility to execute various model chains and to visualize outputs from hydrological and hydraulic models both as time series and grids. Graphical interface of the platform is offering multiple tools for preprocessing and postprocessing phase of the forecasting process. The Sava-FFWS platform is therefore a step forward in the cooperation between institutions in Sava countries responsible for the flood forecasting.

The post-project phase assumes implementation of the additional hydrometeorological data and hydrological and hydraulic models in the moment when they become available. The staff from Sava countries trained during the project will be able to complete such complex tasks.

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РАЗВОЈ СИСТЕМА ПРОГНОЗЕ И РАНОГ УПОЗОРАВАЊА НА ПОЈАВУ ПОПЛАВА У СЛИВУ РЕКЕ САВЕ

Резиме: *Пројекат „Прогноза поплава и систем за обавештавање за слив реке Саве“ је сигурно један од најзначајнијих пројеката у области одбране и ублажавања последица од поплава у којем учествују државе које деле слив реке Саве. Главни задатак на пројекту је формирање заједничке прогностичке платформе на којој су у реалном времену доступни сви подаци неопходни за прогнозу поплава. Измерене вредности метеоролошких и хидролошких параметара заједно са излазима из хидрауличких, хидролошких и модела за прогнозу времена које су обезбеђене од стране свих држава слива омогућавају издавање квалитетних прогноза као и синхронизовану акцију у случају опасних ситуација. За Србију као најнизводнију земљу савског слива овај алат омогућава неопходне информације за брзо доношење одлука као и правовремено издавање упозорења на поплаве на реци Сави.*

Кључне речи: *Сава, Sava-FFWS, поплаве*