

# Hidrološki model za potrebe analize klimatskih scenarija u slivu rijeke Save Razvoj modela i osnovni rezultati

Projekt: Strategija prilagodbe klimatskim promjenama

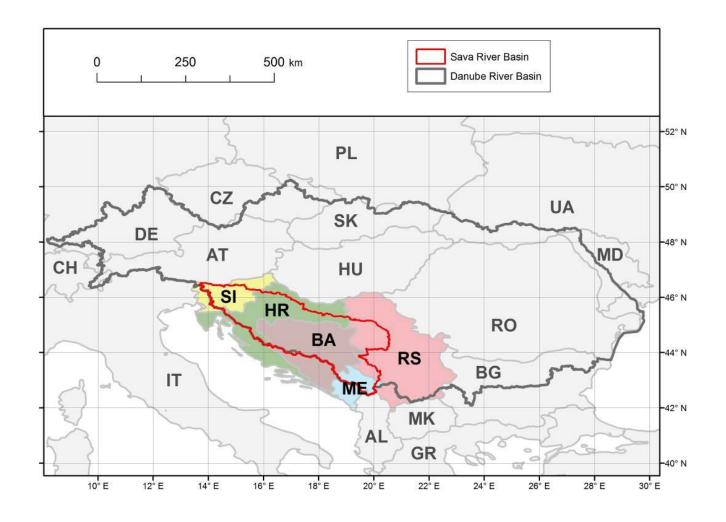
Radionica br. 8/10: HIDROLOGIJA I UPRAVLJANJE VODNIM I MORSKIM RESURSIMA

25. siječnja 2017. godine Hrvatska gospodarska komora, Draškovićeva 45, Zagreb

Mirza Sarač, Sekretarijat Savske komisije



### Sava river basin





### Sava river basin

• Sava – the largest Danube tributary by discharge (contribution: 25%)







### Sava river basin

- Area: 97 713 km² (the second largest Danube sub-basin; share: 12%)
- Average flow at the mouth: 1722 m³/s (the largest Danube tributary)
- River length: 940 km (594 km of which is the waterway)
- Population: approx. 9 million

Country	Share of the basin (%)	Share of the territory (%)
Bosnia & Herzegovina	39.2	75.8
Croatia	26.0	45.2
Serbia	15.5	17.4
Slovenia	12.0	52.8
Montenegro	7.1	49.6
Albania	0.2	0.6



#### **International Sava River Basin Commission**

- **Established in** 2005 (Secretariat: in 2006; Seated in Croatia)
- Established for implementation of the Framework Agreement on the Sava River Basin (FASRB, signed in 2002)
- Four countries involved
  - Bosnia and Herzegovina,
  - Croatia,
  - Serbia and
  - Slovenia
  - Montenegro
    - It was involved at the beginning (as a part of Serbia & Montenegro)
    - Cooperation on technical level, in some fields of work
    - Formalization of cooperation (until the full membership) under consideration



### ISRBC links to national institutions

 Institutions officially nominated by the governments (mostly ministries)

#### NHMSs

- Expert Group for HM issues all members come from the NHMSs
- Annual meetings with directors of the NHMSs representatives
- Water agencies and other institutions
  - Expert Groups (River Basin Management, Floods Prevention, Accident Control, GIS, Navigation,...)
  - Core Working Groups



## ISRBC Scope of cooperation

- Management plans
   (river basin, flood risk, sediment, climate change adaptation)
- Integrated systems

   (information, forecasting, warning)
- **Economic activities** (navigation, river tourism)
- Harmonization of regulation (national → EU)
- Protocols to the FASRB





## The hydrologic model for the climate scenarios analysis in the Sava River Basin

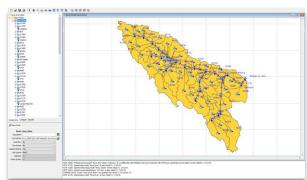
## The HMS model development and basic results

#### ISRBC activities in hydrological modelling



Preliminary hydrological model

prepared by the USACE within the 1st phase of the US Government Support to the Sava countries (2009-2010)

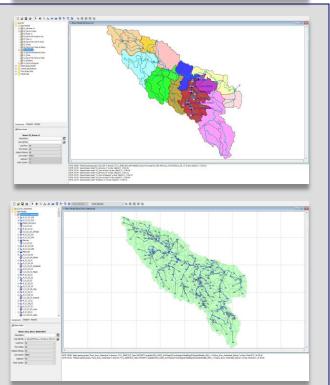


Improved hydrological model

prepared by COWI within "WATCAP" project of the World Bank (2014)

Enhanced hydrological model

prepared by the USACE & ISRBC within the 2<sup>nd</sup> phase of the US Government Support to the Sava countries (2015-2016)





# Sava hydrological model (WATCAP, COWI 2014)

### WATCAP model

INTERNATIONAL SAVA RIVER BASIN COMMISSION

14 models of main river basins separately analyzed

No.	Sub-basin name	Area (km²)
01	Sava to HS Čatež	10186
02	Sava to Kupa	2584
03	Kupa	10032
04	Sava to Una	6627
05	Una	9524
06	Sava to Vrbas	1840
07	Vrbas	6386
80	Sava to Bosna	4491
09	Bosna	10457
10	Sava to Drina	2866
11	Drina	19946
12	Sava to Kolubara	6818
13	Kolubara	3636
14	Sava to Beograd	1007

total: 44 sub-basins



## Model parameters



used HEC methods for each component of the runoff process

Runoff-volume model (loss method)	Deficit and Constant
Direct-runoff model (transform method)	Clark Unit Hydrograph
Baseflow model	Constant Monthly or Recession
Channel flow model (routing)	Muskingum or Lag

used HEC methods for each component of the meteorological model

Precipitation Method	Gage Weights
Snowmelt Method	Temperature Index
Evapotranspiration Method	Monthly Average

Precipitation for each sub-basin in the Sava Basin model is determined as a weighted average of precipitation at gauge locations

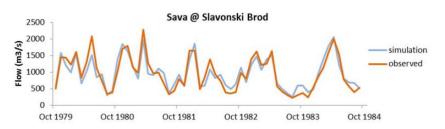
Gage Weights were initially estimated using the Thiessen polygons method, but were later adjusted during the calibration process

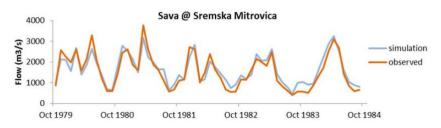
Precipitation gages: 48 ; Temperature gages: 27; Discharge gages: 35

#### Calibration process



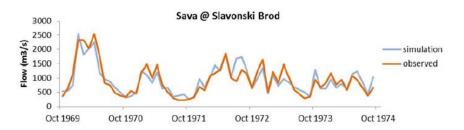






### **Calibration results** for the Sava hydrologic model for selected stations







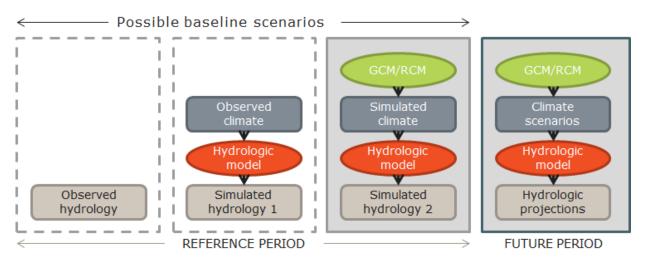
**Validation results** for the Sava hydrologic model for selected stations

## Model application with future climate scenarios



#### Metodology

 Baseline runoff simulated with climate parameters from climate change model for the reference period



- The following indicators of the hydrologic regime are considered to assess the change:
  - mean annual runoff, defined as the long-term average flow across years in a given 30-year period
  - mean seasonal runoff, defined as the long-term average flow in four seasons across years in a given 30-year period
  - high annual flow, defined as the annual flow with 10% probability of exceedance in a given 30-year period
  - low annual flow, defined as the annual flow with 90% probability of exceedance in a given 30-year period

## Climate Change Scenarios as the input to the hydrologic model



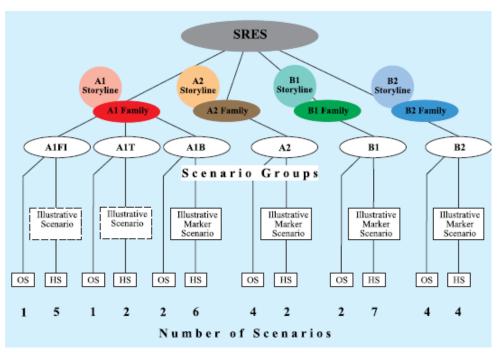
Hidrology simulations with climate change scenarios

- Baseline: 1961-1990

Near future: 2011-2040Distant future: 2041-2070

Ansambl 5 GCM/RCM modela za A1B IPCC/SRES scenario

Climate model	GCM	RCM
CM1	ECHAM5r3	RACMO
CM2	ECHAM5r3	REMO
CM3	HadCM3Q0	CLM
CM4	HadCM3Q0	HadRM3Q0
CM5	ECHAM5r3	RegCM3



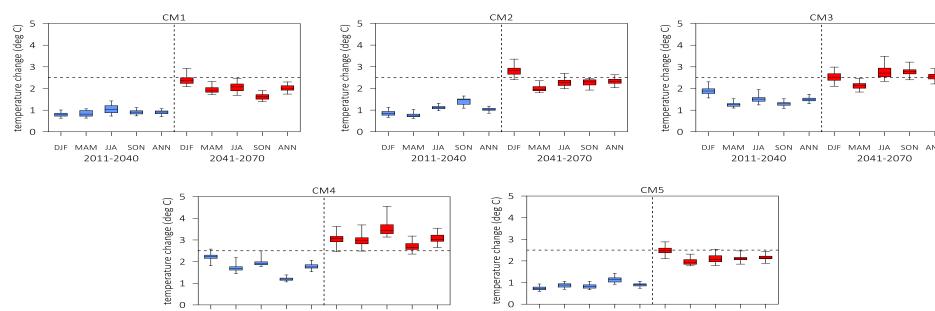
## Future climate as predicted by climate models

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2011-2040

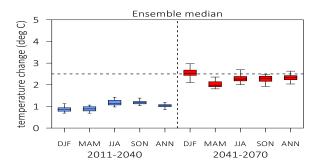


#### **Air Temperature Scenarios Results**



SON ANN

2041-2070



A clear increasing trend, with little variation over the basin

2011-2040

The average change in mean annual temperature over all meteorological stations used in the hydrologic model ranges from 0.9 to 1.8°C (median value 1.0°C) for different climate models in the near future and from 2.0 to 3.1°C (median value 2.3°C) in the distant future

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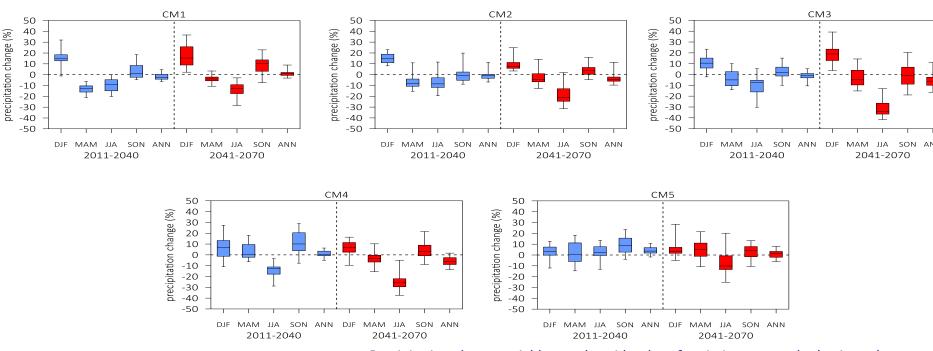
2041-2070

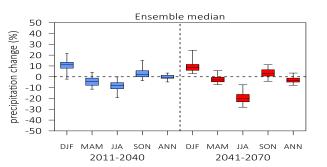
Different climate models predict the most pronounced increase in temperature in different seasons. For the near future, one model predicts the highest increase in summer, two in autumn and two in winter. For the distant future, one model predicts the highest increase in summer, one in both summer and autumn, and three in winter

## Future climate as predicted by climate models



#### **Precipitation Scenarios Results**





- Precipitation shows variable trends, with a lot of variation across the basin and across the climate models and seasons
- The change in mean annual precipitation is generally very small
- A clear increasing or decreasing trend in seasonal precipitation across the whole basin cannot be seen in all models. For the near future, two models predict a clear increasing trend in winter precipitation and a clear decreasing trend in summer precipitation. For the distant future, three models predict a clear increasing trend in winter precipitation and four models predict a clear decreasing trend in summer precipitation.

## Future climate as predicted by climate models

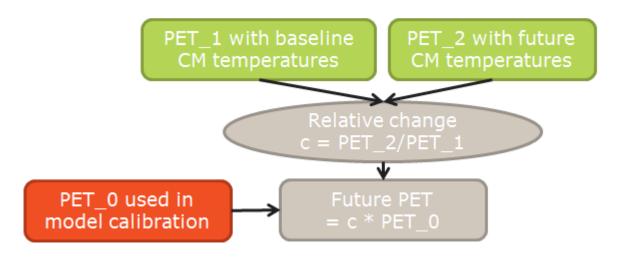


#### Scenarios for evapotranspiration (potential)

The choice of potential methods was very limited since no information was available on any of the climatological parameters affecting PET (e.g. solar radiation, humidity, wind speed) except the air temperatures, neither for the past climate nor for future projections

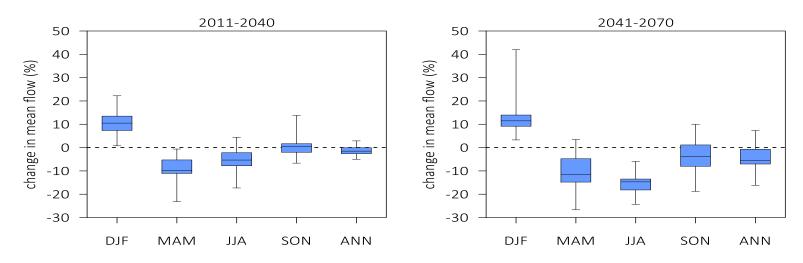
Based on temperature scenarios and the Hargreaves equation for PET

$$PET = 0.0023 R_a TD^{0.5} (TC + 17.8)$$





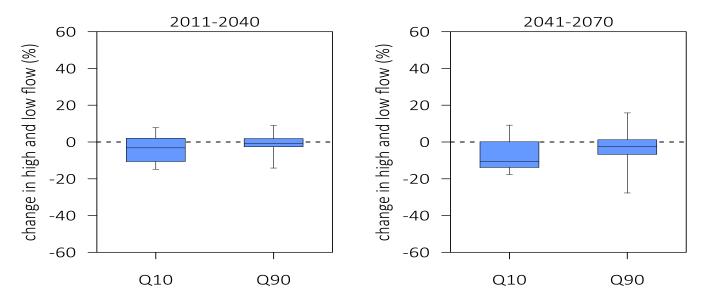
change in ensemble median values of mean seasonal and annual runoff;
 range of changes across 50 locations in the basin



- change in the hydrologic regime corresponds to the projected change in precipitation and temperature
- the most notable change in both the near and distant future is the increase of stream flow in the winter season, as the result of the increased precipitation and a significant increase in temperatures



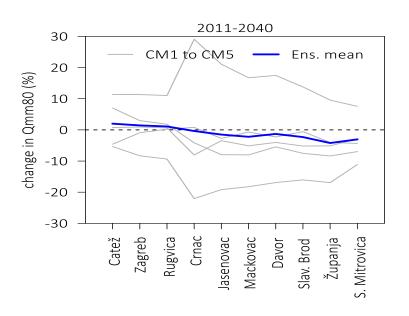
• change in ensemble median values of high (Q10%) and low (Q90%) annual flow characterizing wet and dry years; range of changes across 50 locations in the basin

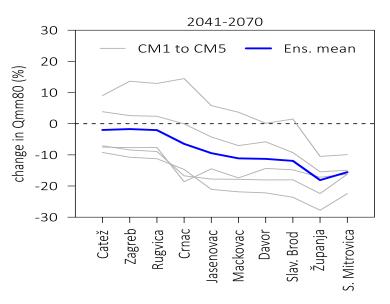


- high annual flows show greater reduction, indicating that the proportion of very wet years would decrease
- low annual flows are subject to a small reduction, meaning that the proportion of very dry years would slightly increase



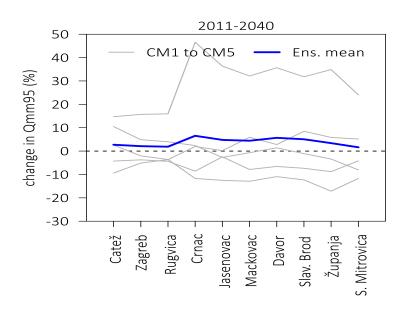
Change in ensemble median values of low flows (80% mean monthly Q)

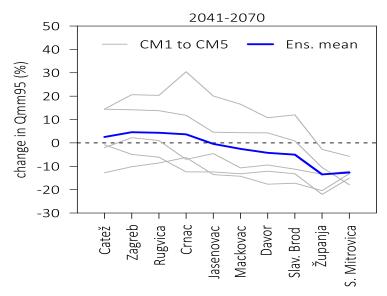






Change in ensemble median values of low flows (95% mean monthly Q)







## Water and Climate Adaptation Plan for the Sava River Basin (WATCAP)

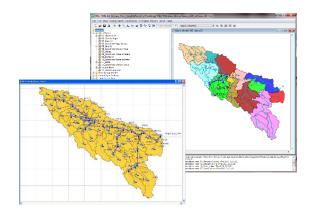
http://savacommission.org/project\_detail/18/1

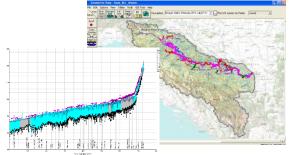


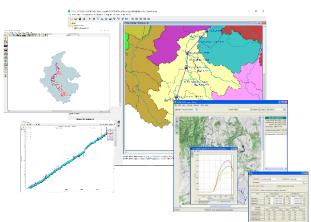
# Sava hydrological model (USACE & ISRBC, 2016)

## 2<sup>nd</sup> phase of US Support

- INTERNATIONAL SAVA RIVER BASIN COMMISSION
- Develop and Calibrate a flood event-based hydrologic model
  - HEC-HMS i HEC-Geo HMS
  - Accurate Delineation
  - Calibration and verification
- Improve upon the latest mainstem Sava River hydraulic model
  - Start point existing model
  - Preparation of new terrain model (LiDAR)
  - A new model based on improved geometry and boundary conditions
  - Calibration and verification
  - 2-D capability in HEC-RAS will be implemented to simulate a levee breach scenario
- Develop detailed hydrologic and hydraulic modeling of the Bosna River Basin using existing models for the purpose of developing a flood forecasting platform using HEC products
  - HEC-RTS (Real-time Simulation)







## Main objectives



- To support the development of hydrological and hydraulic models of the Sava River Basin, tools that will strengthen multilateral cooperation in the basin, primarily in the area of flood protection
- To support activities leading to the preparation of a flood risk management plan as well as the development of the system for flood forecasting
- To establish the models that could be used for other purposes in future (modeling sediment transport, water quality, climate change analysis, etc.)

## Hydrological modelling



Start point – existing WATCAP Model

Use of HEC-HMS & HEC-GeoHMS

- Accurate Delineation
- Temporal Resolution
- Water Storage Components
- Calibration and Verification

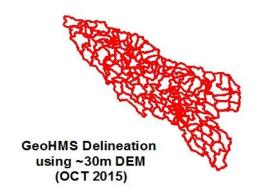


Final HEC-HMS Model contains a separate basin models for each tributary basin and mainstem reach (22 models in total)

#### Improvement of delineation

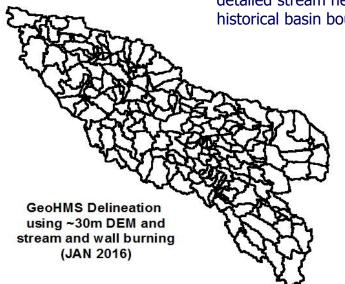






#### 3 Phases of Delineation

- WATCAP Model Delineation (44 sub-basins)
- HEC-GeoHMS Delineation using 30m SRTM DEM with major streams burned into the DEM
- HEC-GeoHMS Delineation using 30m SRTM DEM with detailed stream network burned into the DEM and historical basin boundaries added to the DEM as walls



235 sub-basins

Delineation will support the **Sava River** mainstem HEC-RAS hydraulic model

## Model parameters



used HEC methods for each component of the runoff process

Runoff-volume model (loss method)	Deficit and Constant
Direct-runoff model (transform method)	Clark Unit Hydrograph
Baseflow model	Recession
Channel flow model (routing)	Muskingum or Muskingum Cunge

used HEC methods for each component of the meteorological model

Precipitation Method	Inverse Distance Squared
Snowmelt Method	Temperature Index
Evapotranspiration Method	Monthly Average

Precipitation gages: 79; Temperature gages: 70; Discharge gages: 93

Evapotranspiration: the values computed by COWI during the WATCAP study transferred to the new subbasins

Snow/Snowmelt: each subbasin is divided into elevation bands where initial snowpack parameters are set. The most important parameter is snow-water-equivalent (SWE). To determine initial SWE totals, satellite-based SWE grids are used

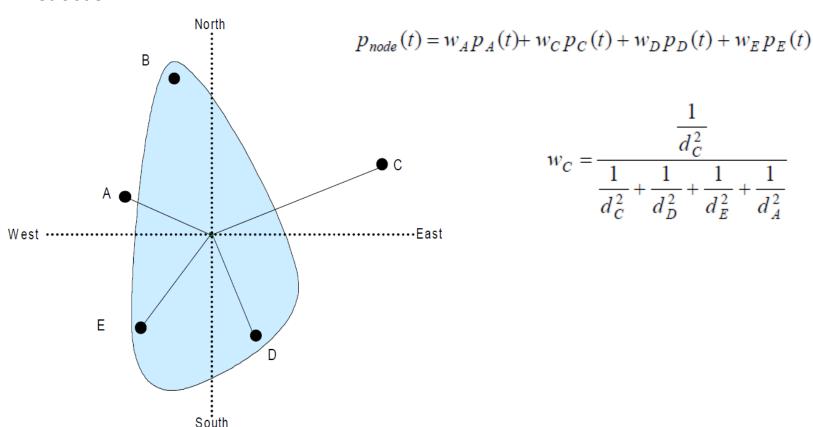
Project for the development of the National strategy on adaptation to climate change, Croatia

## INTERNATIONAL SAVA RIVER BASIN COMMISSION

### Meteorological parameters

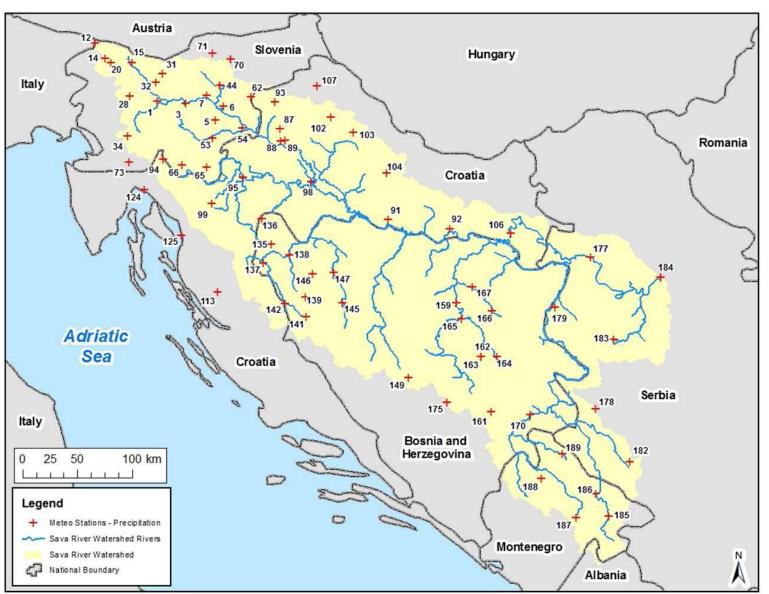
#### Inverse Distance Weighting Method

- Each precipitation gauge and subbasin is assigned location coordinates
- HMS determines rainfall amount for each subbasin by using any gauges within the search radius to assign an inverse distance weighted rainfall amount to each subbasin



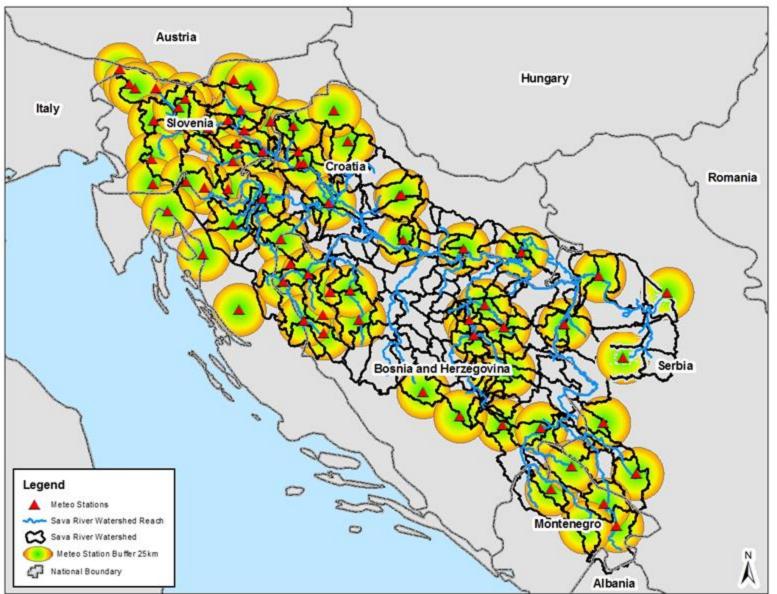
### Precipitation Gauges coverage





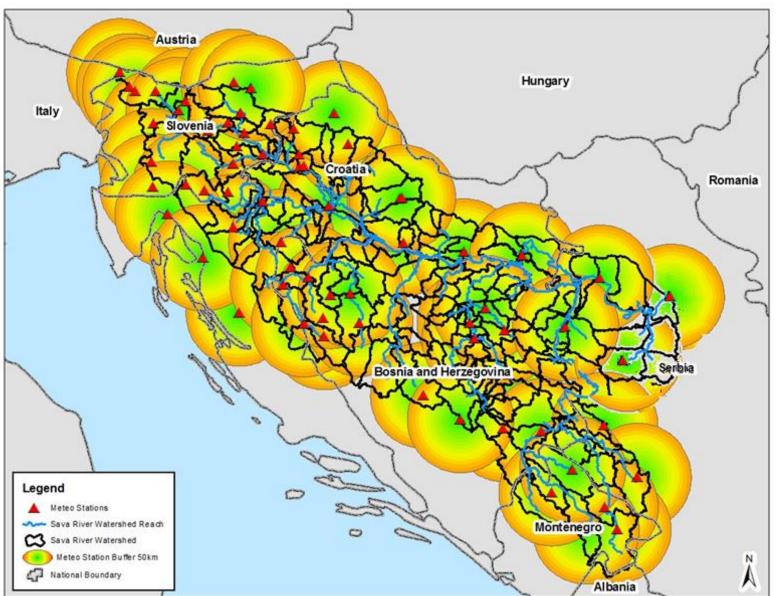
### Precipitation Gauges coverage





## Precipitation Gauges coverage

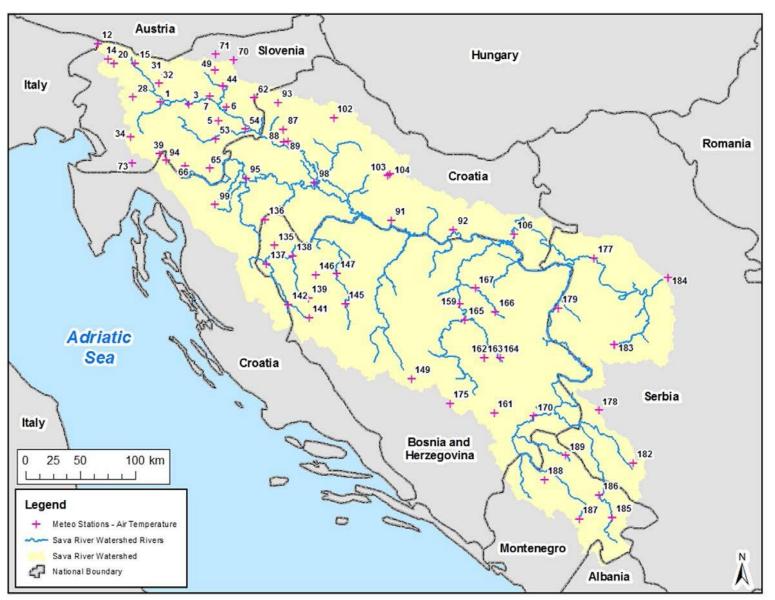




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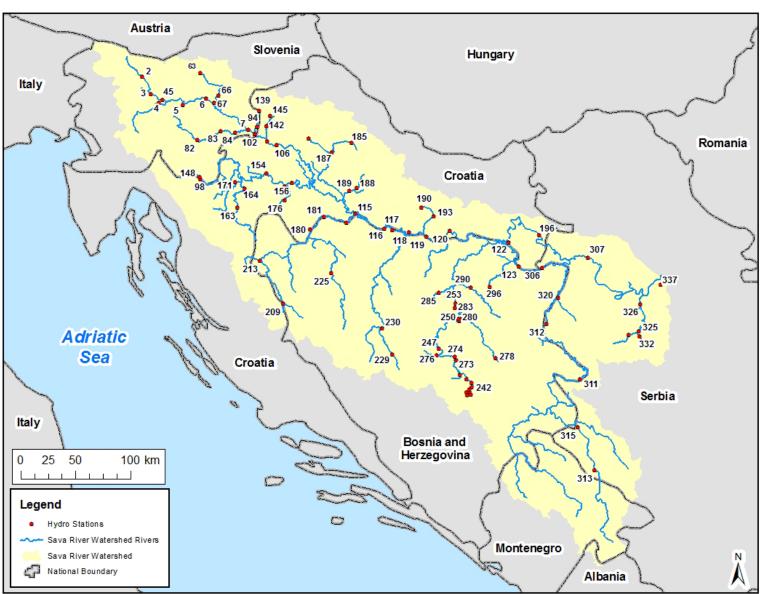
### Air Temperature Gauges coverage





### Discharge Gauges coverage





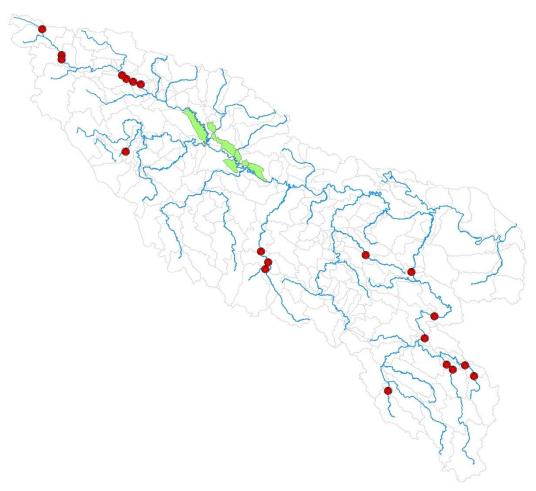
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### Water Storage Components

#### Reservoirs (1st Sava RBM Plan)

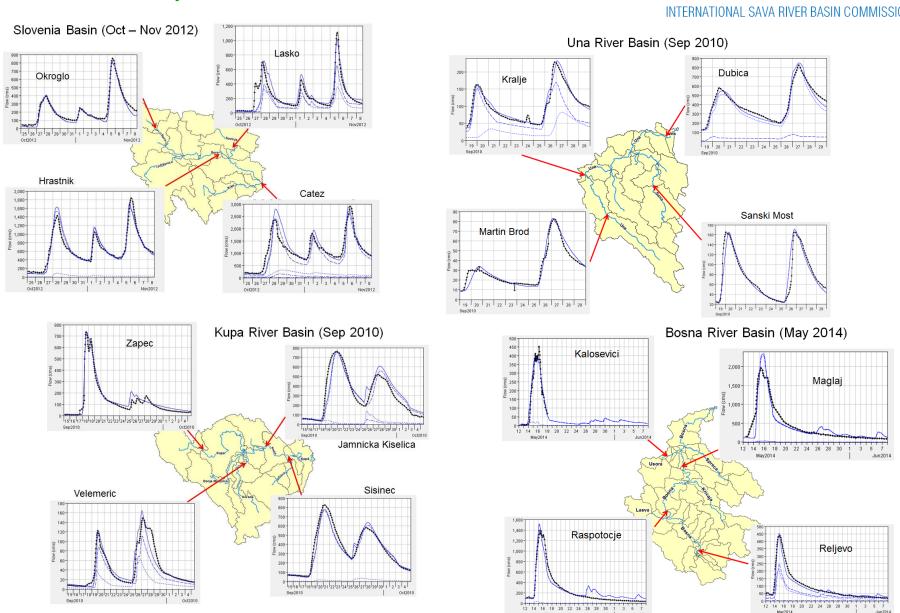
No C	Country	HPP name	River Basin	River
15	SI	Moste/Završnica	Sava direct	Sava
25	SI	Mavčiče	Sava direct	Sava
35	SI	Medvode	Sava direct	Sava
45	SI	Vrhovo	Sava direct	Sava
5 S	SI	Boštanj	Sava direct	Sava
6S	SI	Arto-Blanca	Sava direct	Sava
7S	SI	Krško	Sava direct	Sava
8 H	IR .	Lešce	Kupa/Kolpa	Dobra
9 B	3A	Bočac	Vrbas	Vrbas
10 B	3A	Jajce I	Vrbas	Vrbas
11 B	3A	Jajce II	Vrbas	Vrbas
12 B	3A	Modrac	Bosna	Spreča
13 M	1E	Piva	Drina	Drina
14 B	3A	Višegrad	Drina	Drina
15 R	RS	Bajina Bašta	Drina	Drina
16 R	RS	Zvornik	Drina	Drina
17 R	RS	Bistrica	Drina	Lim
18 R	RS	Potpeć	Drina	Lim
19 R	RS	Uvac	Drina	Uvac
20 R	RS	Kokin Brod	Drina	Uvac



#### Middle Sava Retention Areas

#### Calibration process





Project for the development of the National strategy on adaptation to climate change, Croatia

## Next steps



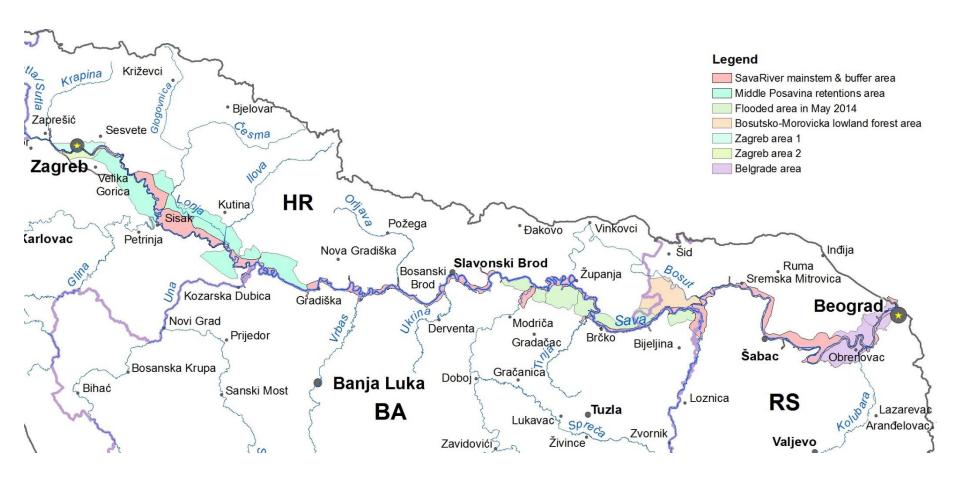
- Improve upon the latest mainstem Sava River hydraulic model
  - Start point existing model
  - Preparation of new terrain model (Sava LiDAR project)
  - A new model based on improved geometry and boundary conditions
  - Calibration and verification
  - 2-D capability in HEC-RAS will be implemented to simulate a levee breach scenario

#### Sava LiDAR project

- To acquire high-quality digital elevation data and products and imagery needed for upgrade of hydraulic model of the Sava River:
  - Lidar based data and products
  - Digital Orto photo (DOP)
- Areas
  - Sava River course "levee to levee with the buffer zone" from SI-HR border to Belgrade
  - Main retention areas along the Sava River
  - Flooded areas due to levee breach 2014
  - Bosutsko-Morovicka lowland forest area
  - Cities Zagreb and Belgrade
- The Consultant (Fly Com, Slovenia) has contracted with the deadline end of April, 2017 for the final submission of products



## Sava LiDAR project area





## **Geographical & Hydrological Information System**of the Sava River Basin

### Sava GIS & Sava HIS

#### Sava GIS & Sava HIS



#### Successfully completed objectives

- common platform of the ISRBC community to enable sharing and disseminating of information and knowledge about protection of the water resources and water management activities in the Sava River Basin
- support to the ISRBC community in sharing and disseminating of hydrologic and meteorological data, information and knowledge about the water resources in the Sava River basin

 enable an effective common channel for exchanging and viewing the hydrologic and meteorological data and information in emergency situations, primarily those

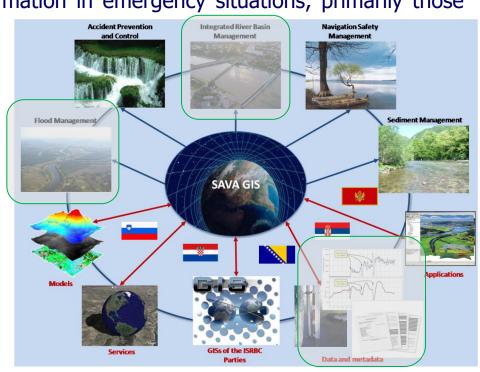
related to flood events

According to *Implementing Documents for Establishment of the Sava GIS* – 2010, establishment of the Sava GIS is focused in following benefit areas: *Modules* 

- 1. Int. River Basin Management
- 2. Flood Management
- 3. Accident Prevention and Control
- 4. Navigation Safety Management
- 5. Sediment Management

#### Submodules

Time-Series Data Management Metadata Management



## Sava GIS & Sava HIS projects



#### Scope of projects

#### Service/deliverable

**Assessment** of the current hydrological and meteorological data collection

Establishment **Sava GIS database** (geodatabase)

Establishment of **Sava Geoportal** for searching, disseminating, processing and visualization information to the stakeholders and public

Establishment of web-based application for data and metadata management

Establishment of web-based application for H&M real time data management

Knowledge transfer - Workshops & Trainings

#### Database models are created based on

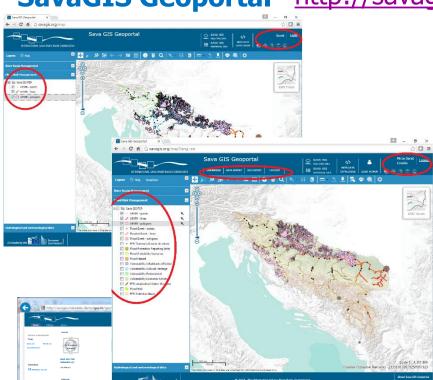
- WFD reporting Guidance 2016 v.4.9
- FD reporting Guidance 2013
- ICPDR database models (Danube GIS)
- INSPIRE Directive and professional requirements
- WaterML 2.0 part 1: Timeseries model implementation

MODULES for:
River Basin Management
Flood Management

MODULE for:
HM Time-Series Data Management

### SavaGIS products

#### **SavaGIS Geoportal** <a href="http://savagis.org/">http://savagis.org/</a>





#### INTERNATIONAL SAVA RIVER BASIN COMMISSION

Access to data from SavaGIS system via WMS/WFS services:

http://savagis.org/wms
http://savagis.org/wfs

Viewing attributes and features <a href="http://savagis.com/nttp://sav

Filtering by attributes or spatial data

Overview of public spatial data

- Exporting areas of map to PDF or PNG format
- ...

#### Registered users

Public users

web application for data management

#### Data and metadata upload Data and metadata download

FGDB

XLS

XML

WFS of GML format

Harvesting

Manually

Spatial formats Attribute formats

SHAPE file – CSV

GeoJSON file – XLS KML file – MSAcce

KML fileGML2 fileMSAccess2010DBF

- WFS & WMS services - XML

WATER ML 2.0 service

#### Data management



#### Metadata catalogue

Project for the development of the National strategy on adaptation to climate chan

## Time-series HM data management within Sava GIS Concept





**CUAHSI** Consortium of Universities for the Advancement of Hydrologic Science, Inc.

A consortium representing 125 US universities

#### 1. Standards

WaterML language for describing water data





#### 2. Services

Catalog of water data sources – web services







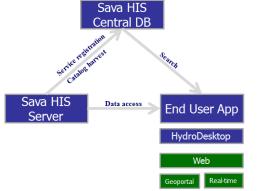
#### 3. End user application

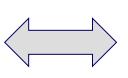
Free software for data access

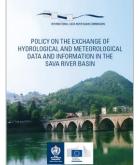


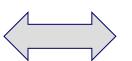














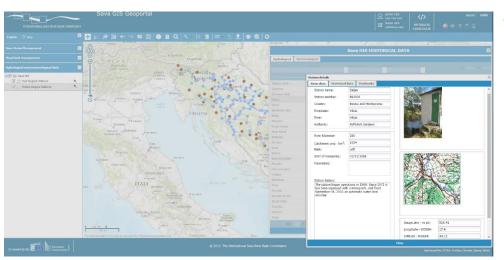
WIS - WMO Information System



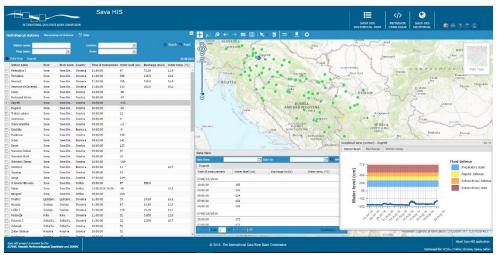


## Sava HIS products





#### http://savagis.org/



#### historical (processed) data exchange

Parameter	Temporal Resolution	
	(Statistic)	
Water Stage	Daily (Mean)	
River Discharge	: Daily (Mean)	
Water Temperature	Daily (Mean)	
Suspended Sediment Discharge	: Daily (Mean)	
Groundwater Level	Daily; Every 5/10th Day	
Ice Condition	Daily	
Relative Humidity	Daily	
Wind (Speed and Direction)	: Daily	
Snow Depth	Daily	
Evaporation	: Daily (Total)	
Solar Radiation	Daily	
Sunshine	: Daily (Total)	
Atmospheric Pressure	Daily	

#### real-time data exchange

Parameter	Temporal Resolution
Precipitation	: Daily (Total)
Air Temperature	Current
Water Stage	Current
River Discharge	Current
Water Temperature	Current

http://savahis.org/



## **Contact information**

**International Sava River Basin Commission** 

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