ORIENTGATE Project: Training seminar on climate change issues

4-5 June 2013, Belgrade, Serbia

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

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Why Water and Climate Adaptation Plan (WATCAP)?

- Intergovernmental Panel on Climate Change (IPCC) has viewed South East Europe (SEE) region as particularly sensitive to climate change.
- European Commission (EC) highlighted the SEE countries below the 40° latitude at considerable risk and need to adapt to climate change.
- Governments of SEE states have acknowledged that impacts from climate change in the region are projected to get worse.

WATCAP Objectives

- To enhance climate resilience of selected water sector investments;
- To stimulate debate among key stakeholders in the water resources sector in SEE on climate-related impacts and adaptation strategies;
- To inform on approaches to adapt water resources management, planning and operations to the forecasted impact of climate change.

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Why Sava Basin for WATCAP?

- SRB is the first of these basins in South-Eastern Europe selected for this work.
- SRB is of a high priority
  - Regional climate modelling suggests an overall reduction of around 15% to 30% in mean annual runoff by the middle of this century, which could be challenging for all investments undertaken in the basin.

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How will WATCAP be achieved?

- Task 1: Historic climate data analysis (data collection, statistical trend analysis)
- Task 2: Future climate data analysis based on GCM outputs
- Task 3: Hydrologic model development and simulations of future water regime
- Task 4: Guidance notes for specific sectors (scenarios and adaptation strategies for hydropower, navigation, flood control, agriculture, economics)
- Task 5: Water and Climate Adaptation Plan (WATCAP) Main Report

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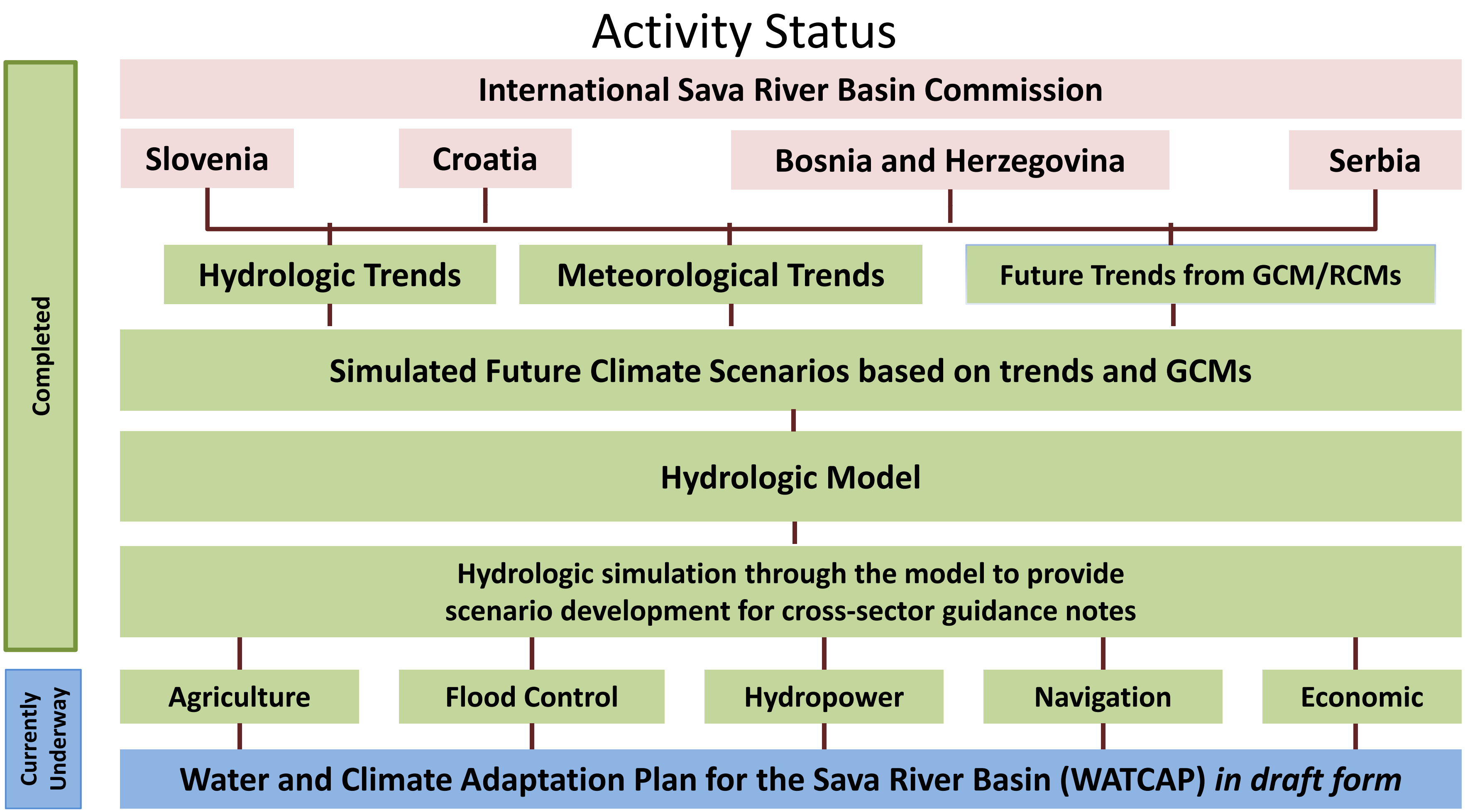
Activity Status
International Sava River Basin Commission
Slovenia
Croatia
Bosnia and Herzegovina
Serbia
Hydrologic Trends
Meteorological Trends
Future Trends from GCM/RCMs
Simulated Future Climate Scenarios based on trends and GCMs
Hydrologic Model
Hydrologic simulation through the model to provide scenario development for cross-sector guidance notes
Agriculture
Flood Control
Hydropower
Navigation
Economic
Water and Climate Adaptation Plan for the Sava River Basin (WATCAP) in draft form
Completed
Currently Underway

Draft WATCAP – Main Report

- Introduction
- Overview for the Sava River Basin
  - Brief Social and Economic Characteristics
  - Current Status of Water Resources
  - Core Water Management Issues
- Trends Analysis
- Future Climate Analysis
- Hydrologic Modelling
- Impacts due to Climate Change
  - Characterization of Future Hydrologic Regime
  - Impacts on Selected Sectors
- Economic Evaluation of Climate Change Impacts
- Adaptation strategies
- Conclusions and Recommendations

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WATCAP funding sources

- Water Partnership Program (WPP)
- Trust Fund for Environmentally and Socially Sustainable Development (TFESSD)

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Sava Basin Hydrologic Model (Task 3)

Sava Basin Hydrologic Model (Task 3)

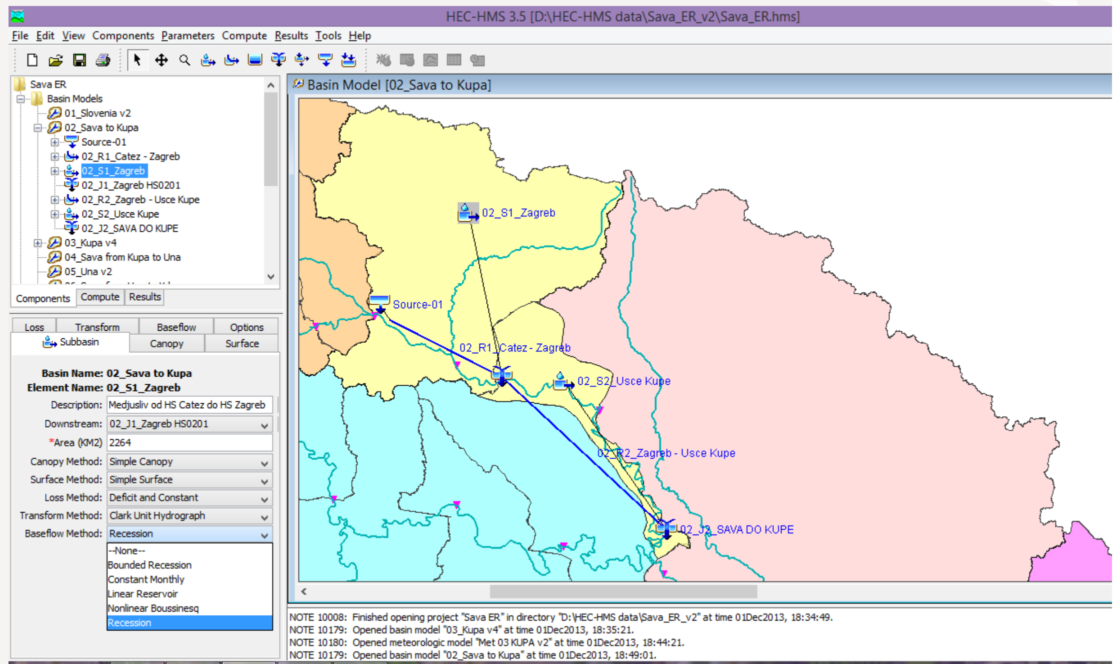
- Scope of work:
  - **Model development**
    - define an appropriate model structure
    - collect necessary data
    - perform model calibration and verification
  - **Characterisation of future hydrologic regime**
    - perform hydrologic simulations with climate scenarios for 2011-2040 and 2041-2070

Hydrologic Model Development

- Sava River Basin: ~ 95,000 km^2
- No previous models of the whole basin

Hydrologic Model Development

- Choice of the model: HEC-HMS
  - used initially by USACE as a link to the hydraulic model developed for ISRBC
  - easily obtainable by future users on the SRB (free of charge)
- Main pros and cons
  - not completely suitable for continuous simulation
  - moderate data requirements (depending on calculation methods)



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Data Requirements

- Input data
  - daily precipitation time series
  - daily temperature time series
  - monthly potential evapotranspiration (seasonal distribution)
- Hydrologic data for calibration and verification
  - daily flows time series
- Geographic data
  - sub-basin areas
  - met station elevations
  - elevation distribution within the basin (elevation bands)

Data Collection

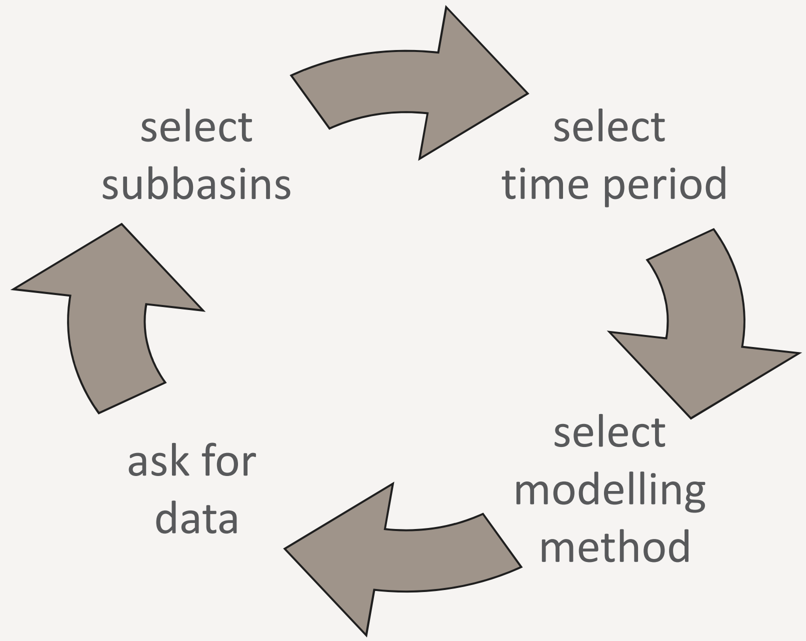
- Data collection by riparian experts
  - hydrologic data at selected stations and in selected periods – daily flow rates
  - precipitation and air temperature data at selected meteo stations – daily data
  - potential evapotranspiration data at selected stations – monthly data
  - basic information on water control facilities

- Precipitation and temperature data from Montenegro
  - additional data needed for the Drina Basin model

Model setup and data availability

- Choice of sub-basins, calibration and verification periods, modelling methods and data collection is an iterative process
  - not all relevant data is readily available
  - short calibration and verification periods due to poor data availability

- Calibration 1979-1984
- Verification 1969-1974



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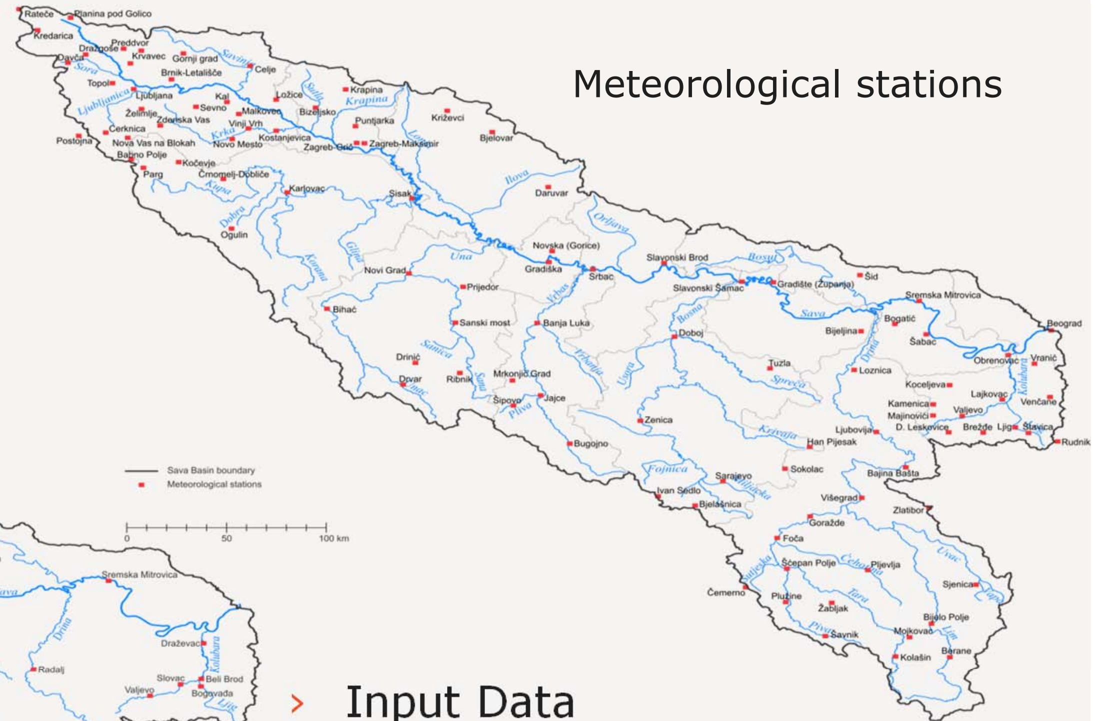
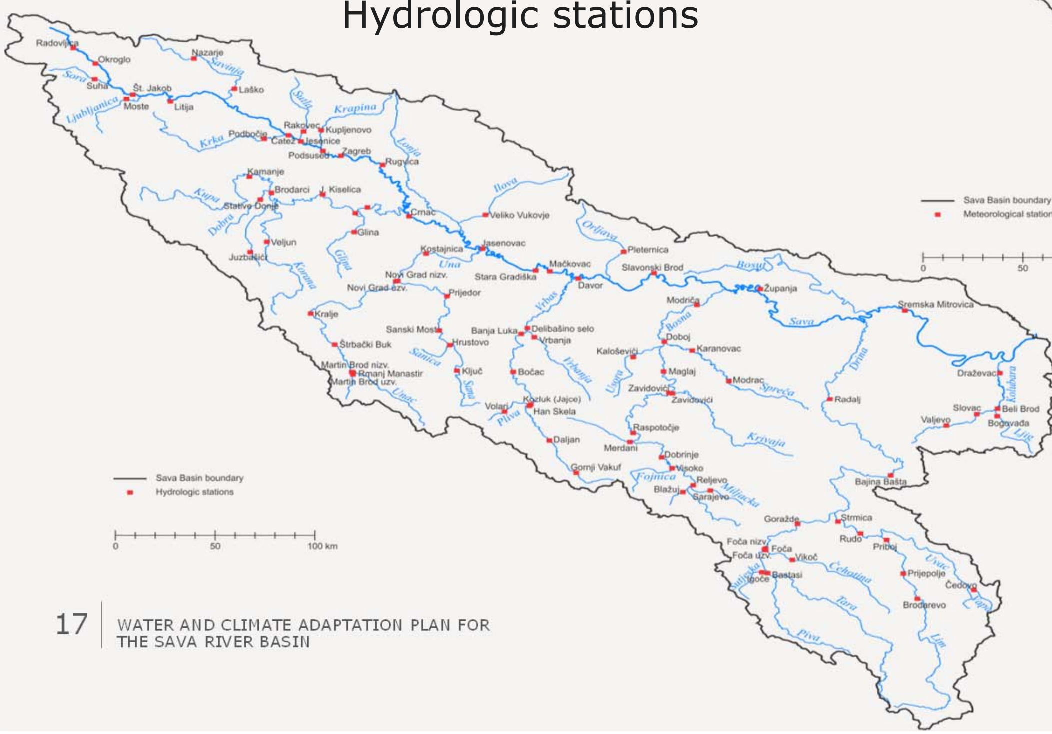
Hydro and meteo stations

Meteorological stations



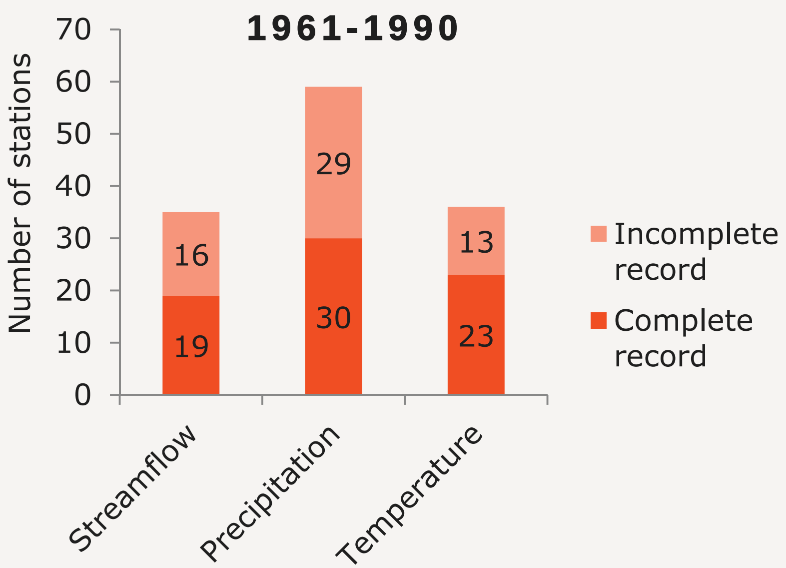
Hydrologic stations



- Input Data
  - Precipitation stations (50)
  - Temperature stations (27)
  - Hydrologic stations (35)

Record extension

- Filling gaps and extending P and T records
  - Records reconstructed using a regional climate model with 1 km horizontal resolution
  - Poorer results for precipitation in Montenegro (improper boundary conditions)



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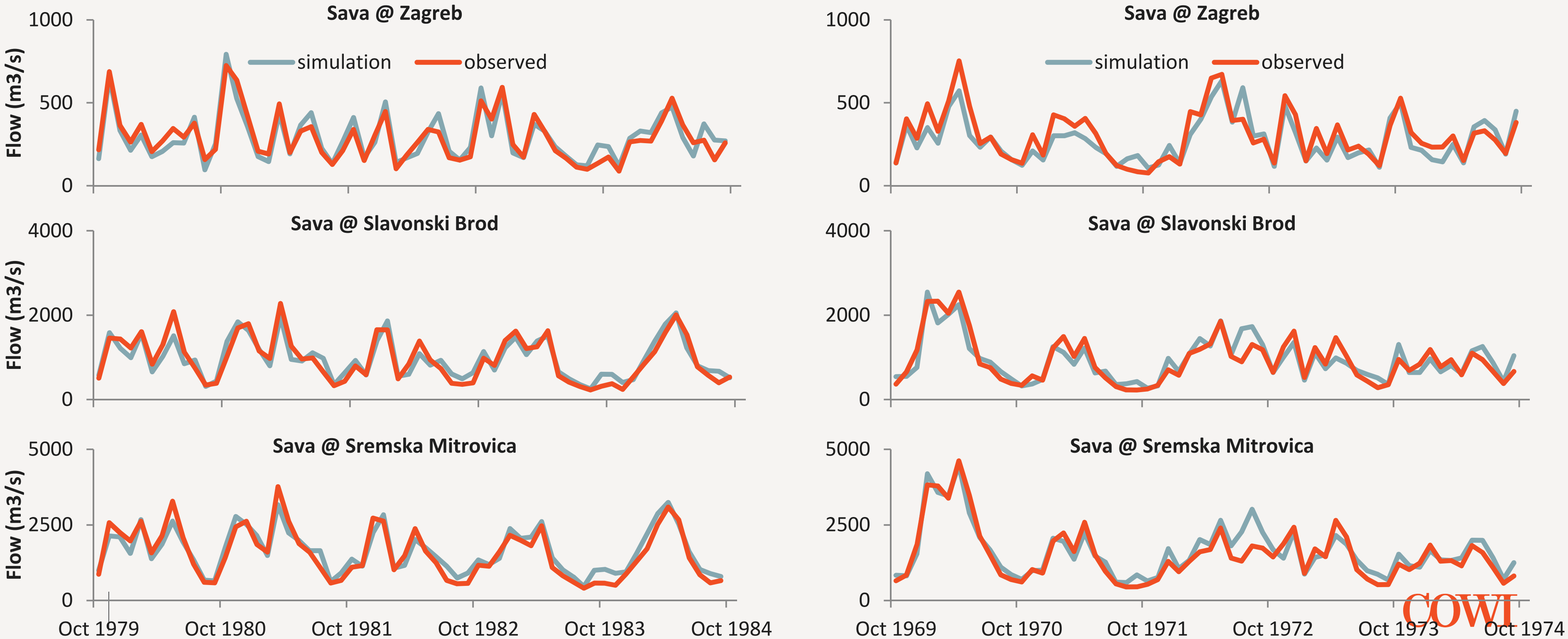
Sub-basin division

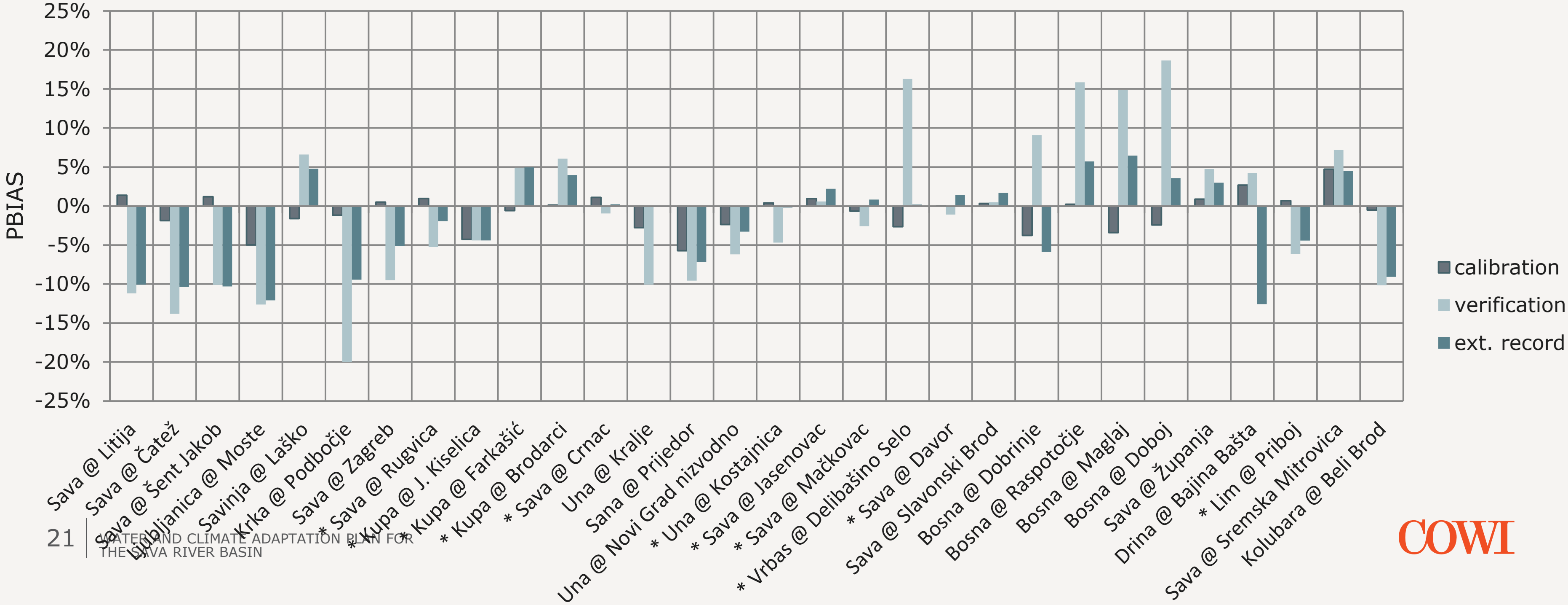
- Basin subdivision with respect to daily time step and to data availability and quality
  - sub-basin sizes 2000-5000 km^2
- 14 major sub-basins modelled separately
- 44 sub-basins in total
- 35 sub-basins controlled by hydrologic stations

Calibration and validation

Mean monthly flows



Model performance: bias (error in mean annual flow)



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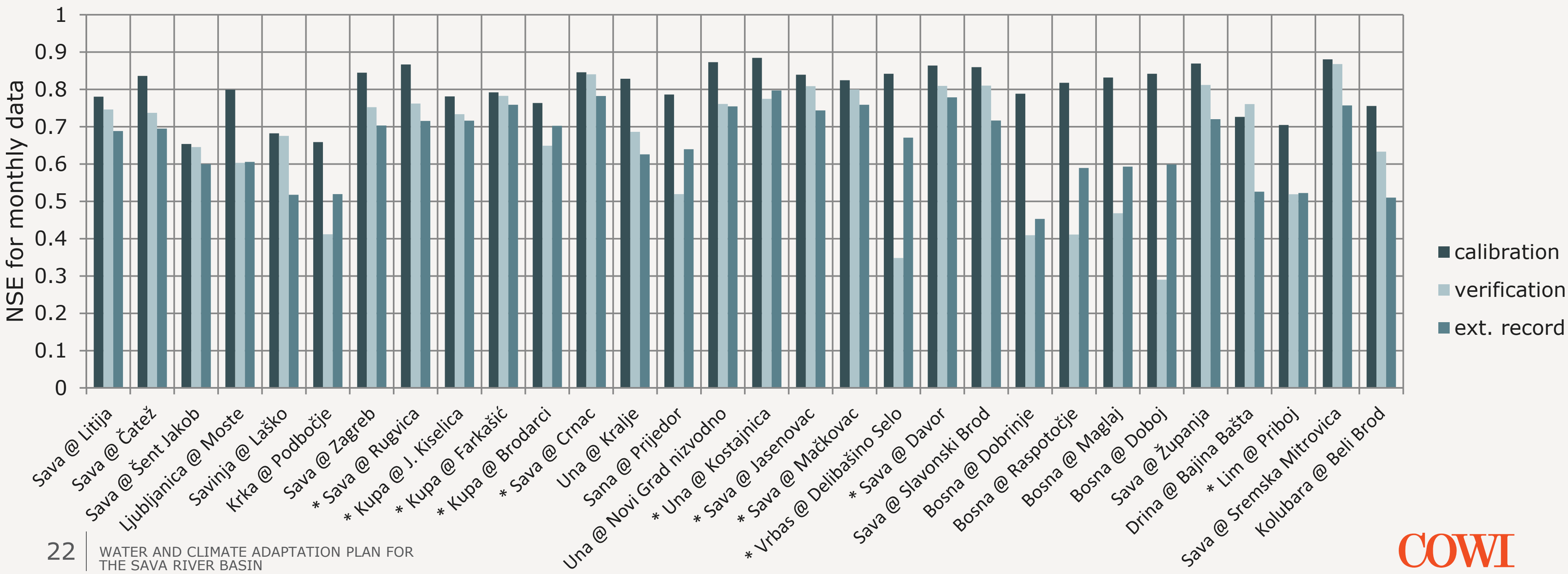
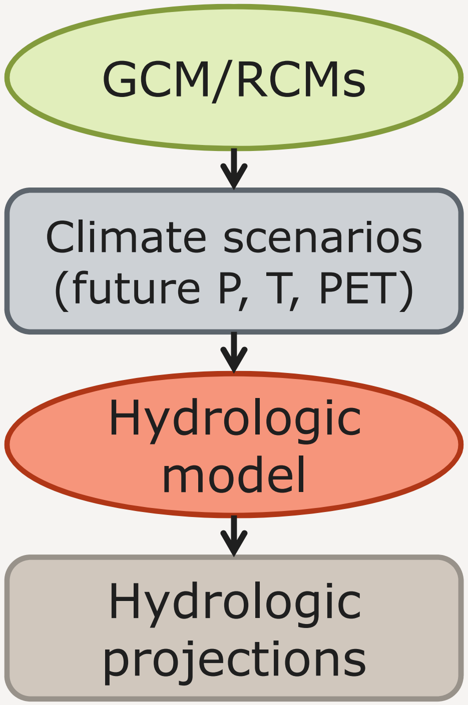
Model performance: Nash-Sutcliffe Efficiency



Model application with future climate: Methodology

- Hydrologic simulations of future regime using future climate scenarios as input

- Baseline: 1961-1990
- Near future: 2011-2040
- Distant future: 2041-2070



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Model application with future climate: Methodology

- Change evaluated by comparing simulated future regime against simulations with baseline climate

$$\frac{Q_{FUT} - Q_{BASE}}{Q_{BASE}} \cdot 100 \ \%$$

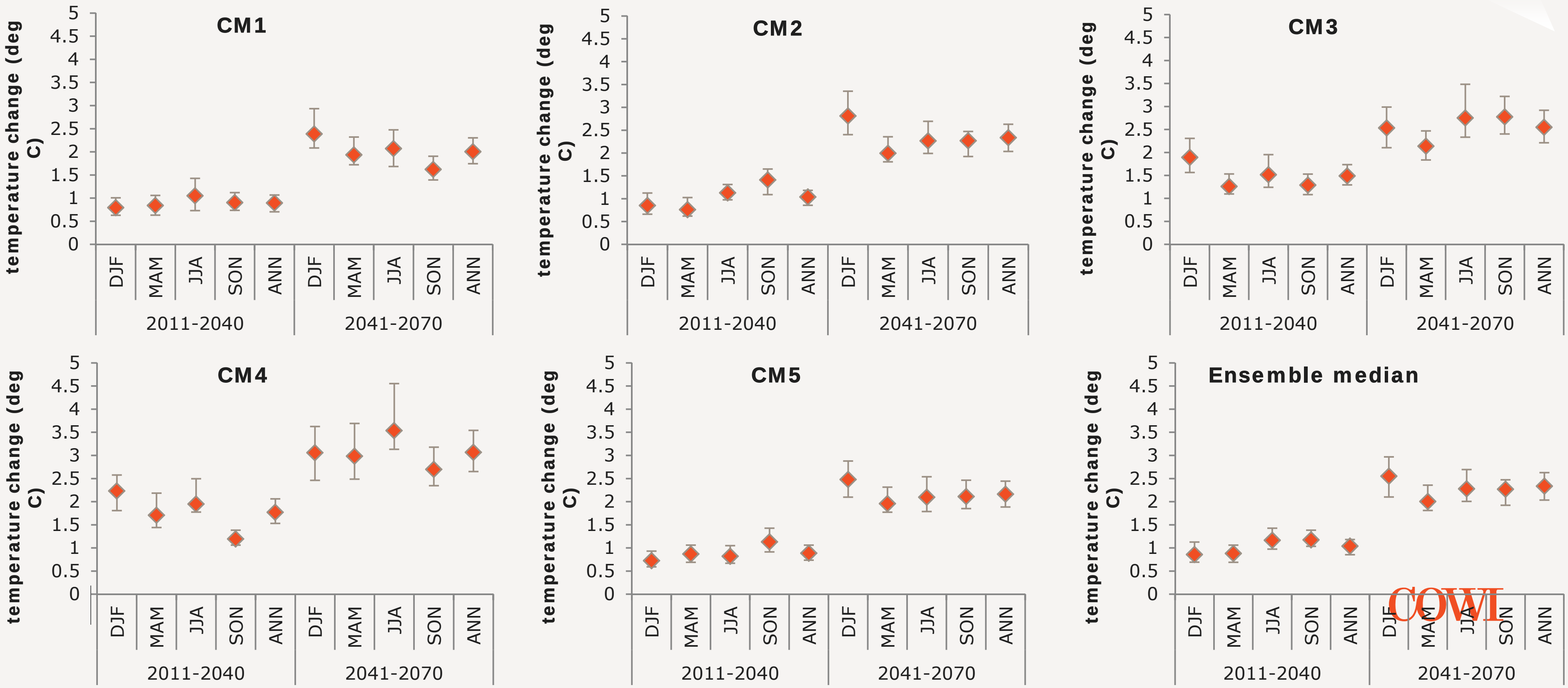
  - annual change (ANN)
  - winter: December, January and February (DJF)
  - spring: March, April and May (MAM)
  - summer: June, July and August (JJA)
  - autumn: September, October and November (SON)

Climate scenarios

- Ensemble of 5 GCM/RCM outputs for A1B IPCC/SRES scenario

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

Temperature scenarios



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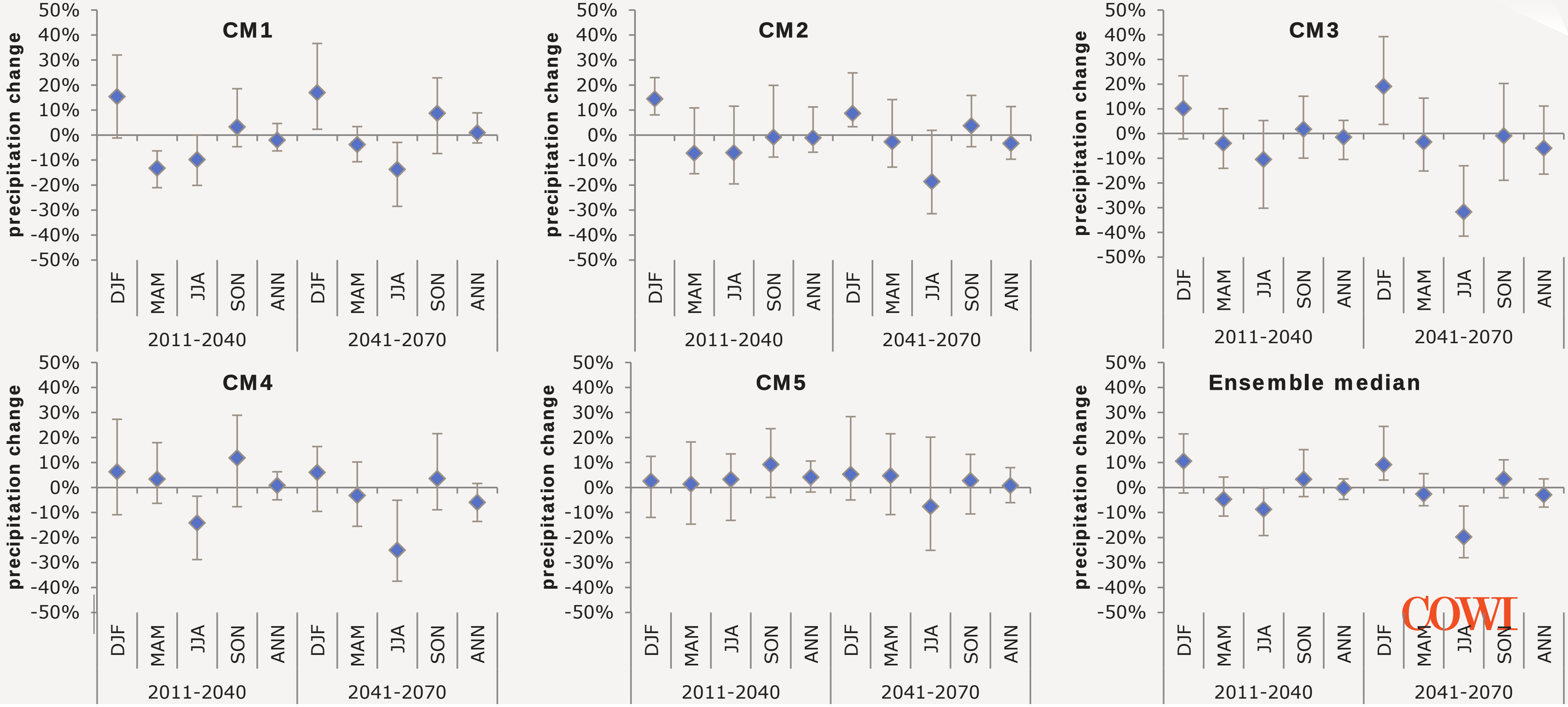
Precipitation scenarios



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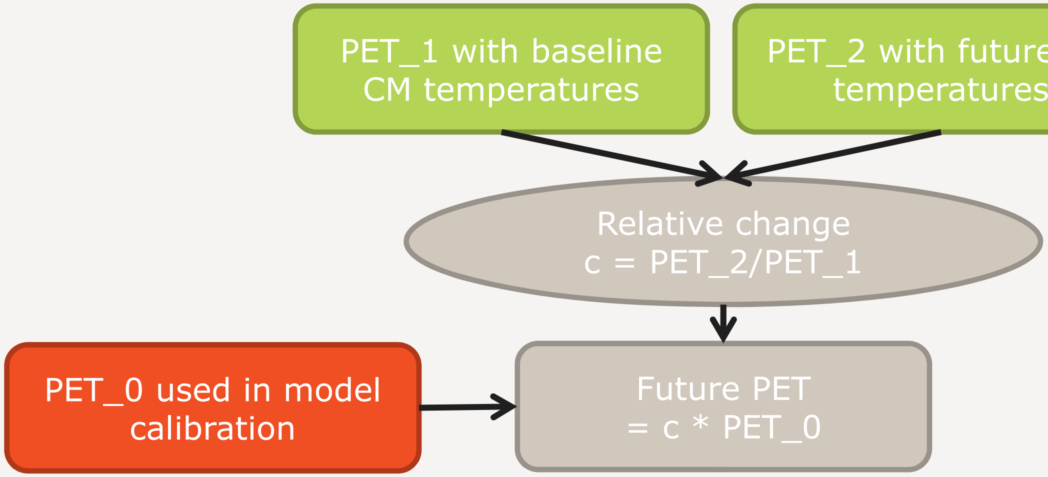
Scenarios for potential evapotranspiration

› Based on temperature scenarios and the Hargreaves equation for PET

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



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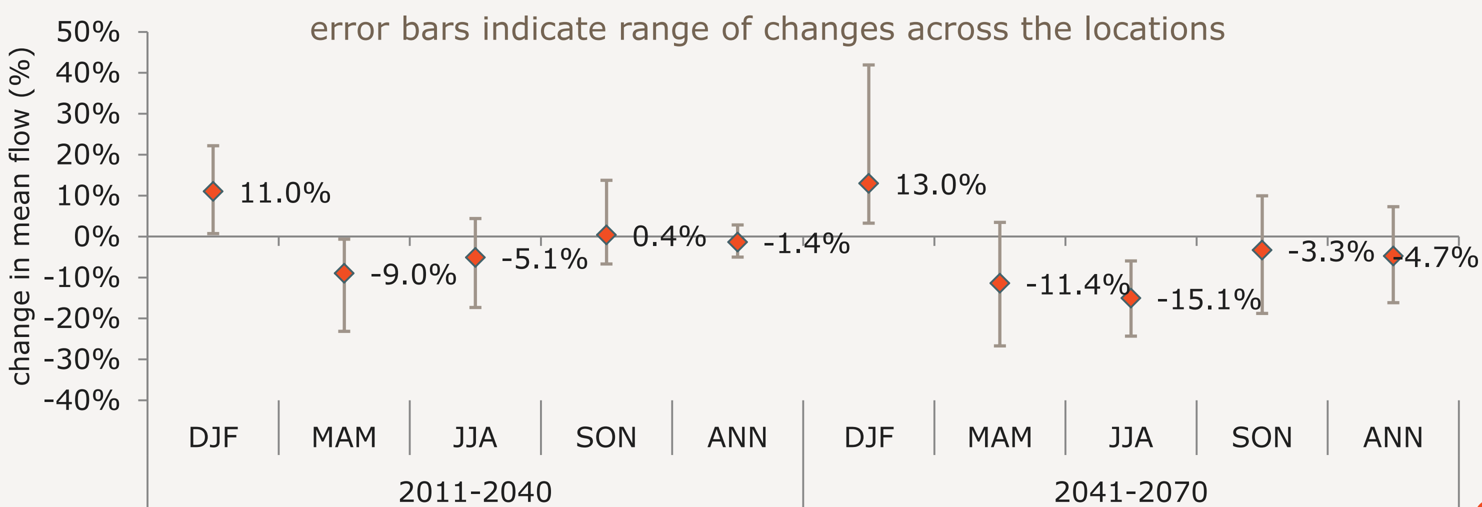
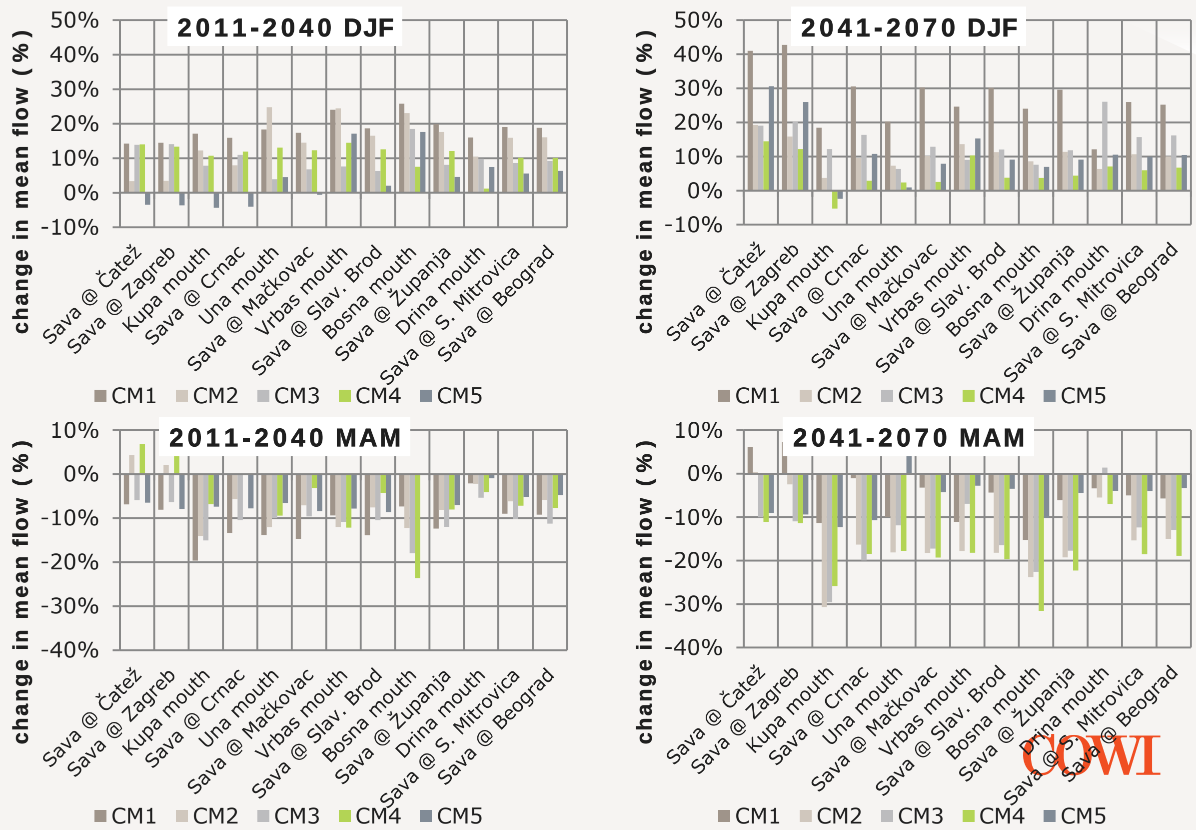
Simulations with future climate scenarios

› Change in ensemble median values of mean seasonal and annual runoff, averaged over 50 locations in the basin



Simulations with future climate scenarios

› Change in mean seasonal runoff at selected locations for five climate scenarios



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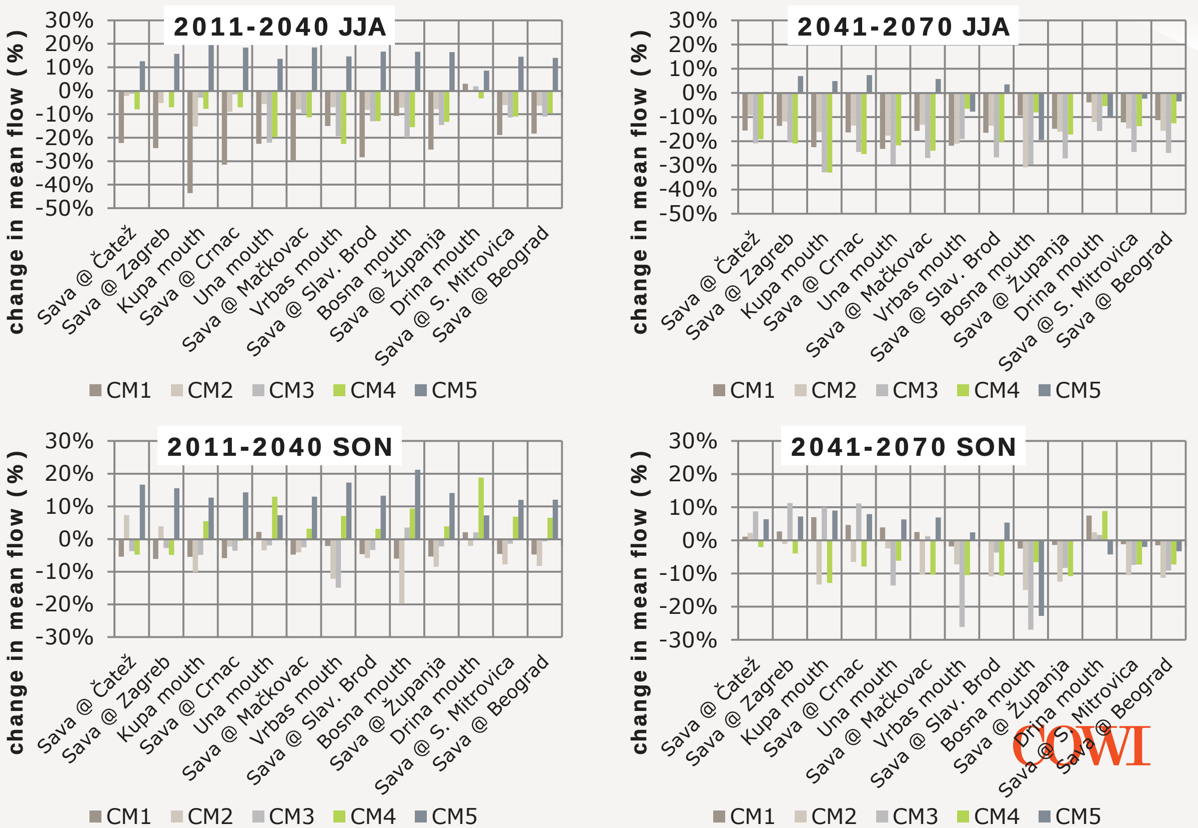

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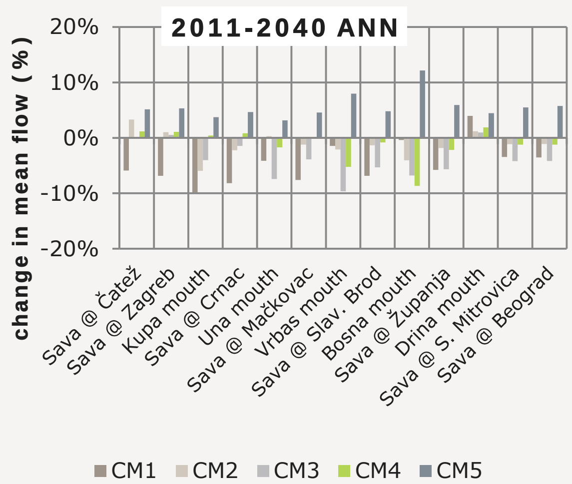

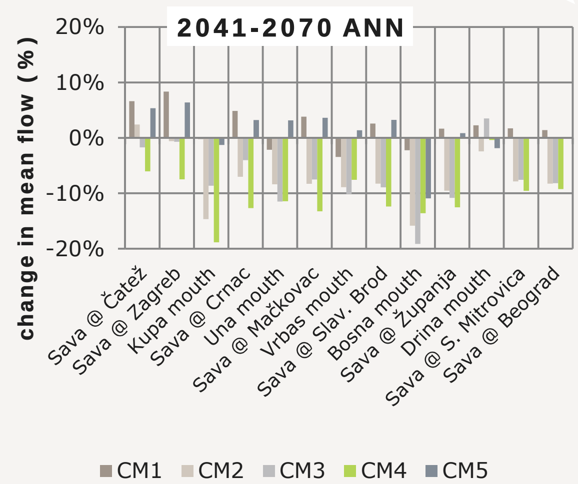

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Sources of uncertainty

- Definition of greenhouse gas emission scenarios (unpredictability of future economic and societal development)
- Climate model structural uncertainty (different GCMs produce different projections for the same emission scenario)
- Downscaling and bias correction of GCM outputs
- Hydrological model structure and parameters uncertainty

- Record extension

CC Impacts on Hydropower

Hydropower: Indicators of CC

- **Mean runoff** at specific dam profiles: a significant change will affect production in the same direction;
- **Intra-annual runoff variation** (duration curves) at the dam profile: a change will affect the change in total volume used for production and in the same manner production by itself;
- **Evaporation** affects volume of available water for production.

Hydropower: vulnerability vs HPP characteristics

Climate parameter	Climate parameter change	HPP type			Reservoir area:volume ratio		Reservoir size	
		Reservoir type	Run-of-river	Pumped storage	High	Low	Large	Small
River runoff	Increase	bigger increase	smaller increase	N/A	N/A	N/A	bigger increase	bigger increase
	Decrease	smaller decrease	bigger decrease	N/A	N/A	N/A	smaller decrease	smaller decrease
Temporal variability	Flood	smaller decrease	bigger decrease	N/A	N/A	N/A	smaller decrease	bigger decrease
	Drought	smaller decrease	bigger decrease	N/A	N/A	N/A	smaller decrease	bigger decrease
	Seasonal offset	smaller decrease	bigger decrease	N/A	N/A	N/A	smaller decrease	bigger decrease
Evaporation	Increase	bigger decrease	smaller decrease	bigger decrease	bigger decrease	smaller decrease	smaller decrease	bigger decrease
	Decrease	bigger increase	smaller increase	bigger increase	bigger increase	smaller increase	smaller increase	bigger increase

Legend: bigger decrease; smaller decrease; bigger increase; smaller increase

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Hydropower: Case Study

› Power plants used in the case study

Country	HPP	River	Reservoir volume (mil m^3)	Reservoir storage area:volume ratio	Installed capacity [MW]-ref. year 2005	Installed discharge (m^3/s)	Average yearly production (ref. 2005-2007) [GWh/year]	Share in average total energy production on SRB [%]	Share in installed capacity [%]
Slovenia	Blanca	Sava	9.95	0.13	43	500	144	2.2	1.8
Bosnia and Herzegovina	Bočac	Vrbas	52.1	0.045	110	240	308	4.8	4.5
Serbia	Zvornik	Drina	89.0	0.146	96	620	515	8	3.9
	Bajina Bašta	Drina	340	0.036	360	644	1691	26	14.7
Total Sava River Basin 2005					**609 of 2449 in total**		**2658/6445 total**	**41**	**24.9**

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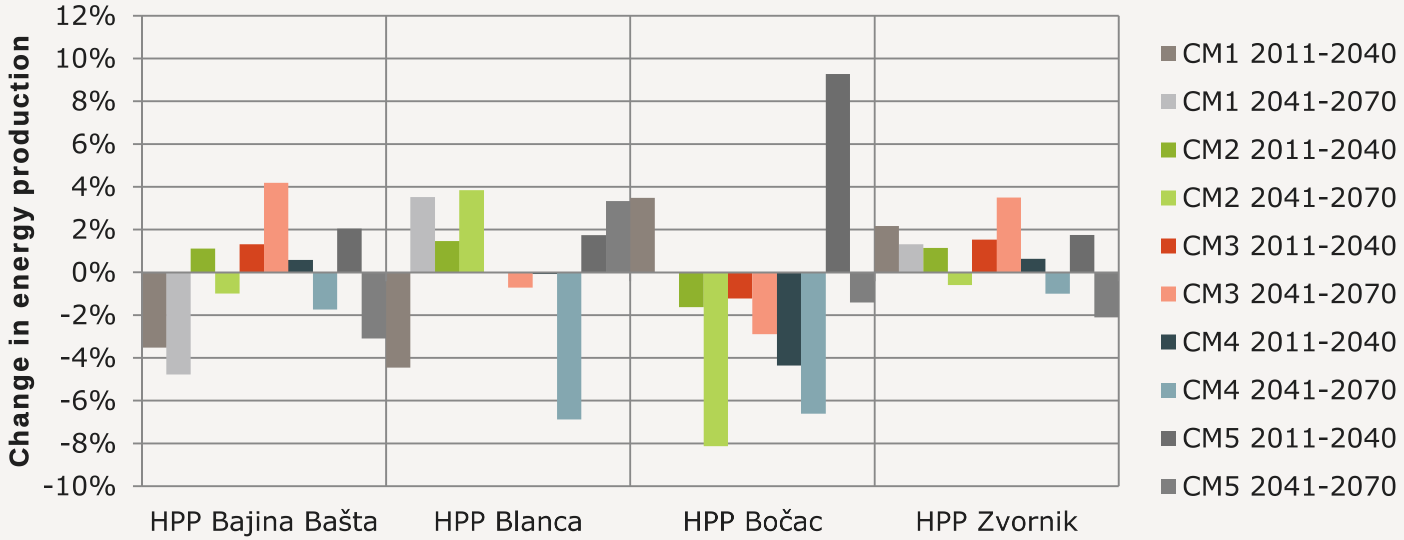
Hydropower: Case Study

Simulated runoff → Energy production → Compare future vs. baseline production

- Daily production for selected HPPs assessed with the following assumptions:
  - Equal generator efficiency coefficient for all HPPs (0.95);
  - Assumed efficiency coefficients for turbines: Francis 0.92, Kaplan 0.9;
  - Constant useable head for energy production in each day;
  - All HPPs are the dam type and no flow and head losses in the tunnel or penstock are taken into account.

Hydropower: Case Study

› Change in energy production



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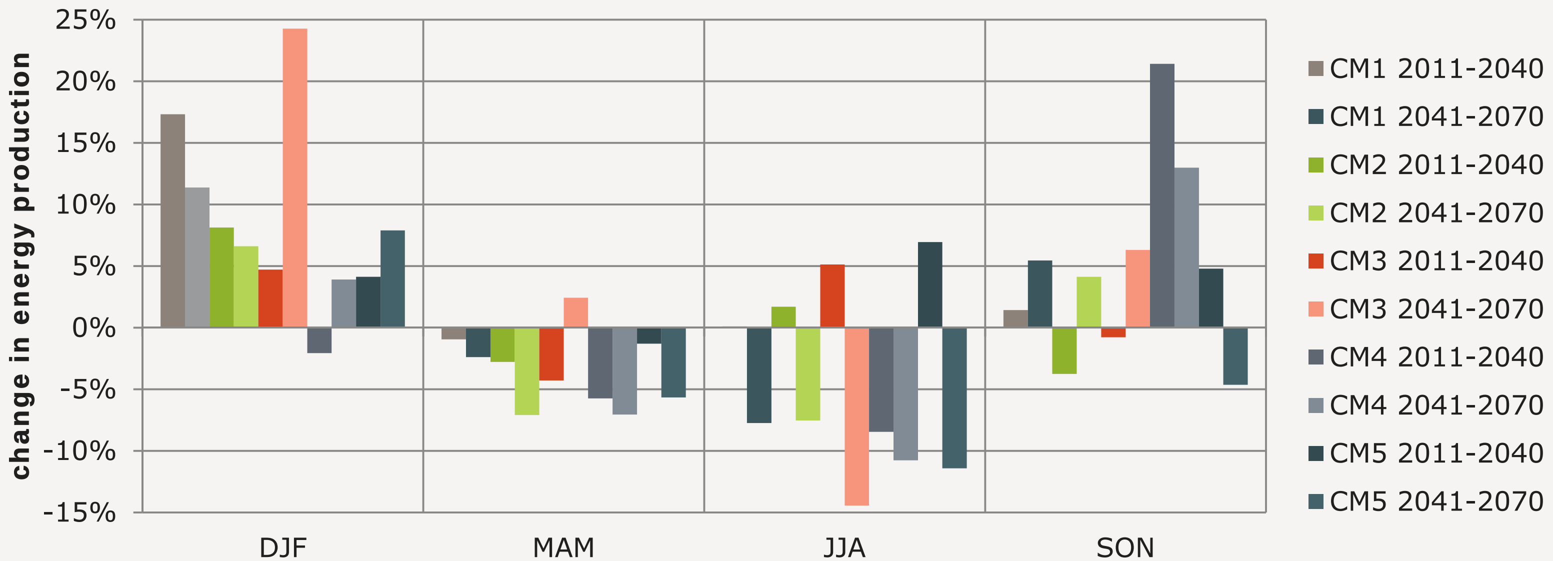
Hydropower: Case Study

› Change in energy production for HPP Bajina Basta by seasons



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Hydropower: Structural Adaptation Measures

- **Enhance dam structural parameters**
  - diverting upstream tributaries to decrease river runoff, new reservoir storage, modifying spillways, changing number and/or types of turbines;
- Build robust dams with **large reservoirs** that can cope with extreme events;
- **Flexible design for installed capacity**;
- Consider structural adaptation effects on **other reservoir purposes** (e.g. irrigation, drinking water supply, tourism, etc.) before reservoir construction or enlargement.

Hydropower: Non Structural Adaptation Measures (1)

- **Reduce energy demand** (public awareness campaigns and training in energy efficiency)
- **Improve hydrological forecasting** to improve operational rules and utilization of HPP capacity
- **Improve O&M practices** at power stations
- **Consider more pumped storage** hydropower technology
- Consider **ecological aspects** (impact of structures on stream morphology, barriers to fish migration, etc.)

Hydropower: Non Structural Adaptation Measures (2)

- Establish a mandatory reporting mechanism for all hydropower companies to provide full operational details on river flow and discharge to **improve future monitoring**
- Regular **review of permitting and licensing of hydropower schemes** (seasonal adjustments to ensure sufficient storage for spring floods and to tie this into the RBMPs)
- Better development/implementation of **strict rules for water withdrawal and discharge**
- Adopt an **integrated water resources and disaster management** approach
- Assess **other renewable energy** production facilities (wind, solar)

CC Impacts on Navigation

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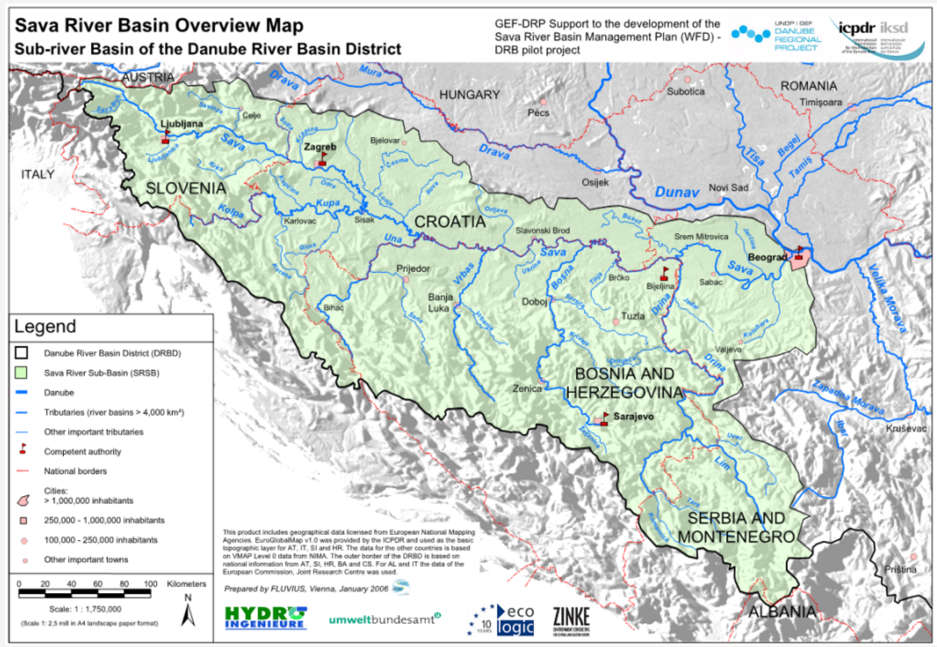
Navigation: Navigable reaches in the SRB

River	Length (in km) from the mouth
Sava	586
Kolubara	5
Drina	15
Bosna	5
Vrbas	3
Una	15
Kupa	5



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Navigation: Standards

- Navigation standards:
  - Navigation with a *reduced* draft must be possible 95% of the time;
  - Navigation with *maximum* draft must be possible 65% of the time.

- Design requirements for an upgrade of Class IV to Class Va

Design parameter	Class IV	Class Va
95% fairway depth (m)	2.3	2.4
waterway width in bends (m)	75	90
horizontal clearance under bridges (m)	45	55

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Navigation: Actual situation on Sava River

- Actual classification: class III and class IV (50%-50%); far from meeting class IV and Va requirements
- Current navigation conditions are poor:
  - limited draft over long periods
  - limited width of the fairway
  - sharp river bends limiting the size of vessels and convoys

- ISRBC aims at rehabilitation and development of the Sava waterway to minimum Class IV waterway and to Class Va on certain sectors

Navigation: Potential CC Impacts

- Climate-related restrictions of inland navigation are due to:
  - low flows (hydrologic regime)
  - high flows (hydrologic regime)
  - river ice (hydrologic regime, water temperatures)
  - visibility – fog (air humidity, air temperatures)
- Key parameter: **water level**
  - related to **flows** and **riverbed morphology**
  - impossible to predict changes in sedimentation processes and morphology

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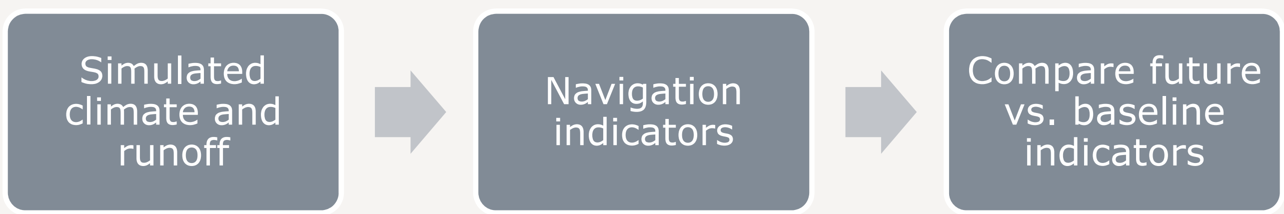
Navigation: Assessment of CC Impacts

- Climate and runoff scenarios for CM1 to CM5 model chains:
  - baseline 1961-1990
  - near future 2011-2040
  - distant future 2014-2070



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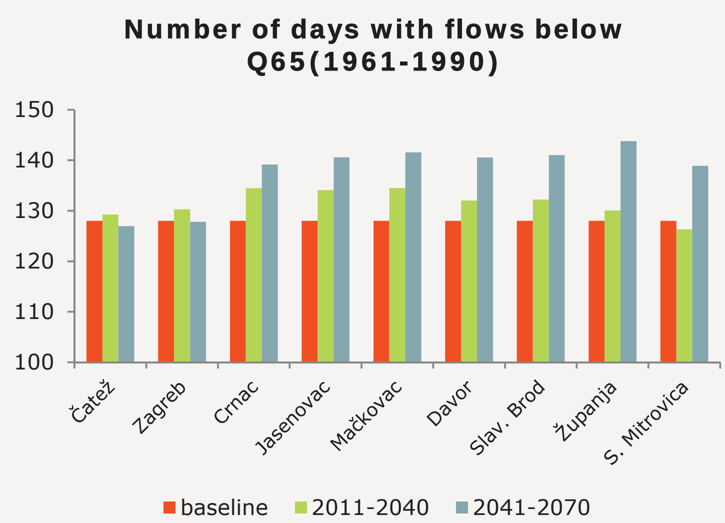
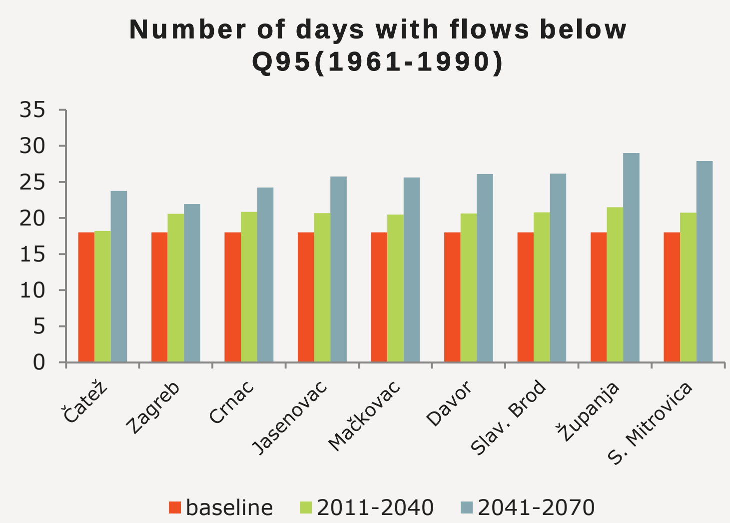
Navigation: Assessment of CC Impacts

› Low flows: increase of number of days below standard levels





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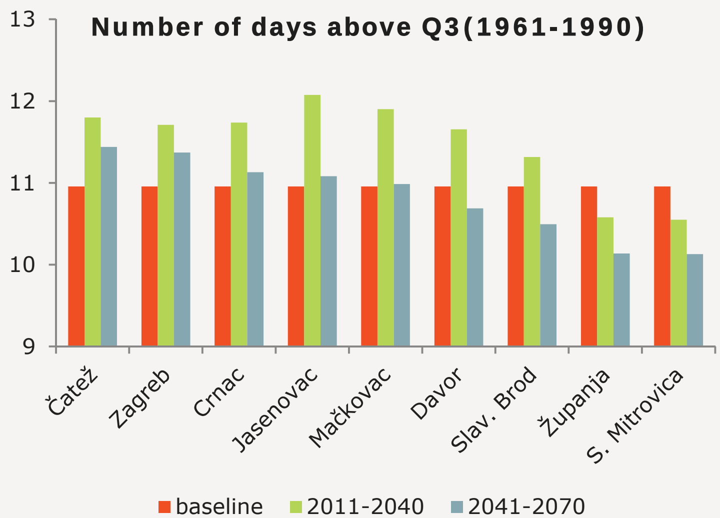
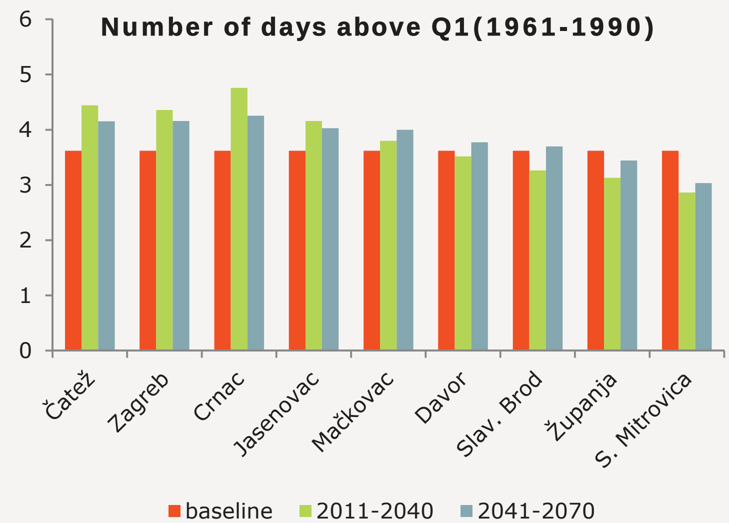
Navigation: Assessment of CC Impacts

- High flows: no change





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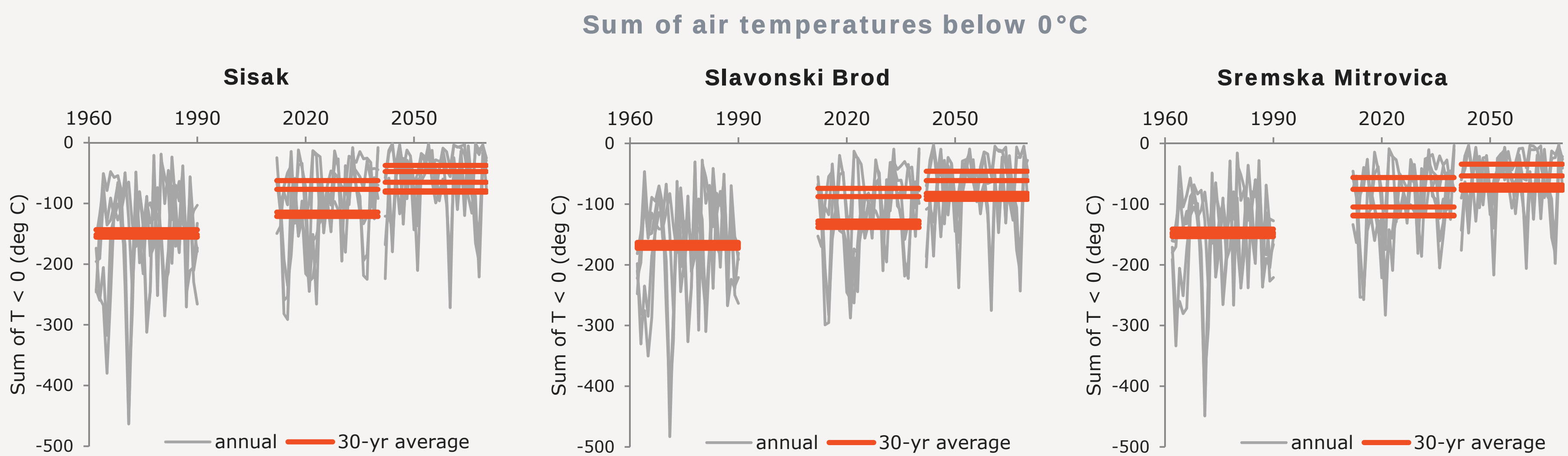
Navigation: Assessment of CC Impacts

› Ice: reduction of days with ice



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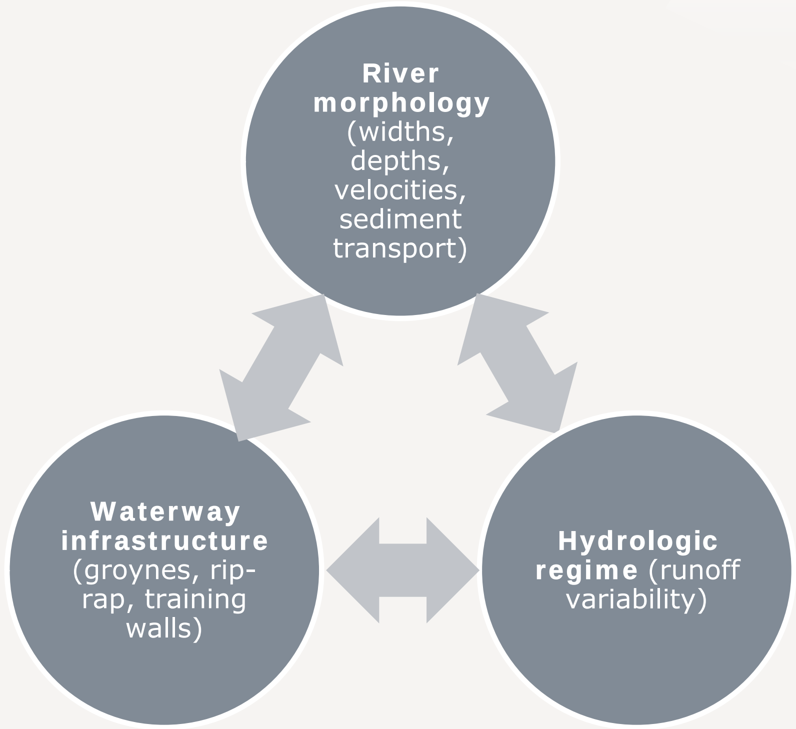
Navigation: Adaptation

› Interconnection of factors relevant for navigation and fairway parameters



adapted from Simoner et al., 2012

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Navigation: Possible adaptation approaches

Area of Intervention	Response (measure)	Additional Information
Waterway design and maintenance	• Creation of water storage • Deepening of channels instead of widening	• (Upstream) reservoirs needed for flood mitigation can also be used to improve navigation
Waterway operation	• Managing water flow • **Improving forecast of water level** • Improved queuing procedures • Implement River Info System (RIS) • Provide up to date electronic charts	• Store water in times of high water flow and release in times of low flow • Better information and decision support systems and automation of queuing will help overcome capacity restriction • RIS in general support safe and efficient navigation • Better information to optimise use of vessels
Transport management	• Chartering additional vessels • Increasing daily operation times • Cooperation with other transport modes • Increasing storage of goods	• Contractual arrangements with road and rail transport companies can be made for time of reduce navigability
Vessel operation	• Using state of the art electronic chart display and info system (ECDIS)	• Provide always up to date information
Vessel design	• Reduction of weight • Increasing width	• Using alternative design/material of install lighter equipment • Wider vessels need less draught

Navigation: Priority Adaptation Measures (1)

- Preparing for adaptation
  - **Better monitoring of water levels**
  - **Improved hydrological forecasting**
- General measures
  - Promoting river transport on Sava will enhance the competitiveness of river transport relative to other modes of transportation.
  - Providing sufficient water depth in times of low water flow
- Ecological measures
  - Definition of navigation fairway conditions according to ecological needs.
  - Combining any increased water storage to support navigation infrastructure with habitat creation initiatives

Navigation: Priority Adaptation Measures (2)

- Management measures
  - Low flows augmentation by better reservoir management
  - Increasing the share of river transport in total transport of goods
  - Look to changes in industrial production leading to lower transport requirements, or shifting transport towards the season with higher river levels
- Technological measures
  - Adaptation / creation / modernisation of waterways and ports
  - Support container shipping with shallow draft vessels
  - Fleet modernisation

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CC Impact on Floods

Floods: Climate change impact assessment

- Separate assessment by University of Ljubljana
  - Ensemble of 16 GCM/RCM outputs for A1B IPCC scenario (ENSEMBLES)
  - E-OBS data 1961-2010 used as reference for the bias correction procedure (1961-1990 for calibration and 1991-2010 for validation)
  - Climate projections for 2011-2040, 2041-2070 and 2071-2100 and change relative to reference period 1971-2000
  - Change estimated for seasonal precipitation and temperature and for **extreme** daily precipitation

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for 2071-2100

Floods: Climate change impact assessment

› Extreme daily precipitation indices

Season	MAM	JJA	SON	DJF
95th percentile of daily seasonal precipitation	+15%	−10% West +10% East	+30%	+30%
long-term mean of maximum 24-hour and 48-hour precipitation	increase	−20% SW +5% NW	increase	increase
daily precipitation of 20-yr and 100-yr return period	increase in central part	increase E	increase	increase in CRO and BiH

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Floods: Climate change impact assessment

- Hydrologic modelling
  - HBV model
  - 13 sub-basins, 12 control stations
  - 32 precipitation stations, 8 temperature + ET stations

- Coarser modelling with an aim to reproduce extreme flood statistics

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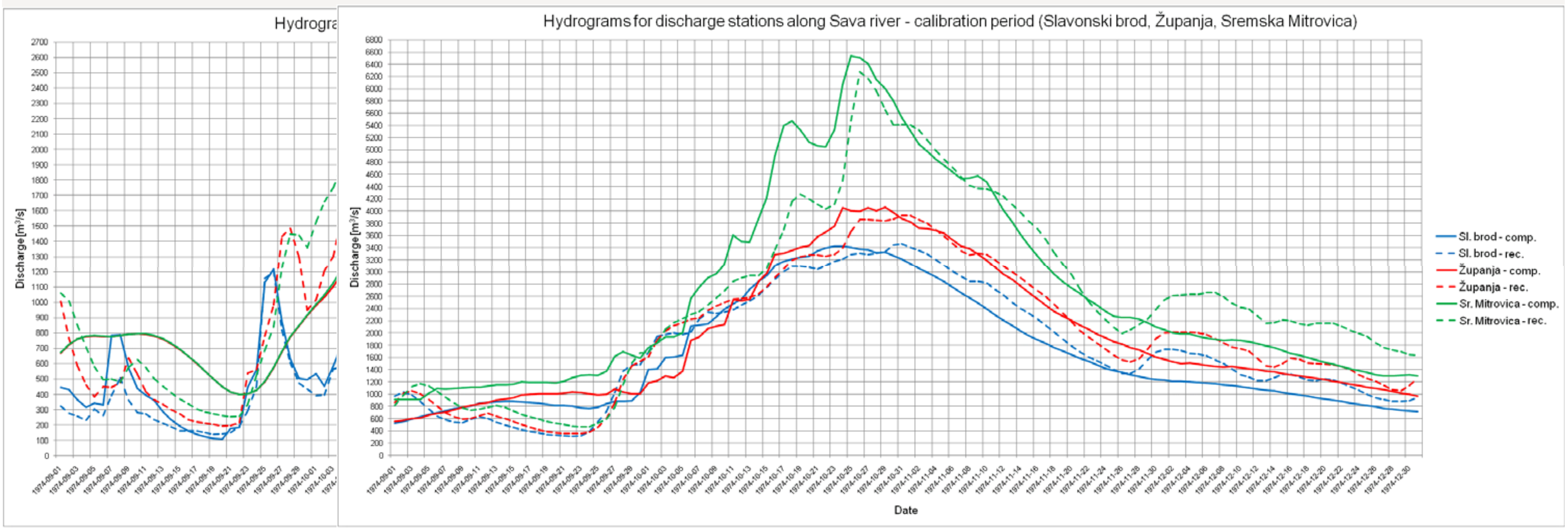
Floods: Climate change impact assessment

- Hydrologic modelling
  - Calibration: 1-Jun-74 to 31-Dec-74, validation 1-Sep-78 to 30-Nov-78



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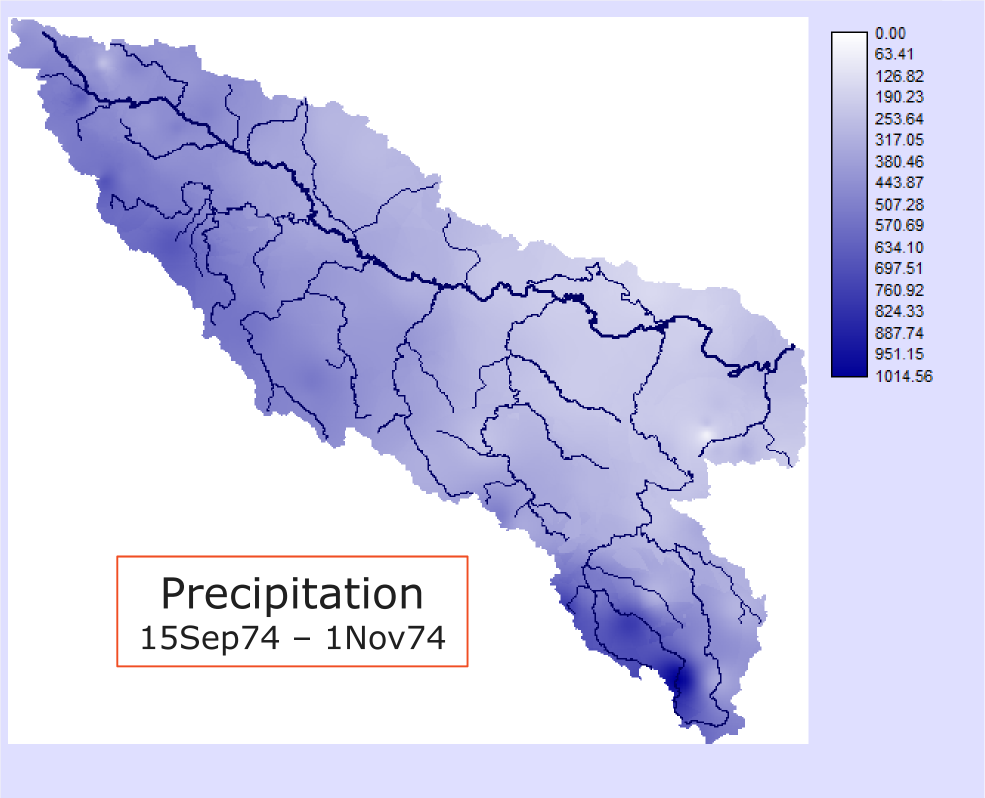
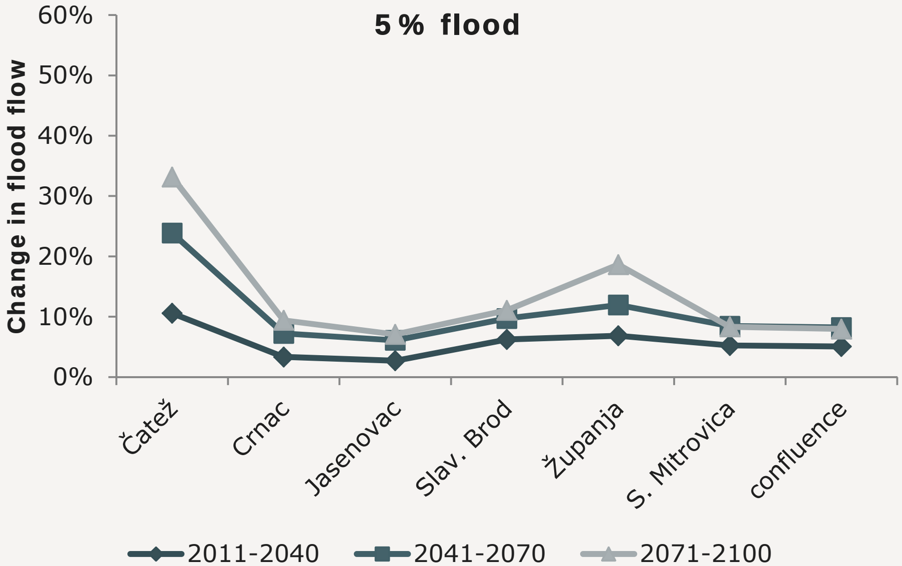
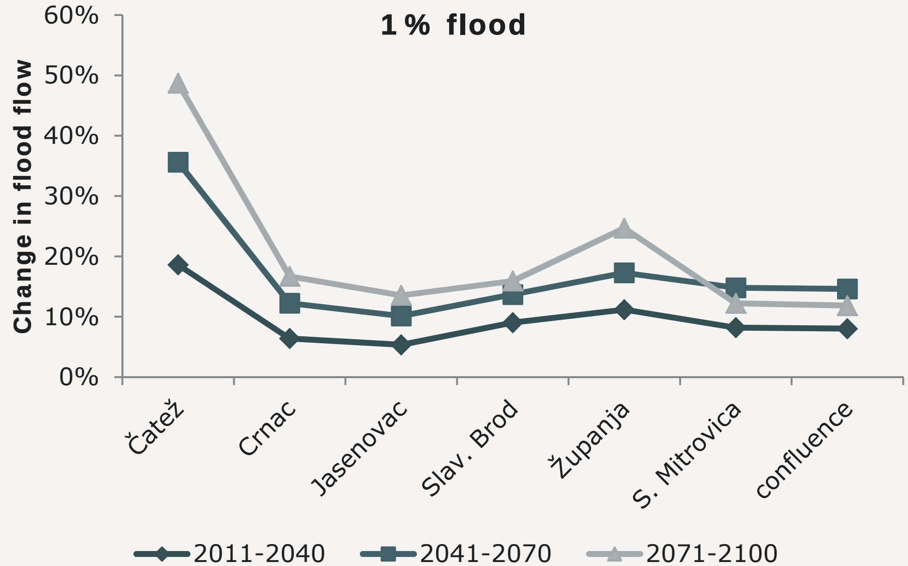


Floods: Hydrologic simulations with future climate

Sava River





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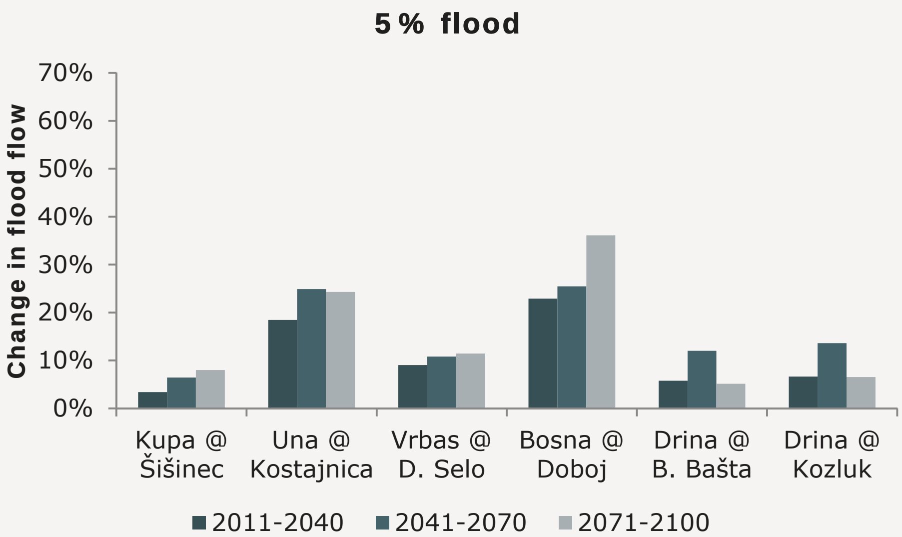
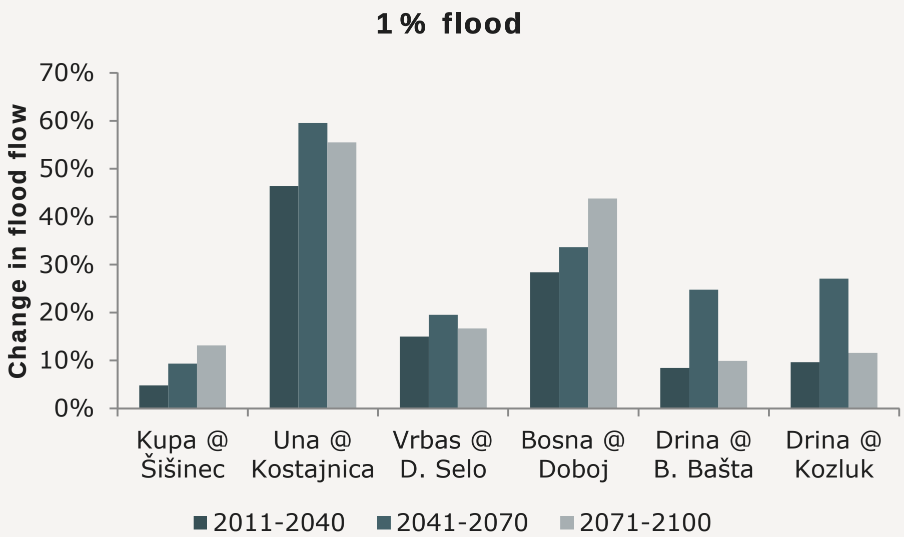
Tributaries





Floods: Climate change impact assessment

- The Central Posavina region is an extremely important flood retention basin which needs to be protected from further land development
- There is clear evidence that reforestation has contributed to a decrease in mean flows in Slovenia by up to 35 % and consequently such actions will decrease flood discharges and mitigate the impact of climate change on floods in the SRB. Further research on reforesting should be undertaken on other areas of the SRB.

Floods: Vulnerability

- 50% of flood prone areas categorized as moderate vulnerability, 25% high and 25% low vulnerability
- The most vulnerable flood prone areas:
  - Zagreb, Belgrade, Semberija and Macva (areas at the Drina River confluence)
  - towns with dense population and economic activities between Zagreb and Slavonski Brod
  - protected natural habitats.
- Historical events (like 1896 on Drina River) and the Probable Maximum Flood event need special treatment
- The question is how will vulnerability change in the future and what will be the change in population density and economy.
- The process of reforestation has a strong impact on the water balance and decrease in discharge.

Floods: Short Term Mitigation Measures

- To be undertaken over the next 3 years at cost of Euro 50 million, including:
  - Development of flood warning system based on institutional strengthening;
  - Determination and survey of permanent geodetic monitoring points (river bed cross sections); surveys to be repeated ideally every 2 years;
  - Hydrologic modelling for predicting flood flows;
  - Hydraulic modelling for calculating water levels; and
  - Maintenance and reconstruction of existing flood protection structures and its mechanical equipment (gates and pumping stations).

Floods: Medium Term Mitigation Measures

- To be undertaken over the next 15 years with cost of Euro 1 billion, including:
  - Institutional strengthening of the organizations responsible for the collection and exchange of hydrological data.
  - Purchase of new state-of-the-art equipment as: meteorological radars, measurement of snow cover water content and soil moisture.
  - Increase of the protection level of major cities along the Sava River: Belgrade, Zagreb and Ljubljana, and for critical infrastructures: highways, railroads, industrial and health care buildings.
  - The protection of other cities and populated areas along the Sava River depending on long-term spatial planning and future development. Zoning of areas should be integrated with spatial planning.

Floods: Long Term Mitigation Measures

- To be undertaken over the next 50 years with a cost of Euro 2 billion, including:
    - Continuation and completion of works in the all of segments.
    - The protection of cities and populated areas along the Sava River depending on long-term spatial planning and future development. Zoning should be integrated with spatial planning.
    - Giving more space to rivers, by deepening and widening of the river channel; increasing the floodplains (flood retention areas) by lowering the surface and the movement of dams; removal of structures that impede water flow; and similar with special attention to river front development.

Thank you for your attention