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Modelling water demand and availability scenarios for current and future land use and climate in the Sava River Basin

Addressing the water-food-energy-ecosystem nexus

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Last but not least it should be mentioned that this work is a collaborative effort within JRC with several groups participating. Some of them are included as co-author, but several others have directly or indirectly contributed as well to this report.

Thanks to you all!

Abstract

The impact of various combinations of land use change, climate change and policy measures on the water-energy-food-environment nexus in the Sava river basin has been evaluated through 170 simulations with the LISFLOOD water resources model for 30-year periods. The LISFLOOD model was first calibrated and validated for the Sava basin against weather and river discharge observations, which were partially obtained from the International Sava River Basin Commission. The goodness-of-fit score obtained for the most downstream station for the calibration period was 0.91, suggesting that the model performance was excellent overall. Also, it was found that the model performance was relatively consistent amongst sub-catchments of the Sava river basin.

For the Sava river basin, we found in this study that more intense irrigated agriculture does have the potential to increase crop yields considerably, but available water resources are not sufficient to realise this. Also, if irrigation would be increased drastically, other sectors would be negatively influenced, such as the energy sector (reduced cooling water availability, potentially less water at times produce hydropower), navigation (more frequent and lower low-flows), and the environment (breaches of environmental or minimum flow conditions).

With respect to most of the water resources indicators, the projected land use changes until 2050 balance each other out, and the net effect is only marginal. Land use projections for Slovenia until 2050 show a substantial increase of forested area at the expense of arable land and semi-natural vegetation. Urban land use is expected to increase by roughly 22% as compared to present day; industrial land use is expected to increase by roughly 27%. For Croatia, forest areas are expected to increase substantially between 2010 and 2050 until 50% of the country's land surface is forested. Areas of arable land and semi-natural vegetation are expected to decrease substantially. Industrial and urban land uses are expected to increase by respectively 22% and 1%.

Effects on water resources would be more significant with increased irrigation to increase the crop yield of e.g maize. This would lead to an increase in water demand from 2216 Mm3/year to 3337 Mm3/year. Overall water demand in the Sava basin would further increase to around 6000 Mm3/year if we combine both increased irrigation and climate projections until 2100. The average simulated maize yield could increase from 5.7 tons/ha at present conditions to 9.9 tons/ha in case of increased and optimum irrigation. These substantial increases in irrigation, which would lead to substantial crop yield increases as well, would lead to water scarcity in parts of the Sava basin. Also, there just is not sufficient water to irrigate all areas which are water-limited for crop growth.

Existing irrigation plans and irrigating the areas which were previously equipped for irrigation (according to FAO) seems more feasible from a water resources perspective.

Flood peaks are projected to remain unchanged as a consequence of projected land use changes until 2050 for the Sava basin. However, with climate change projections we do simulate an overall increase in the flood peaks with 13% for the 2011-2040 period and a 23% increase for the 2071-2100 period.

River low-flows decrease moderately for the 2011-2040 scenarios. For the end of the century 2071-2100, lowflow values are projected to moderately increase as compared to the control 1981-2010 climate. Excessive irrigation would result in a severe decrease of the lowflow discharges with 50-60%. As for ecological flows, similar observations can be made.

Navigation in the main Sava river may be affected by these trends.

Water availability for energy production - hydropower and cooling water for thermal and nuclear power stations – is projected to decrease by an average of 3.3% for 2030 under RCP4.5, whereas RCP8.5 would result in a 1.3% increase. End of the century simulations yield a 17.6% higher Q50 for RCP4.5 and 23.1% higher for RCP8.5. Excessive irrigation could affect the water availability for power production, especially for cooling thermal power stations. Hydropower reservoirs could be turned into multi-functional reservoirs, also serving downstream irrigation needs and flood control, and thus serve multiple purposes.

Soil water stress conditions, which would potentially reduce agricultural crop yields, are especially affecting the lower parts of Bosnia-Herzegovina, Croatia and Serbia under current climate. Climate impact simulations show an increase of soil water stress of 9% for 2030. For the end of the century, RCP4.5 shows a 1% increase, whereas RCP8.5 shows a 7% increase in soil water stress. This might indicate stronger needs for irrigation in the future to maintain current crop yields.

Our climate impact simulations show a moderate decrease of groundwater resources for Slovenia and the higher parts of Croatia and Bosnia Herzegovina until 2030. For the end of the century runs we observe increases in groundwater resources. Increased irrigation practices would seriously reduce groundwater resources again. Also, if relatively more groundwater is used for irrigation replacing surface water, groundwater resources decrease as well.

Feedback of Sava River Basin Commission experts has been taken into account and the suggested improvements will be used in the forthcoming Danube Water Nexus report.

1. Introduction and aim of the research

1.1 Policy context and background

The Joint Research Centre (JRC) provides scientific support to the European Union Strategy for the Danube Region (EUSDR) in two ways. Firstly, it addresses the scientific needs related to the implementation of the EUSDR and thereby helps decision-makers and other stakeholders to identify the policy needs and actions needed for the implementation of the Strategy. Secondly, it contributes to the reinforcement of ties and cooperation amongst the scientific community of the Danube Region.

The JRC Scientific Support to the Danube Strategy initiative is sub-divided into different flagship clusters and activities. They aim to address the scientific challenges faced by the Danube Region from an integrated and cross-cutting perspective, taking into account the interdependencies between various policy priorities.

Four thematic clusters focus on the key resources of the Danube Region, namely water, land and soils, air, and bioenergy. The four thematic clusters are complemented by three horizontal activities: The Danube Reference Data and Service Infrastructure (DRDSI), Smart Specialisation, and the Danube Innovation Partnership (DIP).

The Danube Water Nexus (DWN) flagship cluster covers various water-related issues such as water availability, water quality, water-related risks and the preservation and restoration of ecosystems and biodiversity. It also aims to analyse the interdependencies of between different water-intensive economic sectors such as agriculture and energy.

Within the Danube Water Nexus a case study is carried out on the Water-Energy-Food-Ecology Nexus within the Sava River Basin. This study has been executed in close collaboration with the UNECE and its partner the Royal Institute of Technology (KTH, Stockholm, Sweden) and the International Sava River Basin Commission (ISRBC).

The Danube Water Nexus further aims to support the International Commission for the Protection of the Danube River (ICPDR) and the International Sava River Basin Commission (ISRBC). Furthermore, the research carried out here aims to provide insight and advice to establish Programs of Measures within the Water Framework Directive (WFD), and the Flood Risk Management Plans of the Floods Directive (FD).

1.2 Objectives

The aim of the JRC Water Nexus study is to examine various water futures in the Sava River Basin.

Climate change and land use changes driven by political, demographical and economic factors will have consequences for the balance between water availability and water demand of various sectors. Further changes in the agriculture and energy sector will also be of influence.

Situations may arise, when agricultural or industrial activities may face water shortages, or that insufficient water is available for hydropower operations or for cooling purposes of other power plants. This balance between availability and demand is studied here, and consequences of potential measures are investigated.

Specific aims of this study are:

- Provide an overview of current water resources and pressures in the Sava River Basin, under current climate and current land use practices
- Evaluate future changes in water demand, water resources and pressures under projected land use changes until 2050
- Evaluate the additional effect of climate change projections for the Sava River Basin on water resources and pressures
- Evaluate the effects of various policy measures on water resources and water availability for the various economic sectors, including the environment, agriculture, energy production and navigation.
- Evaluate the water availability for hydropower and thermal power stations, as well as changes of the water availability due to climate change, land use change, and policy measures.

1.3 The Sava River Basin

The Sava River is the third longest and the largest by discharge tributary of the Danube River. The length of the Sava River from its main source in western Slovenian mountains to its mouth to Danube in Belgrade is about 944 km (source: ISRBC). The Sava river runs through four countries (Slovenia, Croatia, Bosnia and Herzegovina, and Serbia) (Figure 1).

The Sava river basin has a surface area of 97,713 km2 and covers considerable parts of Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and a small part of the Albanian territory (Table 1).

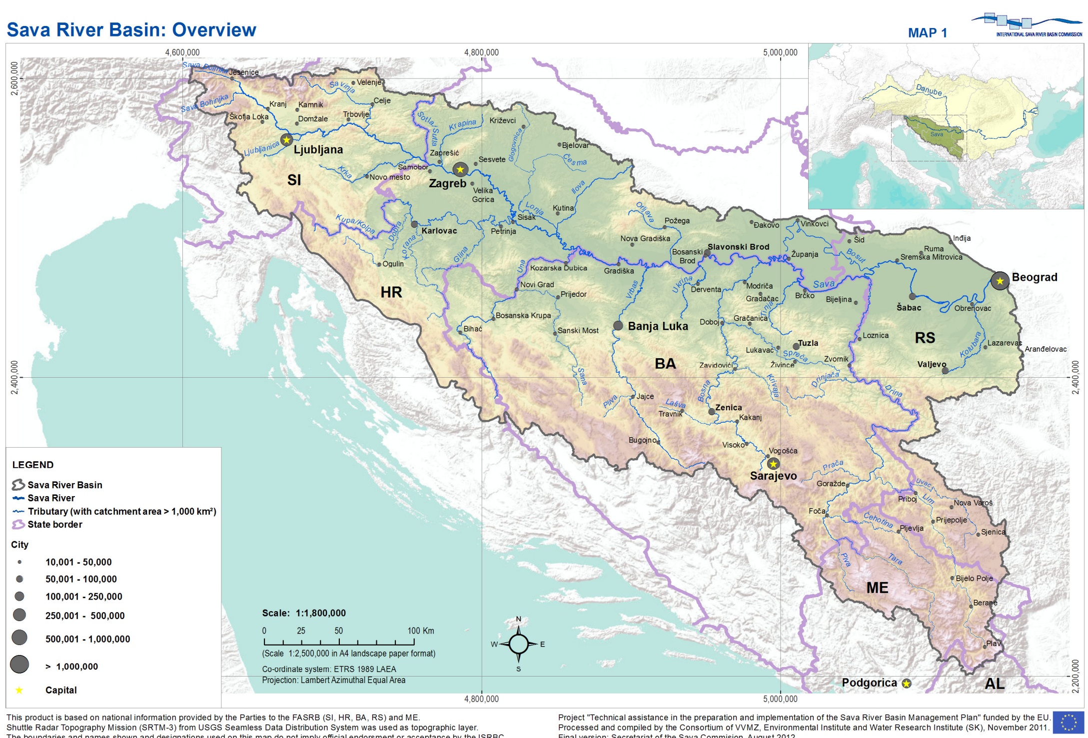

Figure 1 Sava River Basin Overview (Source: International Sava River Basin Commission - ISRBC)

With an average discharge of about 1564 m3/s, the Sava River is the most important Danube tributary with respect to discharge, contributing with almost 25% to the Danube's total discharge at the confluence of the Sava and Danube river in Belgrade (Serbia).

Country	Country share (km²)	Country share (%)	Freshwater (Mm3/year) *(LISFLOOD estimate)*	Water demand (Mm3/year) *(LISFLOOD estimate)*
Slovenia	11,734.8	12.0	10587.7	760.1
Croatia	25,373.5	26.0	17983.3	295.5
Bosnia and Herzegovina	38,349.1	39.2	20462.7	370.6
Serbia	15,147.0	15.5	4207.3	756.7
Montenegro	6,929.8	7.1	4598.5	33.0
Albania	179.0	0.2	NA	NA
Total	**97,713.2**	**100.0**	**57839.5**	**2215.9**

Table 1 Country statistics in the Sava river basin (sources: ISRBC and JRC LISFLOOD model estimates, based on Eurostat current reported water demands)

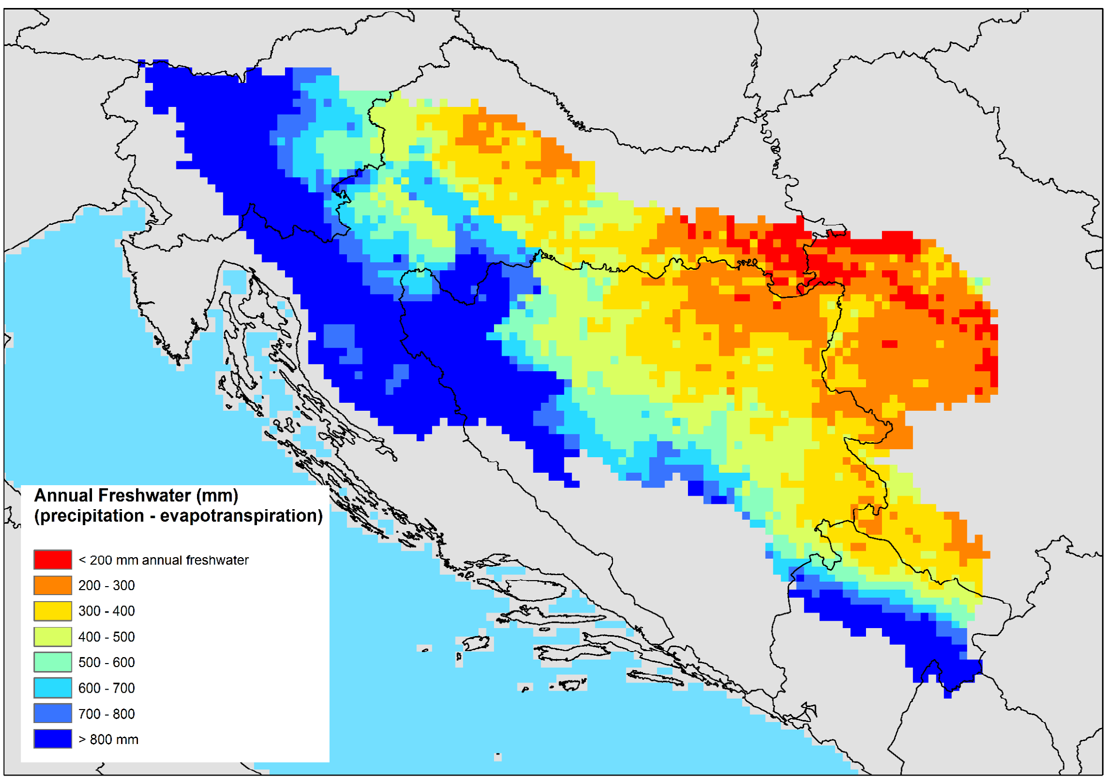

Figure 2 Annual net runoff (precipitation minus evapotranspiration) for the Sava basin, reference period 1990-2013.

2. Modelling methods

This chapter describes the various models that are used in this study. The main water resources calculations are done with the LISFLOOD model. Land use projections are made with the LUISA model, and fed into LISFLOOD with 5-year intervals. The EPIC model was used for the maize crop yield simulations and scenarios.

2.1 The LISFLOOD model

LISFLOOD is a GIS-based spatially-distributed hydrological rainfall-runoff model developed at the JRC. It includes a one-dimensional hydrodynamic channel routing model (De Roo et al., 2000; Van der Knijff et al., 2010; Burek et al., 2013). LISFLOOD is currently used at the JRC for simulating water resources in Europe and Africa. Driven by meteorological forcing data (precipitation, temperature, potential evapotranspiration, and evaporation rates for open water and bare soil surfaces), LISFLOOD calculates a complete water balance at a **daily time step** (for this study) and every grid-cell.

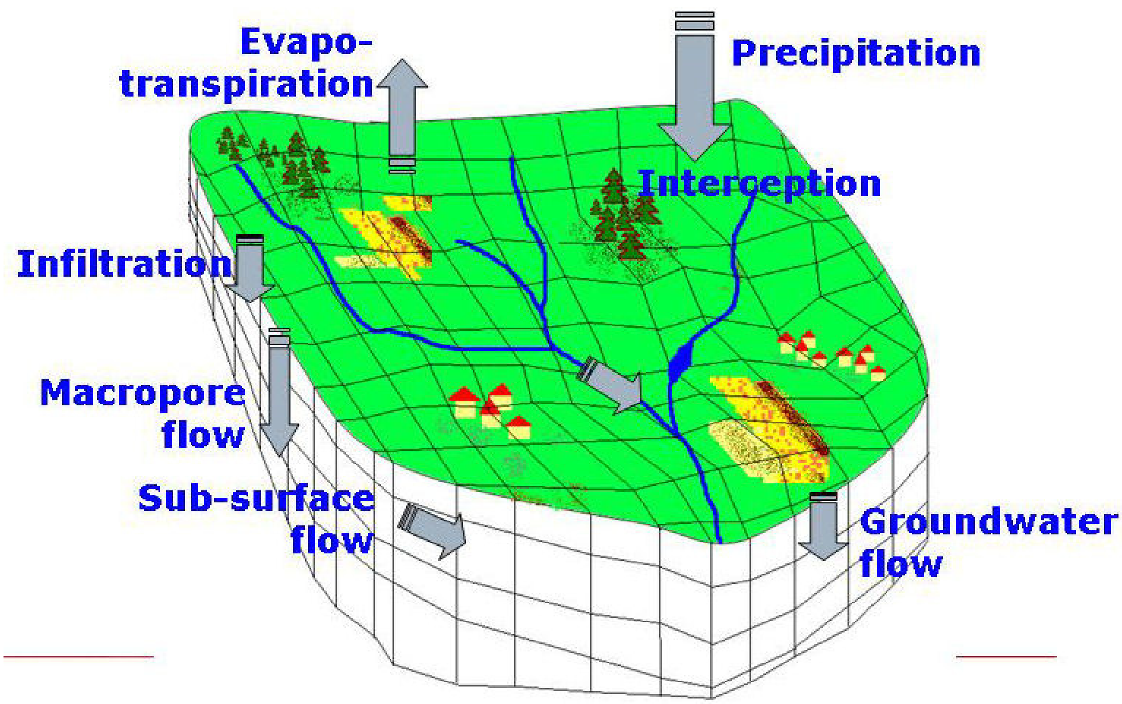

Figure 3 The grid-based LISFLOOD model.

2.1.1 Model design and theory

Processes simulated for each grid cell include snowmelt, soil freezing, surface runoff, infiltration into the soil, preferential flow, redistribution of soil moisture within the soil profile, drainage of water to the groundwater system, groundwater storage, and groundwater base flow. Runoff produced for every grid cell is routed through the river network using a kinematic wave approach.

The model has also options to simulate lakes, reservoirs, and retention polders, which are relevant for low-flow analysis (as they tend to increase low flows) as well as for simulating flood protection during high flows. In the current setting for Europe, 1680 lakes and reservoirs are included. For the global model setup, in total 9300 lakes and reservoirs are included.

A detailed description of the meteorological, soils, vegetation and land use data used for this study can be found in chapter 3 of this report.

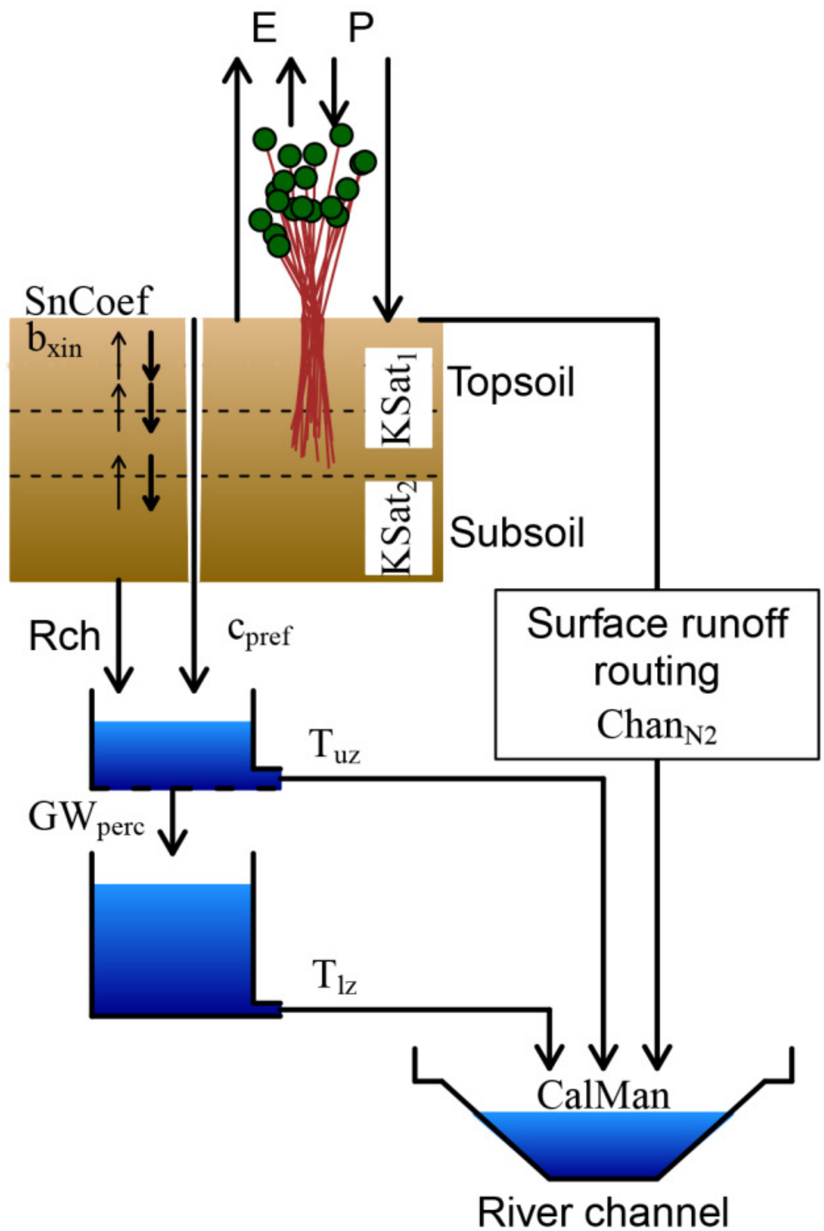

Figure 4 The main structure of the LISFLOOD model for a single grid.

2.1.2 Applications of LISFLOOD

Although this model has been developed with the aim of carrying out operational flood forecasting at the pan-European scale, recent applications demonstrate that it is well suited for assessing droughts and the effects of land-use change and climate change on hydrology (Feyen et al., 2007; Dankers and Feyen, 2009), as well as general water resources (Burek et al, 2012; De Roo et al., 2012). Recently, the model has been applied in Africa (Thiemig et al., 2013) and for global applications (Beck et al., 2015; De Roo et al., 2015).

With a grid size of 5 x 5 km (Europe) and 0.1 x 0.1 degree (global scale), LISFLOOD is developed for simulating medium and large river basins. Satisfactory results can be obtained in basins of a few hundred km2 up to the size of the entire Danube basin. A limiting factor is the availability of good, accurate and homogenous input data for the area of interest, for example soil data, accurate meteorological forcing data or measured discharge data for model calibration. Human influences (e.g. dams, reservoirs, polders, irrigation) also are difficult to quantify, and available data are often scarce. This is an especially important factor for low-flow simulations.

2.1.3 Sub-grid processing

The current pan-European setup of LISFLOOD, which is also used here for the Sava River Basin, uses a 5-km grid and spatially variable input parameters and variables. While the model operates on the relative coarse scale of 5km resolution, subgrid information on land use (100m), soils (1km) and elevation (100m) is used for several sub-grid processes.

This is done to account properly for land-use dynamics, for which also some conceptual changes have been made to render LISFLOOD more land-use sensitive. Combining land-use classes and modelling aggregated classes separately is known as the concept of hydrological response units (HRU). This concept is used in models such as SWAT (Arnold and Fohrer, 2005) and PREVAH (Viviroli et al., 2009) and is now implemented in LISFLOOD on the sub-grid level.

LISFLOOD uses the fractions of landuse within a 5x5km pixel. The model distinguishes for each grid the fraction of forested areas, built up areas, water surface, irrigated land, paddy rice land, and other land use. These fraction maps have been derived from the 100m resolution LUISA land use model output maps. The spatial distribution and frequency of each class is defined as a percentage of the entire (in this case 5 x 5 km) grid. Like this, details of the 100x100m level will remain for a large part. For example changes in urban coverage from 2% to 3% within a 5x5km area are still taken into account.

To address the sub-grid variability in land use, we model the within-grid variability by running the soil modules separately for fractions of land use. Several model processes are simulated seperately:

100m elevation information is used to establish several altitude zones within the 5km grid, important for snow accumulation and snowmelt modelling. Also 100m elevation is used to correct surface temperatures.

1km soils information is used to establish the soil hydraulic parameters at 5km directly.

2.1.4 Water demand, abstraction and consumption

Water demand for livestock, manufacturing industry, energy production (cooling water needs), and public sector water use are input grids for LISFLOOD and in line with the land use data.

Crop irrigation and paddy-rice irrigation needs are simulated dynamically. Crop irrigation is simulated depending on soil moisture and evapotranspiration deficits, thus dynamically responding to changes in weather and climate, during the model runs. For the actual water abstraction, the efficiency of the used irrigation type (sprinkler or drip irrigation) is taken into account, as well as conveyance efficiency.

Paddy rice irrigation is simulated by initial saturation at the start of the growing season, and then assuming a 5cm water ponding in the rice fields, until 3 weeks before harvesting. The water is either drained into the soil or evaporates.

Actual water abstraction is calculated while checking if the demand can actually be met. Specifically, the model takes into account if the water is abstracted from groundwater, lakes or reservoirs, or is available from non-conventional sources, such as desalination plants. The remaining water is abstracted – if a available – from the river surface water. A – user defined - minimum flow threshold is built in in LISFLOOD to prevent discharge going below a certain predefined level, to mimick ecological flow constraints.

Net water consumptions from the various sectors are calculated taking into account for example the type of cooling facility, or using fixed consumption coefficients for e.g. public water use and livestock water use. LISFLOOD takes into account return flow to the river or soil.

For the moment, LISFLOOD contains a fixed water allocation scheme, by which irrigation gets the last priority. User-definable water allocation schemes are being built in at the moment.

2.1.5 Model output and indicators used for this study

The LISFLOOD model can basically output any internal variable used, such as river discharge, soil moisture, snow cover or evapotranspiration. In addition, specific water resource indicators have been developed as well as output options. Output can be time series (hydrographs), summary maps or stacked maps over the complete time period. Below, the main variables and indicators used in this study are listed:

State variable outputs

- Discharge (m3/s) in rivers as maps
- Hydrographs for specific points
- Water volumes in lakes and reservoirs (m3)
- Soil moisture content in any of the three soil layers (m/m) as maps
- Soil moisture at specific location as timeseries
- Groundwater level in lower groundwater zone (LZ) (mm)

Indicator outputs:

- Discharge statistics (percentiles)

- Water Exploitation Index
- Water Dependency Index
- Sectorial water demands, abstractions, and net consumption
- Root Water Stress Indicator
- Environmental flow indicator
- Evaporation deficit or Climatic Water Deficit

2.1.6 Discharge statistical indicators

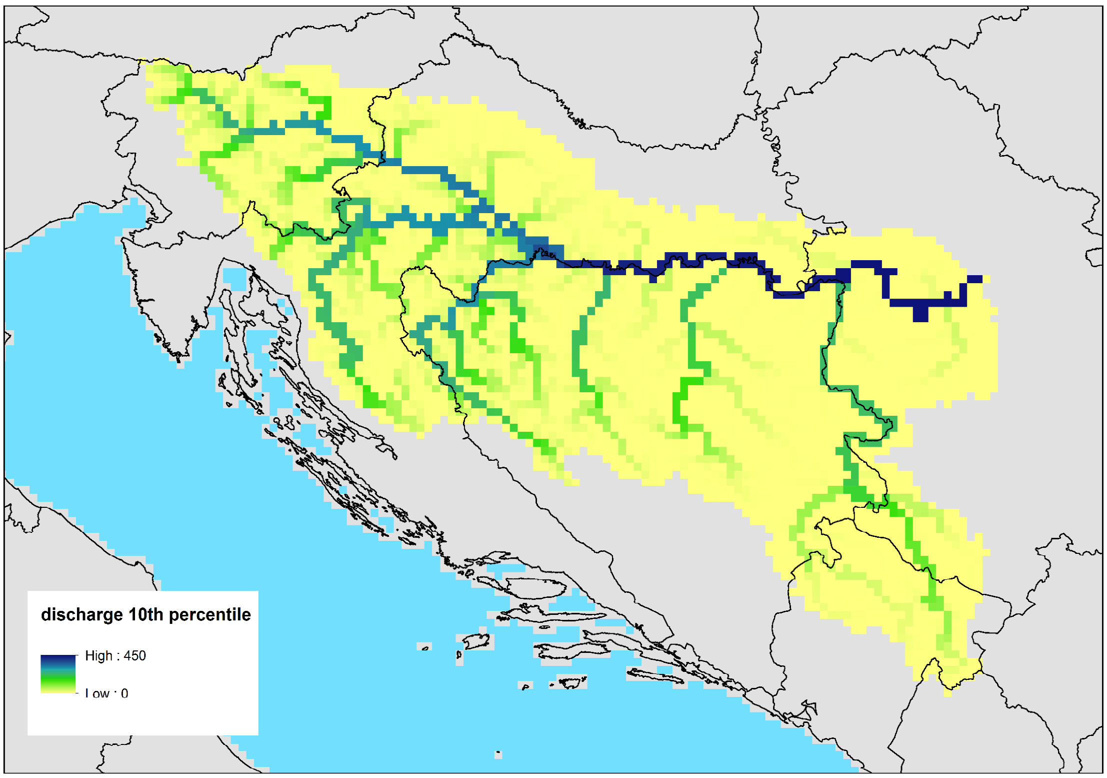

Figure 5 The discharge 10th percentile, simulated with LISFLOOD using observed meteorological data 1990-2013 and present land use

From the simulated daily river discharges at each location and for all the multiple year runs, the following percentiles are calculated:

- Q001: discharge value, for which 0.1% of duration Q is lower, and during 99.9% Q is higher (once in 1000 days low flow)
- Q01: discharge value, for which 1% of duration Q is lower, and during 99% Q is higher (once in 100 days low flow)
- Q05: discharge value, for which 5% of duration Q is lower, and during 95% Q is higher (once in 20 days low flow, ~ 18 days per year low flow)
- Q10: discharge value, for which 10% of duration Q is lower, and during 90% Q is higher
- Q25: 25% quartile, for which 25% of duration Q is lower
- Q50: median discharge value
- Q75: 75% quartile, for which 25% of duration Q is higher

- Q95: discharge value, for which 95% of duration Q is lower, and during 5% Q is higher
- Q99: discharge value, for which 99% of duration Q is lower, and during 1% Q is higher (once in 100 days high flow)
- Q999: discharge value, for which 99.9% of duration Q is lower, and during 0.1% Q is higher (once in 1000 days high flow)

In addition, also return period discharges can be calculated. To calculate those return periods, annual flood peaks from the simulated discharge series were fit to a Gumbel distribution. We have evaluated the HQ05, HQ10, HQ20, HQ50 and HQ100 return period discharge.

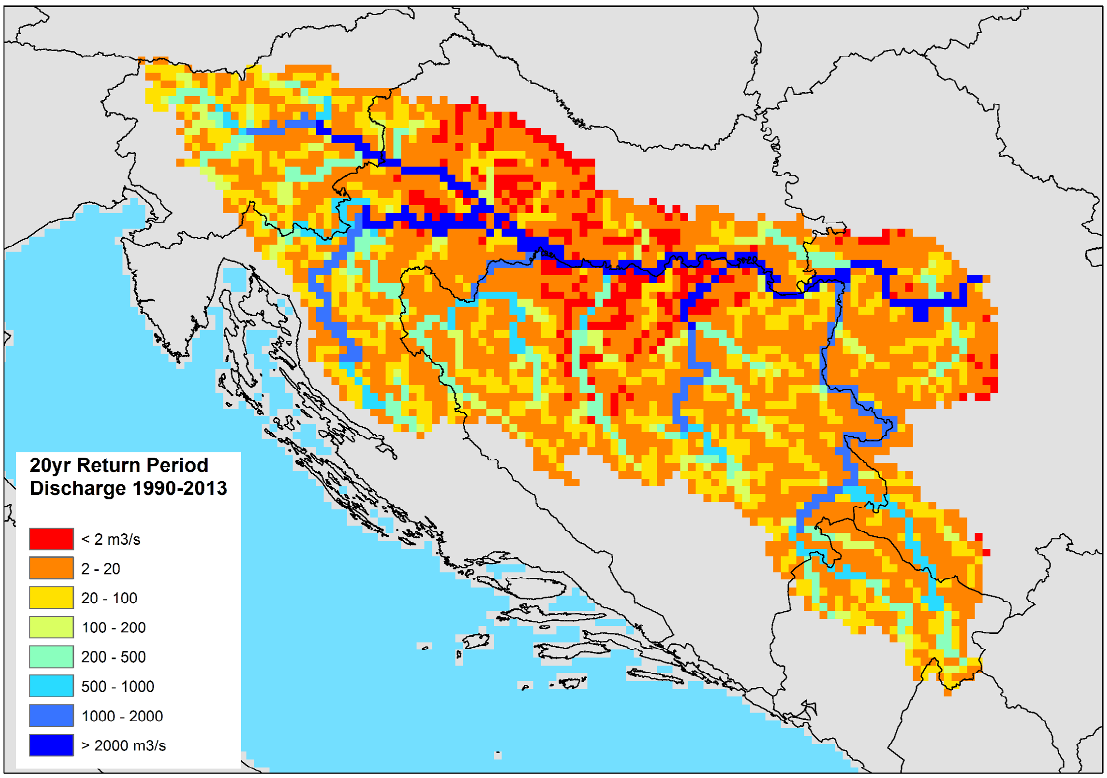

Figure 6 The 20-year return period discharge in the Sava basin, based on simulations with observed weather 1990-2013.

2.1.7 The Water Exploitation Index (WEI and WEI+)

The Water Exploitation Index (WEI) (withdrawal ratio) in a country is defined as the mean annual total abstraction of fresh water divided by the long-term average freshwater resources (EEA indicator fact sheet). It describes how the total water abstraction puts pressure on water resources. Thus it identifies those countries having high abstraction in relation to their resources and therefore are prone to suffer problems of water stress. The long-term average freshwater resource is derived from the long-term average precipitation minus the long-term average evapotranspiration plus the long-term average inflow from neighbouring countries. Values

WEI = Local Water Abstraction / (Local Renewable Freshwater + Upstream inflow)

The related Water Exploitation Index Plus (WEI+) (consumption ratio), is the total consumption divided by the long term freshwater resources of a country. This index highlights those regions with a higher consumptive use of water.

WEI+ = Local Water Consumption / (Local Renewable Freshwater + Upstream inflow)

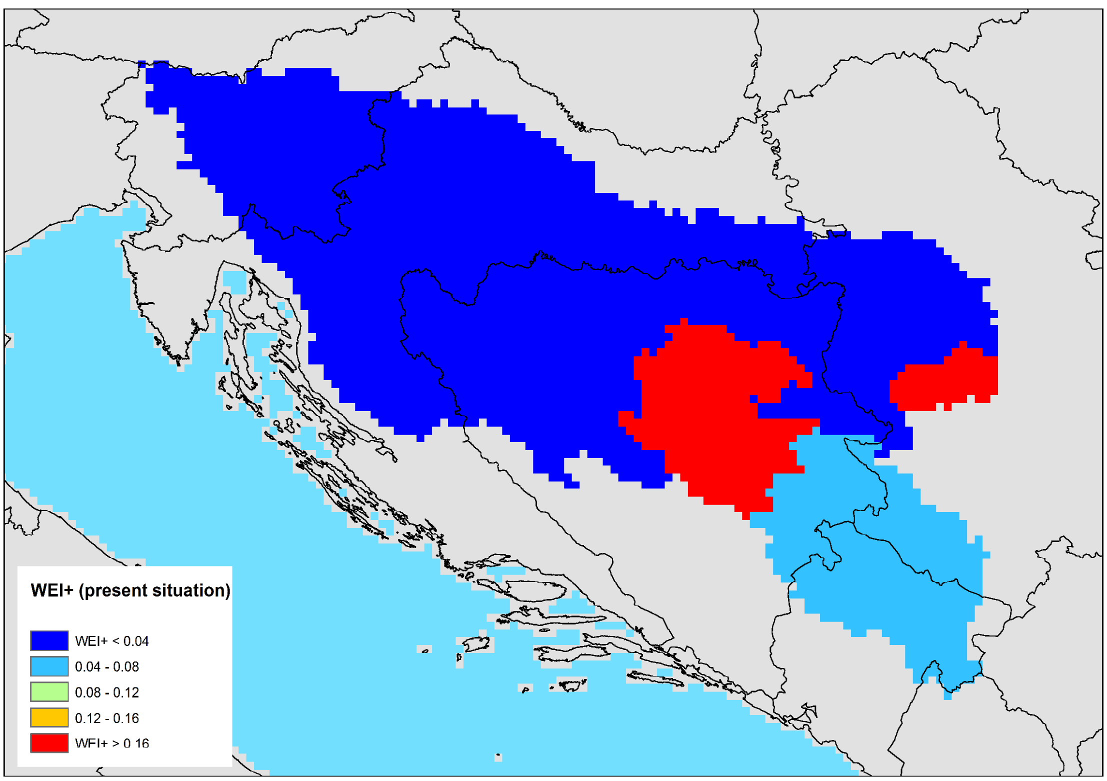

Figure 7 The Water Exploitation Index (WEI+) estimated for the Sava for current conditions

2.1.8 The Water Dependency Index (WDI)

The Water Dependency Index (WDI) (De Roo et al 2015) of a country or a sub-riverbasin in a country is defined as the Local Water Demand that cannot be met by the Local Renewable Water Resources, as a fraction of Upstream Inflowing Water from cross-border river basins, thus:

Water Dependency = (Local Water Demand – Local Renewable Freshwater) / Upstream inflow

Water Dependency Index (WDI) values between 0 and 1 indicate that a region is depending on upstream inflow for a part of their local water needs. Higher values indicate stronger dependencies. WDI values above 1 indicate unsustainable situations, where additional upstream freshwater is also not sufficient to meet local water needs, and likely fossile groundwater or desalination is used to meet the remaining demand. Negative WDI values mean that the amount of locally renewable freshwater is higher than local water demand, and thus that regions or countries are self-sufficient.

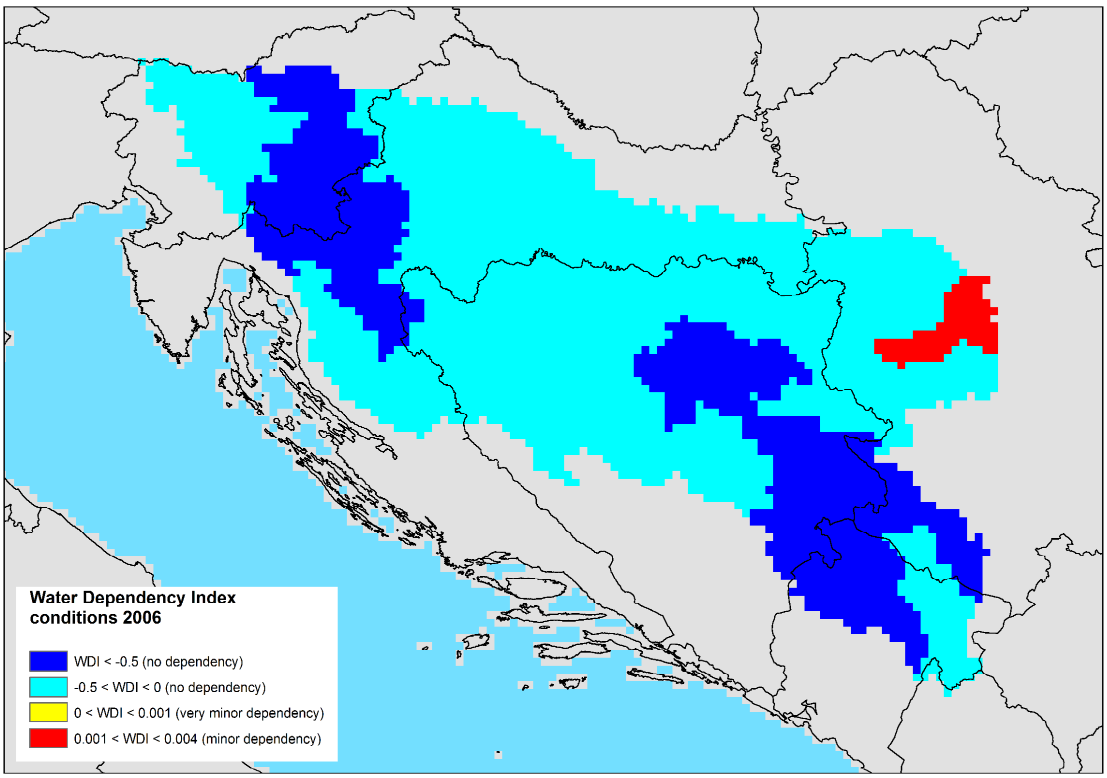

Figure 8 Water Dependency Index for the Sava River Basin sub-regions, estimated using the LISFLOOD model. Only Serbia has a marginal water dependency.

2.1.9 Sectorial water abstraction and consumption

Water demands, abstractions, and consumption are summed up at local and/or regional level and per month and are available as indicator. Amounts are available for irrigation, livestock, energy, industry, and public sector water usage. LISFLOOD distinguishes between abstractions, return flow and net consumption.

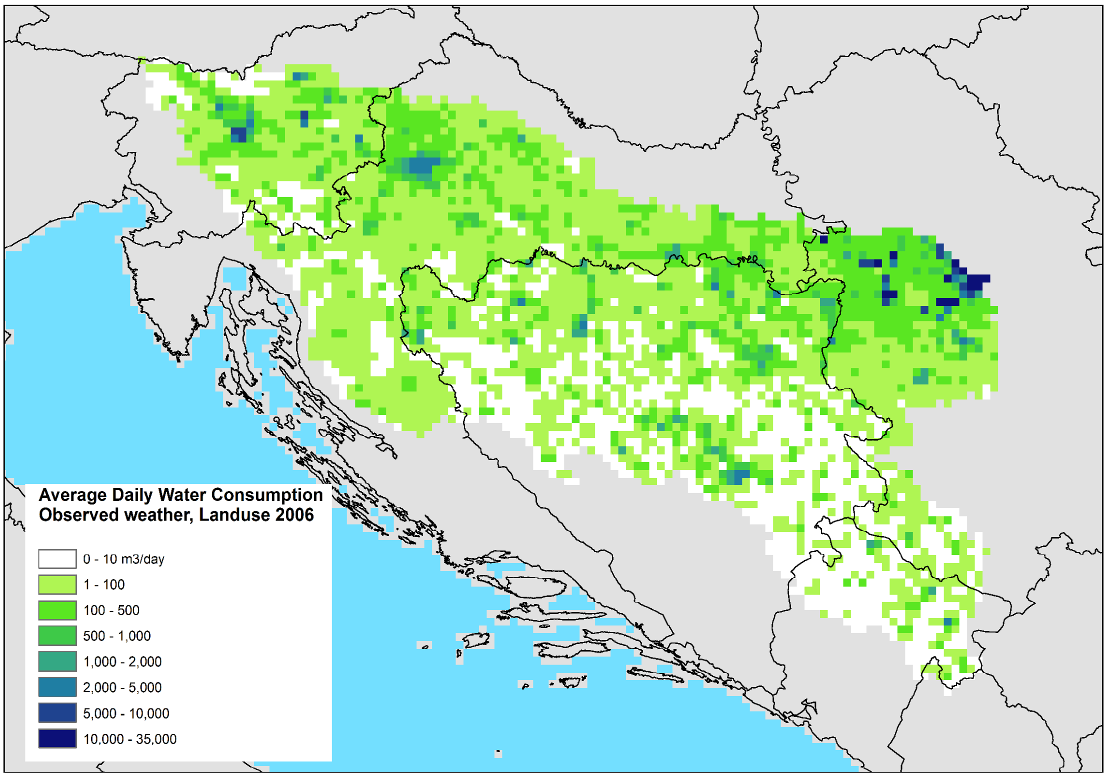

Figure 9 Average Daily Water Consumption (m3 per 25km2 grid), for current climate and landuse.

2.1.10 The Root Water Stress index (RWS)

The Root Water Stress indicator shows the reduction of crop and/or vegetation transpiration due to limited water availability, following the standard FAO method. When the soil is wet, the water is relatively free to move and is easily taken up by the plant roots. In dry soils, the water is strongly bound by capillary and absorptive forces to the soil matrix, and is less easily extracted by the crop.

For soil water limiting conditions RWS lies between 0 and 1. Where there is no soil water stress, RWS equals 1. Both the daily RWS value and the number of days RWS<1 are optional LISFLOOD model output.

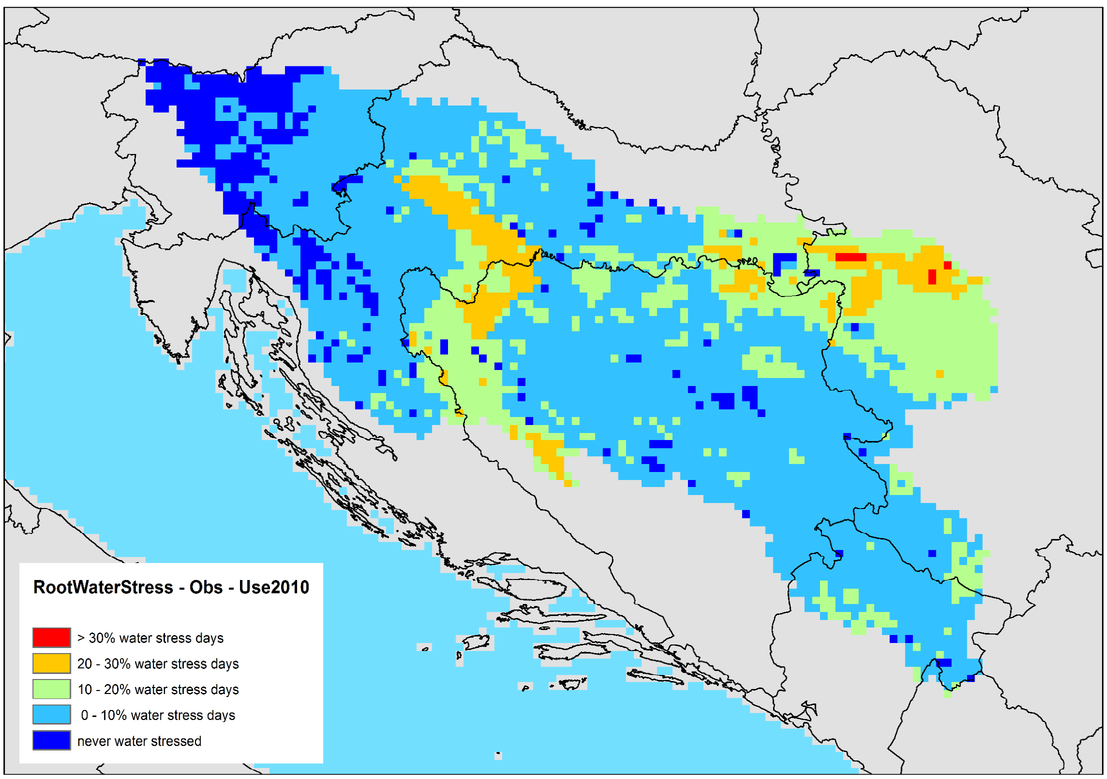

Figure 10 Example of LISFLOOD water stress output: the average number of days per year with water stress, resulting in limited transpiration, resulting in possible yield decreases.

2.1.11 Environmental flow indicator

LISFLOOD has an option to flag individual days and locations where a pre-defined discharge amount is not met, and then counts the total number of days over a defined period that discharge values are below this threshold.

For the moment, pending a better scientific and agreed definition of environmental flow in Europe, the 10% percentile of discharge is taken, calculated over the entire year, so ignoring - for now - seasonal effects or requirements etc.

At present we implement witihin the LISFLOOD model an option where abstraction can be limited if e-flow is to be respected, as well as a user-definable water allocation schemes.

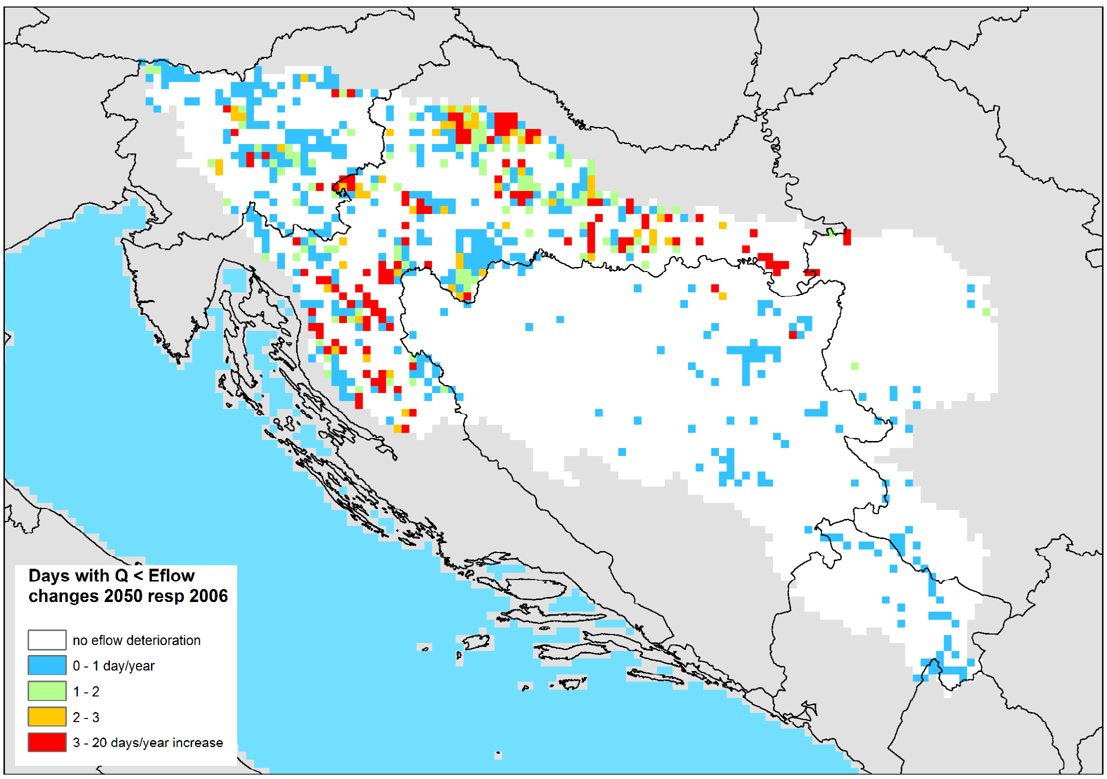

Figure 11 Changes in the number of days per year that the Environmental Flow threshold is not met; difference between baseline 2006 scenario and land use 2050 with additional irrigation; note: the current land use change data only cover Slovenia and Croatia(EU28)

2.1.12 The evaporation deficit or climatic water deficit

The term climatic water deficit defined by Stephenson (1998) is quantified as the amount of water by which potential evapotranspiration (PET) exceeds actual evapotranspiration (AET). This term effectively integrates the combined effects of solar radiation, evapotranspiration, and air temperature given available soil moisture. Climatic water deficit can be thought of as the amount of additional water that would have evaporated or transpired had it been present in the soils given the temperature forcing. This calculation is an estimate of drought stress on soils and plants, and gives an indication of the climatic pressure on water resources, independent from human influences in the river basin.

The climatic water deficit can also be thought of as a surrogate for water demand based on irrigation needs, and changes in climatic water deficit effectively quantify the supplemental amount of water needed to maintain current vegetation cover, whether natural vegetation or agricultural crops.

Within the LISFLOOD model, the climatic water deficit is indeed used as an estimate for irrigation water needs as well.

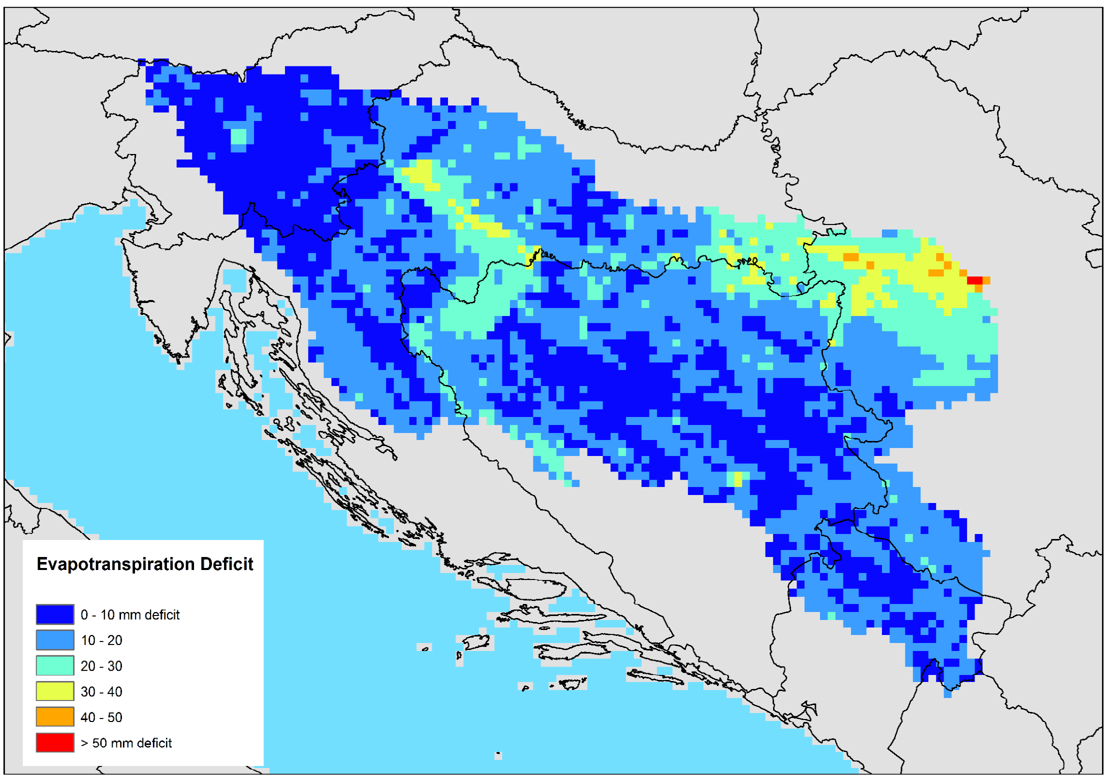

Figure 12 Monthly average climatic water deficit (mm), estimated by LISFLOOD using 1990-2013 observed weather data.

2.2 The LISFLOOD model calibration procedure

LISFLOOD was calibrated to improve the response behavior of the model. For the calibration we used as objective function the Kling-Gupta Efficiency (KGE; Kling et al., 2012) computed between simulated and observe daily Q. We used the KGE, rather than the more widely used Nash and Sutcliffe (1970) Efficiency (NSE), because the latter is generally considered to be a weak metric of model performance (e.g., Criss and Winston, 2008). To evaluate the temporal transferability of the calibrated parameter sets, for each station the record of simultaneous forcing and observed Q data was split into a calibration and a validation period. If the record of simultaneous forcing and observed Q data was >10 years long, the second half was used for calibration and the first half for validation. If the record of simultaneous forcing and observed Q data was 5 to 10 years long, the last 5 years were used for calibration and the remainder for validation. If the record of simultaneous forcing and observed Q data was <5 years long, the station was discarded. In total 38 catchments were found to be suitable for calibration.

Evolutionary algorithms have been widely used for the calibration of hydrologic models (Wang, 1997; Maier et al., 2014). The (μ+λ) evolutionary algorithm was used to calibrate LISFLOOD against daily observed Q for the calibration period. The algorithm was implemented using the Distributed Evolutionary Algorithms in Python (DEAP) toolkit (Fortin et al., 2012). The population size (μ) was set to 32 and the recombination pool size (λ) to 64. Crossover and mutation probabilities were set to 0.9 and 0.1, respectively. For each generation, λ offspring were produced from the population. Offspring were evaluated, after which the population of the next generation was selected from both offspring and population. The number of generations was limited to 13, as this was found to be sufficient to achieve convergence in most cases. This resulted in 832 model runs and objective-function evaluations per catchment. The calibration of all 38 catchments lasted about 7 days on a workstation equipped with two Intel Xeon E5-2640 CPUs (total 16 cores and 32 threads).

2.3 The LUISA land use model

The future land use projections used in this study are modelled using the JRC platform for `Land-Use-based Integrated Sustainability Assessment' (LUISA). Several scenarios have been modelled using that platform; for this study the results of the 2014 Reference scenario have been provided. For an overview of the Reference Scenario we refer to (Baranzelli, Jacobs-crisioni, et al., 2014). For a complete description of the LUISA modelling platform and its underlying mechanics we refer to (Batista e Silva et al., 2013; Lavalle et al., 2011).

The LUISA platform is developed to satisfy the EC's growing need for an instrument for the ex-ante evaluation of its policies from a holistic perspective; thus, by taking into account the economic, social and environmental effects of those policies. The LUISA platform consists of dynamically interlinked models that are tasked with the computation of regional future land demand, accessibility levels, population distribution, land-use patterns and sustainability-related indicators. Next to a wide range of indicators, key outputs of the LUISA platform are fine resolution maps (100m x 100m grid cells) of accessibility, population densities and land-use patterns for each of the model's time steps covering all 28 EU member states. In this section the land demand and land-use pattern aspects of the model will be briefly described, after which some of the results relevant for this report will be shown.

All results in the LUISA platform are governed by estimates of regional future land demand that are the direct or indirect results of various sectoral models. Those expected regional demands are fed into the LUISA platform with in the case of expected land demand a short bandwidth of acceptable deviations from the input model. These land demands form fixed constraints for the area of land that the population and land-use models in LUISA may assign while running. Relevant regional inputs are Eurostat for population projections (EUROPOP 2011 scenario); GEM-E3 for economic projections; the CAPRI model for projections of agricultural land demand (PRIMESCOR scenario); and UNFCC for projections of changes in forested areas. The latter are based on trends of afforestation/deforestation that are obtained from national counts of forest area as declared to the UNFCC. In some cases additional data are used to obtain land demands from the specialised model outputs. For instance, GEM-E3 delivers estimates of future GDP. Those estimates are translated into expected demand for industrial areas by exploiting data on historical industrial land-use intensities. The mechanisms to obtain land-use demands from various specialised models are described in (Baranzelli, Castillo, et al., 2014)(Baranzelli, Jacobs-crisioni, et al., 2014).

As noted before the input population numbers and land demands are constraints for the LUISA modules that manage the spatial distribution of people and land-use patterns. Because in particular land-use patterns are relevant for the subject of this report, we will focus on the modelling of those land-use patterns here. For a description of the population allocation module we refer to (Batista e Silva et al., 2013). The land-use allocation module distributes discrete land-use classes by simulating competition between the modelled land-uses. Its core was initially based on the Land Use Scanner (Hilferink and Rietveld, 1999)(Koomen et al., 2011), CLUE and Dyna-CLUE (Verburg and Overmars, 2009; Verburg et al., 2002) land-use models (Verburg and Overmars, 2009; Verburg et al., 2002), but has since been substantially modified to allow for interactions with the population allocation and accessibility modules. The land-use allocation module assumes that land-uses attempt to achieve most attractive locations through a bidding process. For each land-use, total regional areas are limited by the demand for the land use as well as the supply of land in the region. The attractiveness of locations is defined through potential accessibility, exogenous variables such as slope and distance to roads, neighbourhood relations, expected policy effects and a-priori defined costs involved in the transition from one land use to another.

LISFLOOD (5km resolution) integrates future land-use patterns on a substantially coarser spatial and thematic resolution than the LUISA platform output data (100m resolution). To deal with this resolution difference, LISFLOOD uses the fractions of landuse within a 5x5km pixel. Like this, details of the 100x100m level will remain for a large part. Like this e.g. changes in urban coverage from 2% to 3% within a 5x5km area are still taken into account.

Outcomes of the land use projections for Slovenia and Croatia are presented in chapter 4.

2.4 The EPIC model

The biophysical continuous simulation model EPIC (Williams 1995) integrated with a spatial geodatabase is applied in this analysis to simulate crop growth as affected by agriculture practices and irrigation in particular.

EPIC is a biophysical, continuous, field scale agriculture management model. It simulates crop water requirements and the fate of nutrients and pesticides as affected by farming activities such as the timing of agrochemicals application, tillage, crop rotation, irrigation strategies, etc., while providing at the same time a basic farm economic account. EPIC maintains a daily water balance taking into account runoff, drainage, irrigation and evapotranspiration. Potential crop growth is based on daily heat unit accumulation. The model adjusts the daily potential growth by constraints including the influence of the following limiting factors: nutrients, water, temperature, and aeration. These stresses can impact biomass production, root development and crop yield. A stress is estimated for each of the limiting factors and the actual stress is equal to the minimum stress value. EPIC simulates nitrogen and phosphorus cycles by considering different pools: active organic, stable organic, fresh organic, nitrate and ammonium pools for nitrogen, fresh organic P and stable organic P, labile P, active and inactive mineral pools for phosphorus.

A geodatabase was developed to support the application of EPIC for the entire Europe. The geodatabase includes all the data required for EPIC modelling (meteorological daily data, soil profile data, landuse data with crop distribution and agriculture management data) and all necessary sets of attributes required to simulate different strategies, management and scenarios. The reference spatial resolution for data aggregation is 5km x 5km cells.

With EPIC crop yield can be estimated, as well as (irrigation) water requirements and nutrient fluxes, while changing fertilizer input, climatic inputs and irrigation extent.

3. The data used for this study

This chapter describes the data used for this modelling sources and where they originate from. As much as possible we aimed to use the best locally available data. The Sava Commission was very helpful in providing some of the data. For other data, we have relied on data collected at JRC at pan-European level, as well as some data from FAO-Aquastat.

3.1 Observed meteorological data

The JRC meteorological 5x5 km gridded data from 1990-2013 are used in this modelling study (Ntegeka et al., 2013). This dataset is based on spatial interpolation of various gauging datasets. The variables daily precipitation, daily minimum and maximum temperature, dewpoint temperature, relative humidity, wind speed at 2m, reference evapotranspiration, and evaporation rates for open water and bare soil surfaces are derived from various data sources for the period 1/1/1990 until 31/12/2013. These data sources include the JRC MARS database (http://mars.jrc.ec.europa.eu/mars/), data obtained from MeteoConsult, SYNOP data, as well as data from the European Climate Assessment & Dataset (ECA&D, http://eca.knmi.nl/). This dataset contains more station data then the public available E-obs dataset from KNMI>

All meteorological variables are interpolated on a 5 x 5 km grid using inverse distance weighting with a weight of d-2 and a maximum number of 5 points for the interpolation. Temperature variables are first corrected using the elevation obtained from a DEM with a resolution of 1 x 1 km and using a constant lapse rate of 0.006 (0.002 for dewpoint temperature) and are then interpolated onto the 5 x 5 km grid.

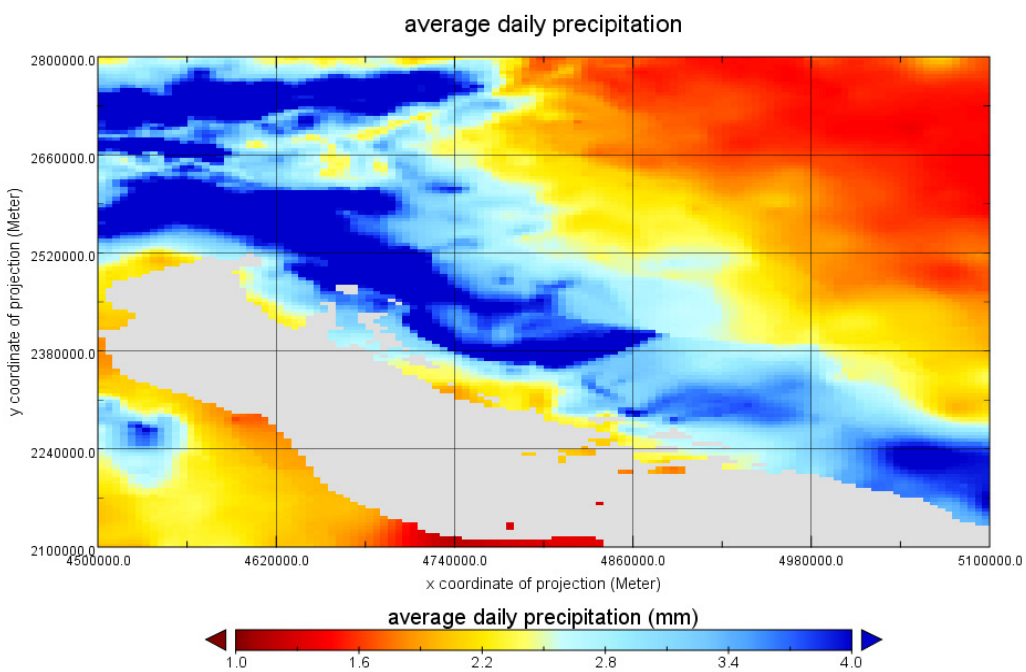

Figure 13 Average Daily Precipitation 1990-2012 (JRC gridded meteorological dataset)

Potential evapotranspiration, and evaporation rates for open water and bare soil surfaces, are calculated in two different ways during the 21-year time span. For periods before 23/01/2003 e0, et and es are taken from the JRC MARS database directly and interpolated as described above. However, from 23/01/2003 onwards, LISVAP (van der Knijff, 2008), an evaporation pre-processor for LISFLOOD, is used to derive the maps using the observed variables minimum daily temperature (tn), maximum daily temperature (tx), dewpoint temperature (td) and windspeed (ws).

Merged into this gridded meteorological datasets are the Alpine precipitation grids from Euro4M (http://www.euro4m.eu), covering parts of Slovenia and Croatia as well.

JRC funded work is also ongoing with the Serbian, Montenegro and Bosnia-Herzegovina meteorological services to establish an extention of the Carpatclim gridded 10-km meteorological database from 1961-2010 to the Sava region. (http://www.carpatclim-eu.org). Slovenia and Croatia are already reasonably covered with data from Euro4M). The Hungarian meteoservice is coordinating this – as they coordinated Carpatclim. Efforts will be made to digitize archived data and attempts will be made to fill the 1990-2005 period with sufficient information. Work is envisaged to be finished in summer 2016.

The available monthly precipitation data in the Sava yearbooks are useful, but unfortunately for simulation modelling at least daily resolution data are needed.

3.2 CORDEX climate change projections

Climate projections data are taken from the Coordinated Downscaling Experiment over Europe (EURO-CORDEX; Jacob et al., 2014), which is an international climate downscaling initiative that aims to provide high-resolution climate projections up to 2100. Scenario simulations within EURO-CORDEX use the new Representative Concentration Pathways (RCPs) (Moss et al, 2010). The RCP scenarios are four greenhouse gas concentration (not emissions) trajectories towards the end of 21st century, adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000. The pathways describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively).

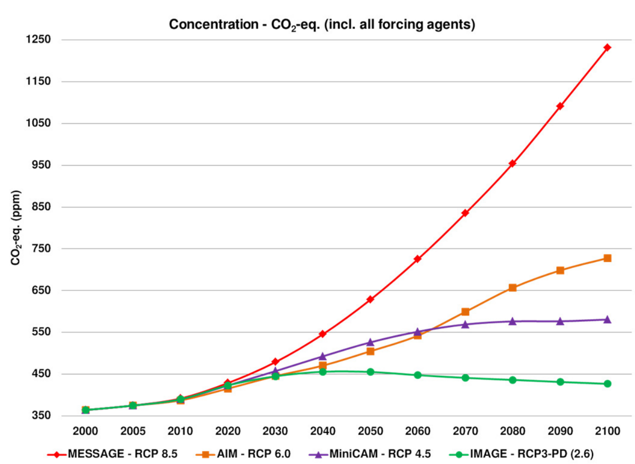

Figure 14 The 4 Representative Concentration Pathways (RCPs) (source: Wikipedia).

In this study, historical climate scenarios and future projections (1981-2100) from four regional climate models (RCMs) at 0.11 degree horizontal resolution were used to fed into the LISFLOOD hydrological model. The climate projections are based on both RCP4.5 and RCP8.5 corresponding to an increase in radiative forcing of 4.5 W/m2 and 8.5 W/m2 by the end of the century respectively. Meteorological fields extracted are average (tas), minimum (tasmin) and maximum (tasmax) surface air temperature, total precipitation (pr), surface air pressure (psl), 2 m specific humidity (huss), 10 m wind speed (sfcWind), surface downwelling shortwave radiation (rsds), surface upwelling shortwave radiation (rsus) and surface upwelling longwave radiation (rlus).

Both the precipitation and temperature fields are bias-corrected to tailor the data for the application in climate impact research. The statistical bias correction technique applied to the set of RCMs in the EURO-CORDEX framework is based on a transfer function (Piani et al., 2010; Dosio and Paruolo, 2011; Dosio et al., 2012), which is constructed from climate statistics of the E-OBS 30-yr (1961-1990) dataset (Haylock et al., 2008) and transferred to future climate. The gridded E-OBS dataset includes daily observations of temperature and precipitation based on station networks covering the whole European land area. Poor station coverage in Turkey, Northern Africa and some Mediterranean islands reduces the utility to use E-OBS for calculating the transfer function due to inhomogeneity's (both spatial and temporal). In these regions gaps are filled with raw model output instead of the bias-corrected scenarios.

All the meteorological variables are re-gridded at 5 km x 5 km and for each time step potential evapotranspiration maps are computed using the Penman–Monteith formulation. The hydrological model LISFLOOD is then run for the period 1981–2010 and for the future climate scenarios 2011–2100 forced by both RCP4.5 and RCP8.5 using the bias-corrected daily precipitation, average temperature and the generated potential evapotranspiration maps.

3.3 Discharge data

Observed historical daily river discharge data were available originating from several sources. The Sava yearbooks 2001-2010 data for the available stations were kindly provided by the ISRBC (ISRBC, 2001-2010). In addition, data made available through the Global Runoff Data Centre (GRDC) were used. Finally, several discharge station data were obtained through bilateral exchanges between the Slovenia and Serbian national hydrological services with JRC. As much as possible, these historical discharge data have been used for model calibration and verification.

3.4 Other spatial data used

Several more datasets are used for this study, and they are described below.

3.4.1 Elevation

While the model resolution of this Sava study is 5*5km, elevation information at 100m resolution available from the Shuttle Radar Topography Mission (SRTM) (Farr et al., 2007) is used to determine several elevation zones, which are then used by LISFLOOD for snow and snowmelt modelling at various altitudes within a 5*5km grid. Also, air temperature data are corrected for elevation.

3.4.2 River channel network

The Sava river network is derived from a mixture of automated digital elevation model analysis at 100m resolution (CCM data), the main river data file as provided by the Sava Commission, and several manual corrections in the karstic areas.

The LISFLOOD model uses a so-called Local Drainage Direction map, with the dominant flow direction in eight possible directions: N, NE, E, SE, S, SW, W, and NW. LISFLOOD works with one dominant downstream drain direction only. The model cannot deal with braided rivers, or rivers in delta areas that split in several parts.

River length can be longer than the 5km pixel and is user defined. Thus increased storage in a meandering river, and longer travel times can be simulated.

River channel dimensions are deducted from several known locations in Europe and then further extrapolated using the upstream drained area of a particular point along the river.

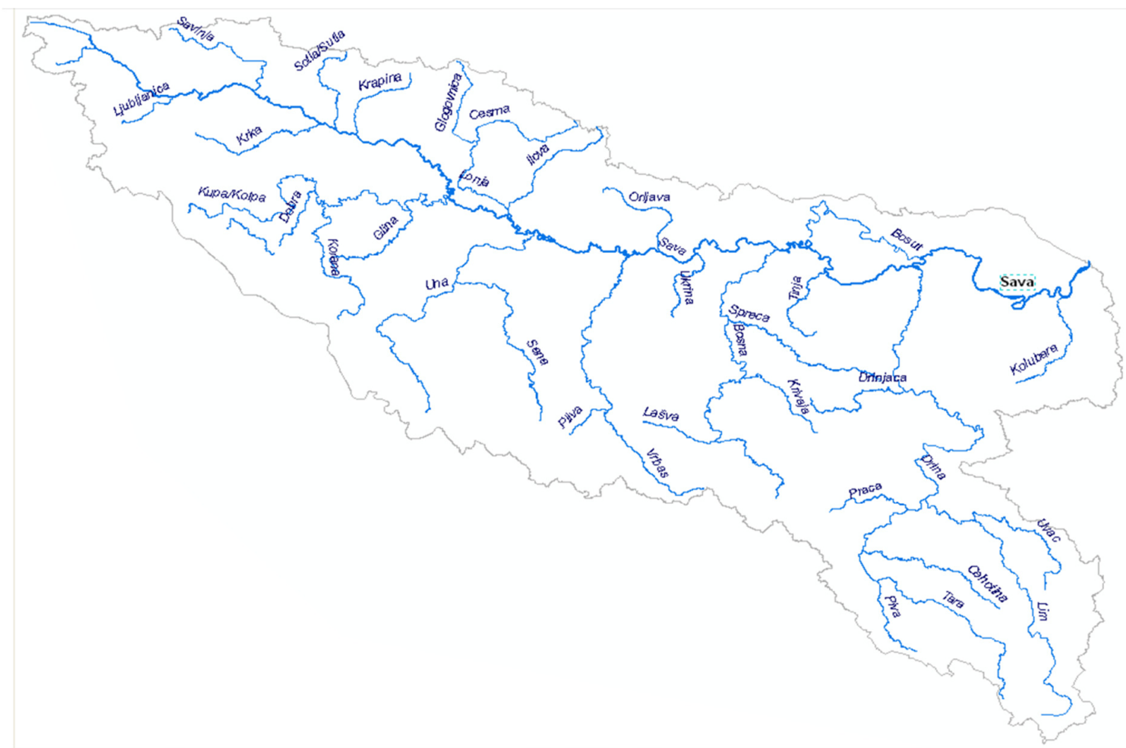

Figure 15 River network as obtained from the Sava Commission (Source: ISRBC, 2014)

3.4.3 Land use

For the land use pattern used for the reference/baseline scenario (year 2006), we have used the 100m resolution land use data from Corine landcover (http://www.eea.europa.eu/publications/COR0-landcover).

Corine, which means 'coordination of information on the environment' is an inventory of land cover in 44 classes, and presented as a cartographic product, at a scale of 1:100,000. This database is operationally available for most areas of Europe.

For the years 2010, 2030 and 2050 we used the land use projection output from LUISA at 100m resolution.

LISFLOOD runs for this study at 5*5km, but we apply sub-grid processing to take advantage of the higher resolution data available, mainly land use and elevation, both at 100m.

Every 5X5km pixel consists of a fraction:

- urban area
- open water area
- forested area
- paddy-rice irrigated area
- crop-irrigated area
- other area, with a specific dominant land use (arable, grassland or natural vegetation)

Several relevant processes are then first calculated on the subgrid – specific land use. Outgoing water fluxes for example are then aggregated later at the grid-scale.

3.4.4 Soil data

Soil textural data were derived from the ISRIC Soilgrids database http://www.isric.org/content/soilgrids , supplemented with data from JRC's European Soils Bureau. Pedotransfer functions applied on 1km soil texture data - originating from the HYPRES database (Wösten et al., 1999) - were used to obtain the Mualem-VanGenuchten soil hydraulic parameters used for soil water transport modelling in LISFLOOD.

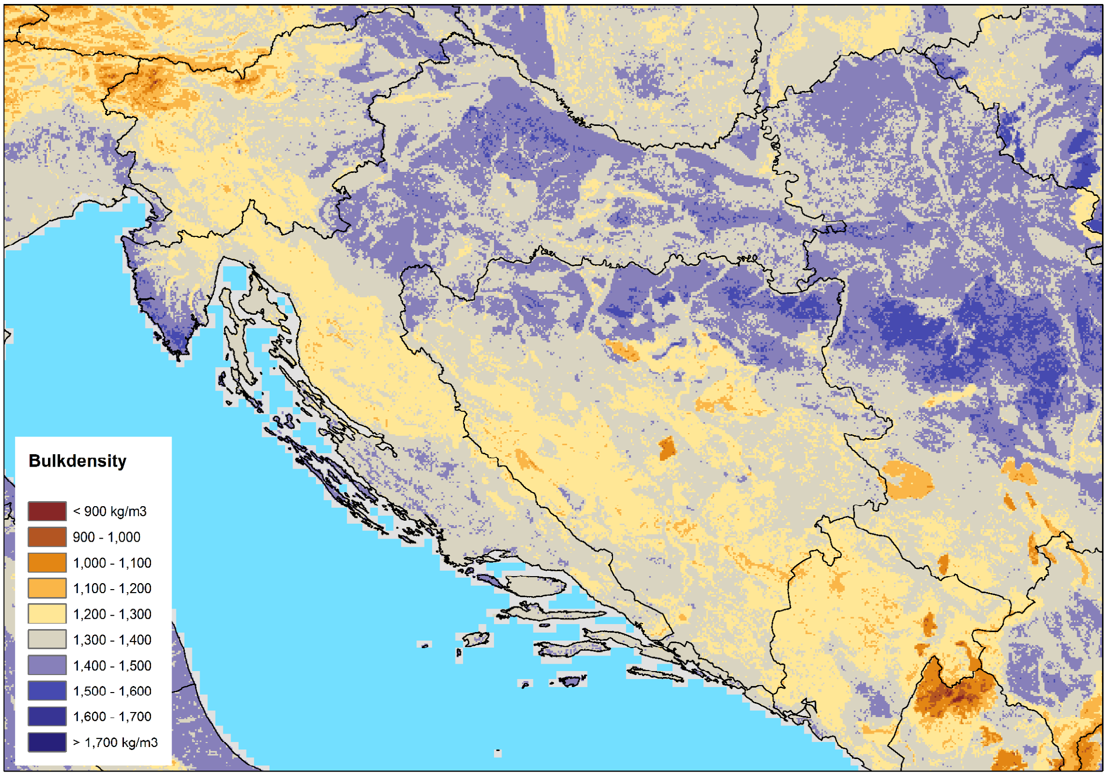

Figure 16 Bulk density of the top soil (0-30 cm). Source: ISRIC Soilgrids database.

3.4.5 Reservoirs and Lakes

The location of hydropower and thermal stations is derived from various sources:

- information provided from ISRBC experts and national focal points;
- information from the Stockholm Royal Institute of Technology (KTH);
- information from Sava member states internet sources;
- GRanD database (Global Reservoir and Dam database) (2011);
- Global Lakes and Wetlands Database (GLWD, Lehner & Doell, 2004)

For almost all reservoirs, only basic parameters as location and total volume of the reservoir are available. Many of the reservoir steering parameters had to be estimated. Some of the parameters were included in the calibration. The calibration of the model was done taking the reservoirs and current water use into account.

3.4.6 Irrigation

Current irrigated areas are derived from Wriedt et al (2009), who established a pan-European irrigation map based on regional European statistics, a European land use map and a global irrigation map. The map provides spatial information on the distribution of irrigated areas per crop type which allows determining irrigated areas at the level of spatial modelling units. The irrigation map was compiled in a two step procedure. First, irrigated areas were distributed to potentially irrigated crops at a regional level

(European statistical regions NUTS3), combining Farm Structure Survey (FSS) data on irrigated area, crop-specific irrigated area for crops whenever available, and total crop area. Second, crop-specific irrigated area was distributed within each statistical region based on the crop distribution given in our land use map. A global map of irrigated areas with a 5′ resolution was used to further constrain the distribution within each NUTS3 based on the density of irrigated areas. The constrained distribution of irrigated areas as taken from statistics to a high resolution dataset enables us to estimate irrigated areas for various spatial entities, including administrative, natural and artificial units.

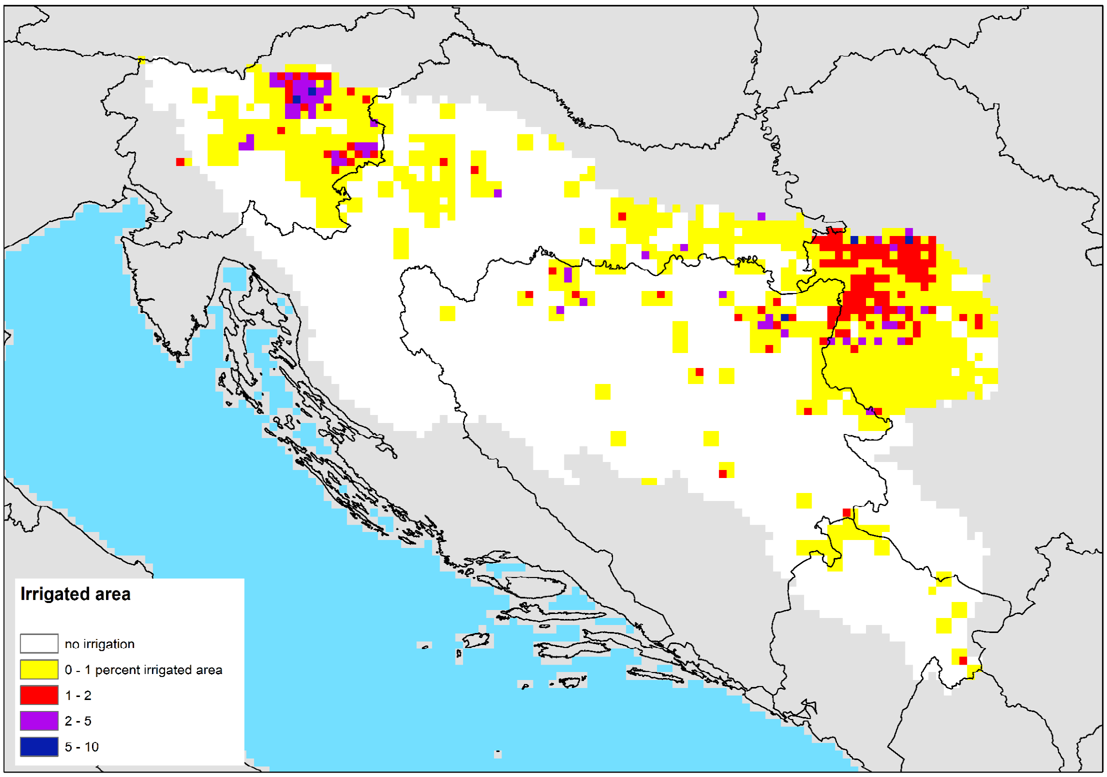

Figure 17 Current irrigated areas in the Sava basin.

Furthermore, sources from where water is abstracted are taken into account. The percentage of the source of the abstracted water used for irrigation is given, either from:

- surface water
- groundwater
- non-conventional sources (e.g. desalination plants)

These data are derived from the FAO/Aquastat website (http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm), and in many cases only available at country scale (see below). Croatia apparently has regional data available.

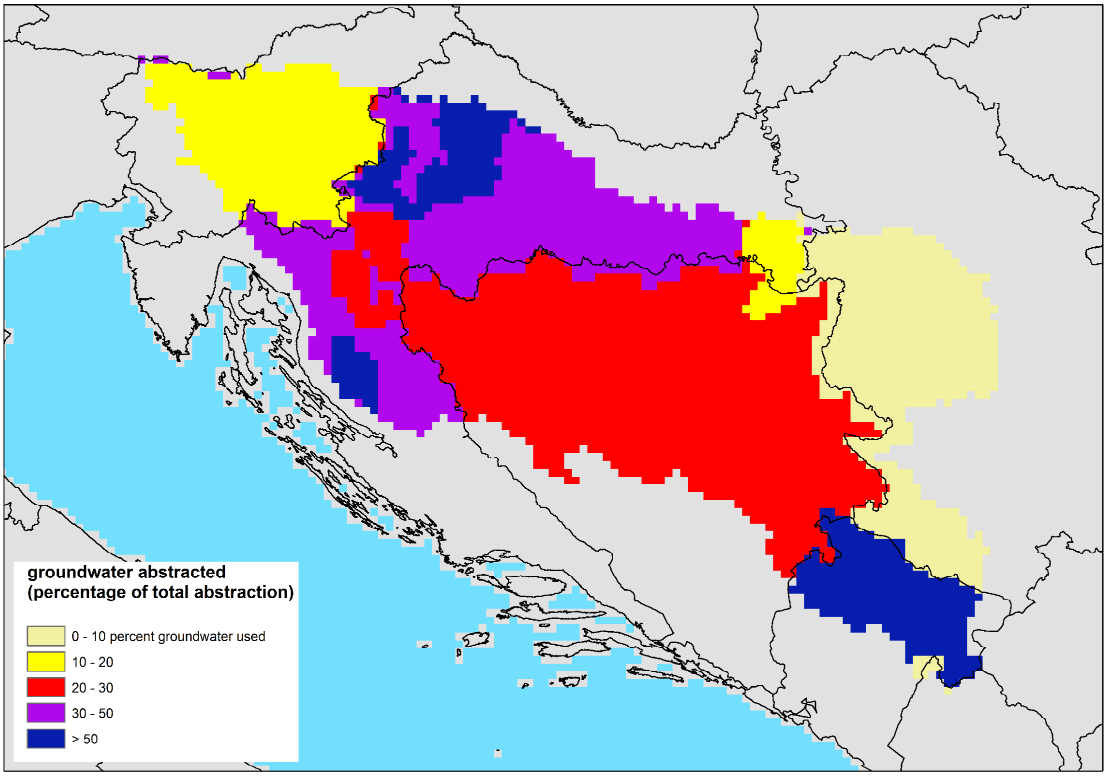

Figure 18 Fraction of groundwater used for water abstraction (source: FAO/Aquastat)

3.4.7 Water demand, abstraction and consumption

Water demands for the livestock sector, energy production and cooling, and the manufacturing industry are derived from downscaled Eurostat data mainly, as described by Vandecasteele et al (2013). Disaggregation has been achieved using 100m land use data.

Estimating cooling water abstractions were based on data from thermal power stations selected from the European Pollutant Release and Transfer Register data base (E-PRTR).

Energy water withdrawals and projections are based on energy consumption projections from Prospective Outlook on Long-term Energy Systems (POLES) (JRC).

Livestock water withdrawals are based on FAO livestock density maps (FAO, 2012), refined with actual livestock figures for 2005 (CAPRI, 2012). Specific water requirements per livestock type were defined, and are varied with daily.

Household and public sector water demands are derived from ongoing work of Bernhard (2015, in preparation), using Eurostat reported data, disaggregated with land use and population maps to water use per capita. Projections include the influence of GDP and water price, as well as intra-annual seasonal influences and tourism, based on the number of hotel nights booked in a region.

Actual consumption is lower than abstraction. The remaining water is assumed to flow back to the system. Consumption percentages are based on literature values for each sector. For thermal power-stations, the type of cooling plays an important role in the actual consumption (evaporation) of water.

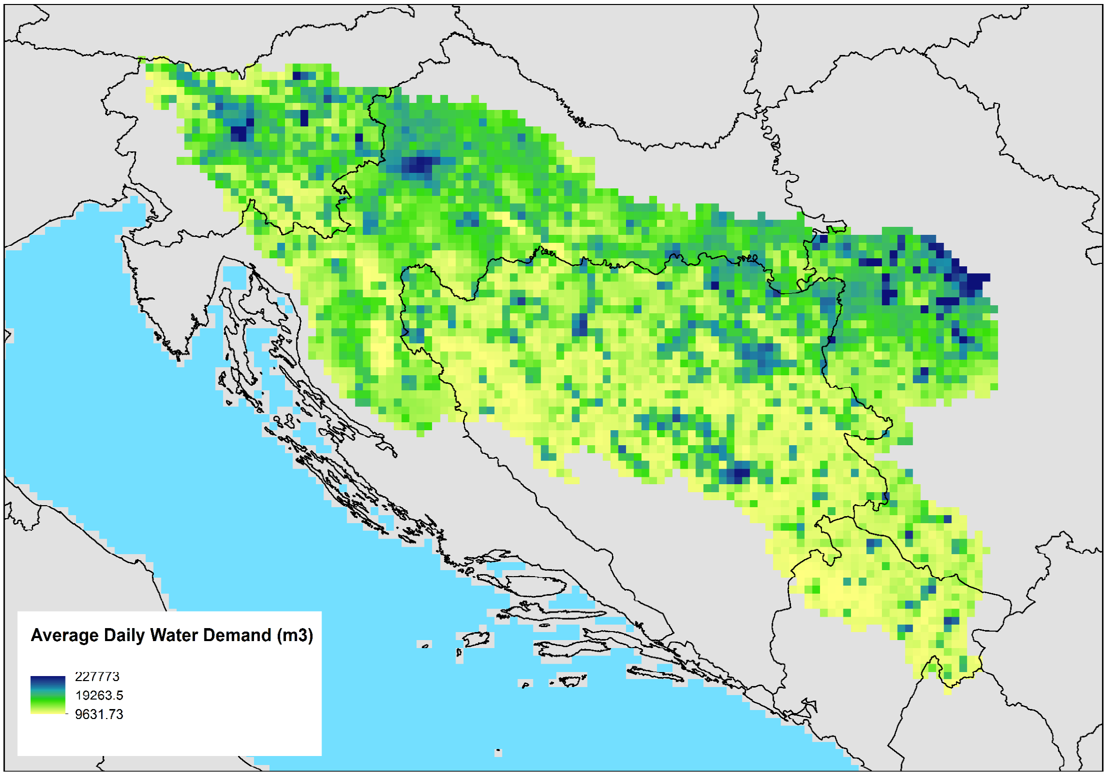

Figure 19 Average Daily Water Demand (m3 per 25km2 grid), for current climate and landuse.

Irrigation requirements are estimated inside the model – thus fully dynamically linked to changing precipitation and temperature, and thus adapting itself inside the climate scenario runs.

At a daily timescale, the difference between the potential evapotranspiration – depending on the weather forcing and crop requirements - and the actual evapotranspiration – based on soil moisture availability in addition – is taken as an estimated of the required irrigation water gift.

4. Descriptions of the scenarios

Below, the various scenarios are described for which the results are presented in Ch. 5.

4.1 Scenarios of future climate

Besides the baseline 1990-2013 observed weather data run, LISFLOOD has been run with a series of climate projections to evaluate the impact of future climate, combined with land use and measures such as irrigation, on water resources and extreme events.

EURO-CORDEX bias corrected climate projections from the following sources were used:

- KNMI (Royal Netherlands Meteorological Institute) (NL)
- SMHI (Swedish Meteorological and Hydrological Institute) (SE)
- DMI (Danish Meteorological Institute((DK)
- IPSL (Laboratoire des Sciences du Climat et de l'Environment) (FR)

From each of those main climate models, the following scenarios were used

- 1981-2010 (Historical)
- RCP4.5 2011-2100
- RCP8.5 2011-2100

The hydrological model LISFLOOD is then run for the historical period 1981–2010 and for the future climate scenarios 2011–2040 and 2071-2100 forced by both RCP4.5 and RCP8.5 using the bias-corrected daily precipitation, average temperature and the generated potential evapotranspiration maps.

4.1.1 Comparison of climate control runs with observed weather data

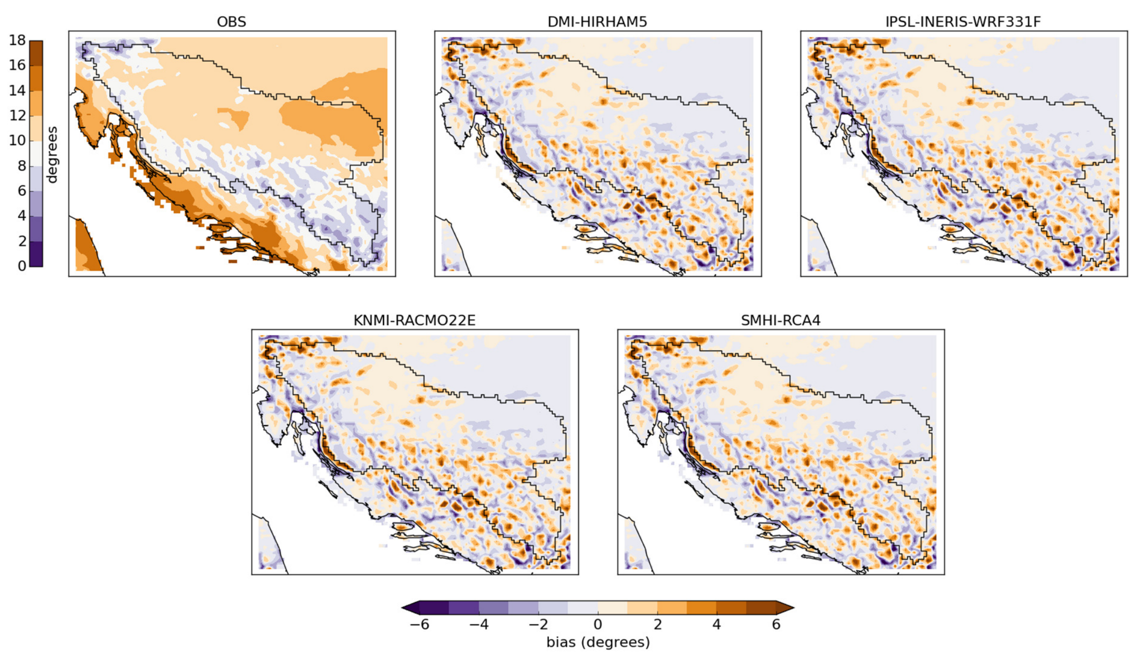

Figure 20 Average daily mean observed surface temperature (OBS) for the period 1990-2010 and the bias as simulated by the 4 RCMs.

It should be noted, that even though bias-correction using the E-obs gridded dataset has been applied, there are difference between the 1981-2010 historical (control climate) runs from those 4 suppliers and the gridded observed precipitation 1990-2012 which we use as observed weather, as can be seen in the figures below. Differences are mainly visible in the mountainous areas. Bias correction could be improved if better quality precipitation data would be available. The ongoing JRC funded extended CARPATCLIM project covering the Sava countries is aiming to achieve this improvement.

Figure 17 shows the bias of the average daily mean surface (2 meter) air temperature for each of the 4 RCMs for the period 1990-2010. In the same picture, the observed temperature is shown for reference, which is based on the JRC gridded meteorological data set (Ntegeka et al., 2013) for the same period. Similar scattered patterns of both warm and cold biases are found amongst the different RCMs. Warm biases up to 8o can mostly be found in the mountainous regions.

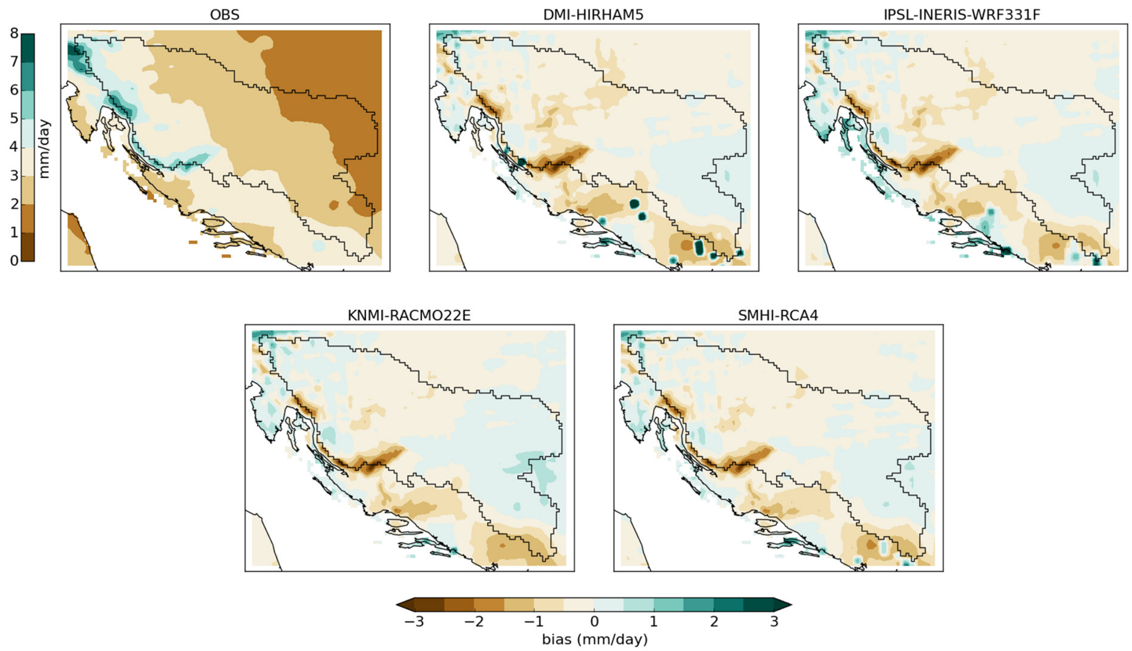

Figure 21 Average daily mean observed precipitation (OBS) for the period 1990-2010 and the bias as simulated by the 4 RCMs.

Figure 18 shows the bias in daily precipitation as modeled by the RCMs. The RCMs are in good agreement and are in general drier compared to the observations and extremely dry in mountainous regions. According Christensen et al. (2010) this is due to a lack of cloudiness modeled by the RCMs in this part of Europe. On the contrary the number of precipitation days (>0.1mm) modelled by the RCMs (Fig. 19) is higher compared to the observations. This turns out in less dynamic behavior of the RCMs in precipitation compared to observations with. Probably this is due to the fact that the relevant role of land-atmosphere interactions (e.g., convection) in summer is underestimated by the RCMs.

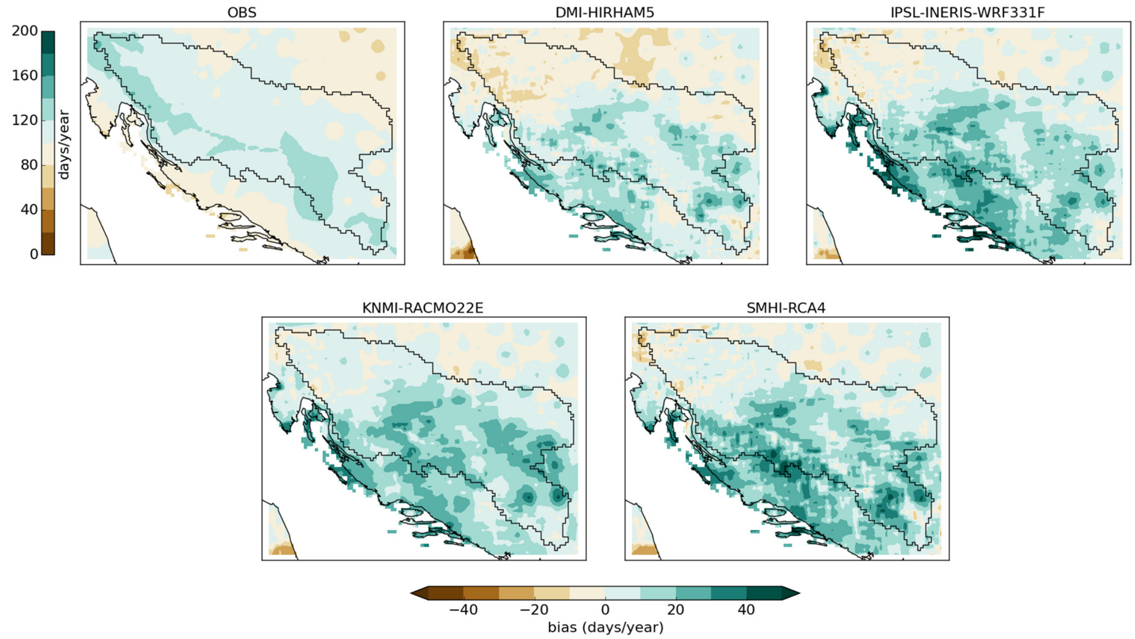

Figure 22 Average yearly mean observed (OBS) number of rain days (>0.1mm) for the period 1990-2010 and the bias as simulated by the 4 RCMs.

4.1.2 Evaluating RCP4.5 and RCP8.5 climate projections for the Sava

In this section an analysis is made of the end of the century (2071-2099) climate change signal of both the RCP4.5 and RCP8.5 emission scenarios relative to present climate (1981-2010) as simulated by the RCMs. Figure 20 shows the temperature change at the end of the 21st century. In both scenarios and for all the 4 RCMs an increase in temperature is observed with values ranging between 0 and 2 degrees for the RCP4.5 scenario and up to 7 degrees for the RCP8.5 scenario. The most pronounce temperature increase is likely to be in the southeast part of the Sava catchment.

In general, all models project an increase in precipitation for the end of the 21st century for both the scenarios. Although the SMHI-RCA4 model projects a decrease in precipitation in the coast lines for the RCP8.5 scenario, a common feature in the RCMs is the slight increase in precipitation between the RCP4.5 and RCP8.5 scenario. The inter-model variability is in general small with the exception of the IPSL-INERIS-WRF2331F model which projects much larger precipitation amounts compared to the other three RCMs.

The climate signal in terms of the number of precipitation days is more diverse and with opposite trends between the different RCMs. Figure 22 shows the change in number of precipitation days larger than 0.1 mm with some models (DMI-HIRHAM5, KNMI-RACMO22E and partially also IPSL-INERIS-WRF331F) projecting a slight increase in the number of precipitation days and others (SMHI-RCA4) a decrease for the RCP4.5 scenario. For the RCP8.5 scenario an opposite trend is observed with most models projecting a decrease in the number of precipitation days up to 25 days per year.

Looking at the more extreme events the climate projection show an increase in the number of precipitation days larger than 20 mm for all the RCMs and both the climate scenarios (Fig. 23).

Summarized, it is expected according the climate projections that both the temperature and precipitation amount will increase at the end of the 21st century. Most likely the increase in temperature triggers convection in summertime resulting in heavy precipitation events.

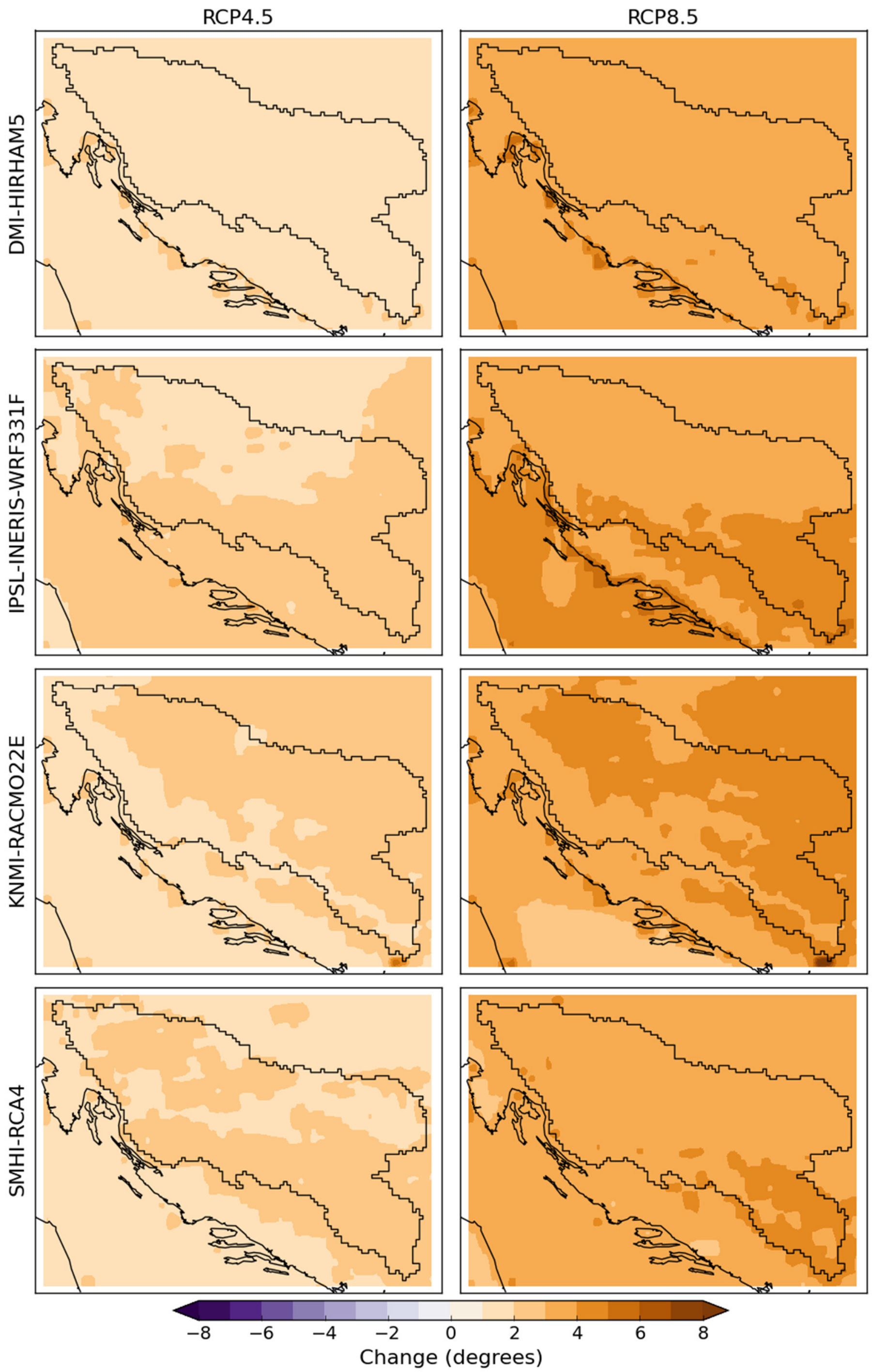

Figure 23 Average daily temperature change as simulated by the RCM's at the end of the century (2071-2099) for both the RCP4.5 and RCP8.5 scenario. The temperature change is relative to the present reference climate (1981-2010) according to the RCMs.

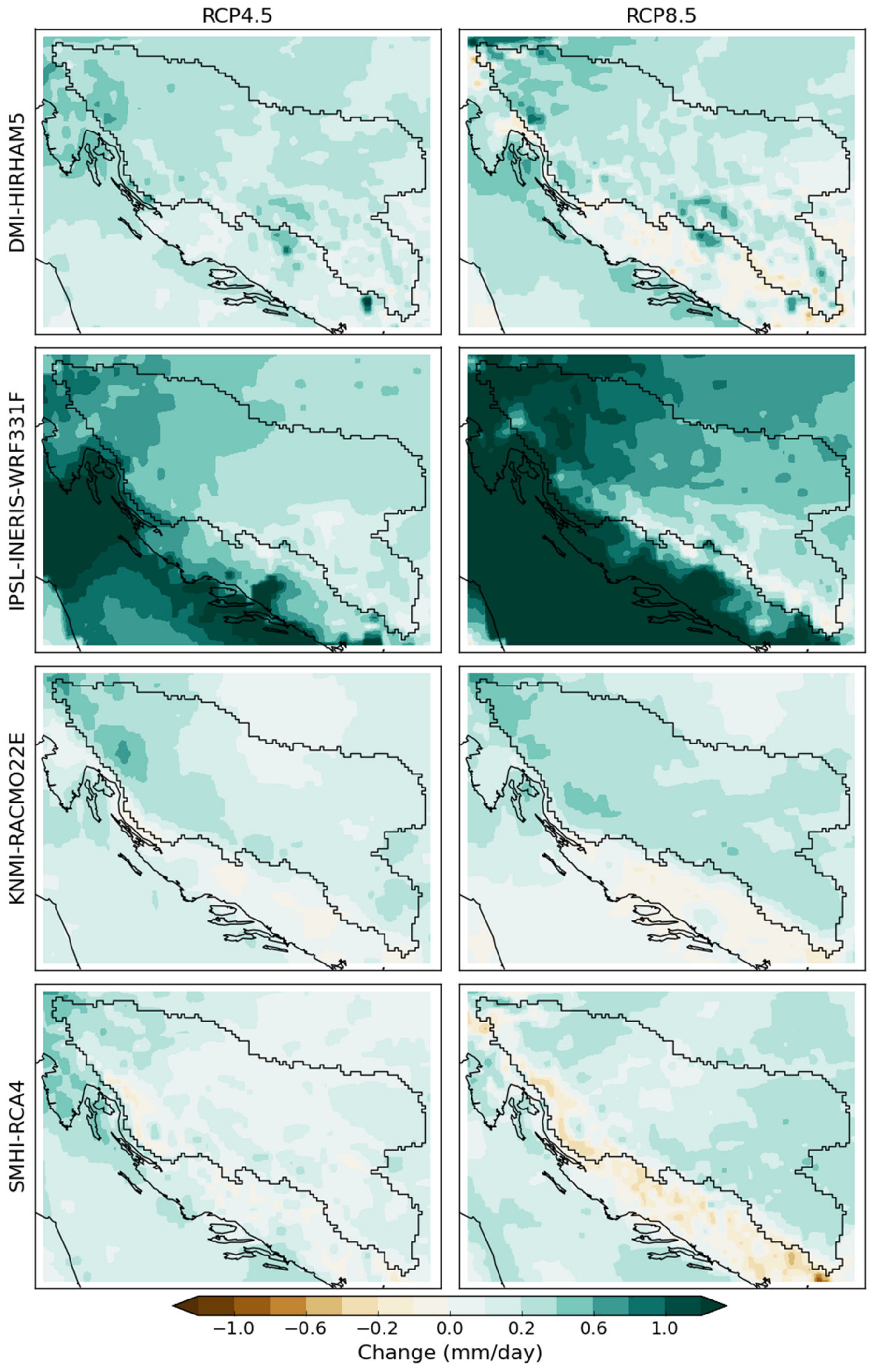

Figure 24 Average daily precipitation change as simulated by the RCMs at the end of the century (2071-2099) for both the RCP4.5 and RCP8.5 scenario. The temperature change is relative to the present reference climate (1981-2010) according to the RCMs.

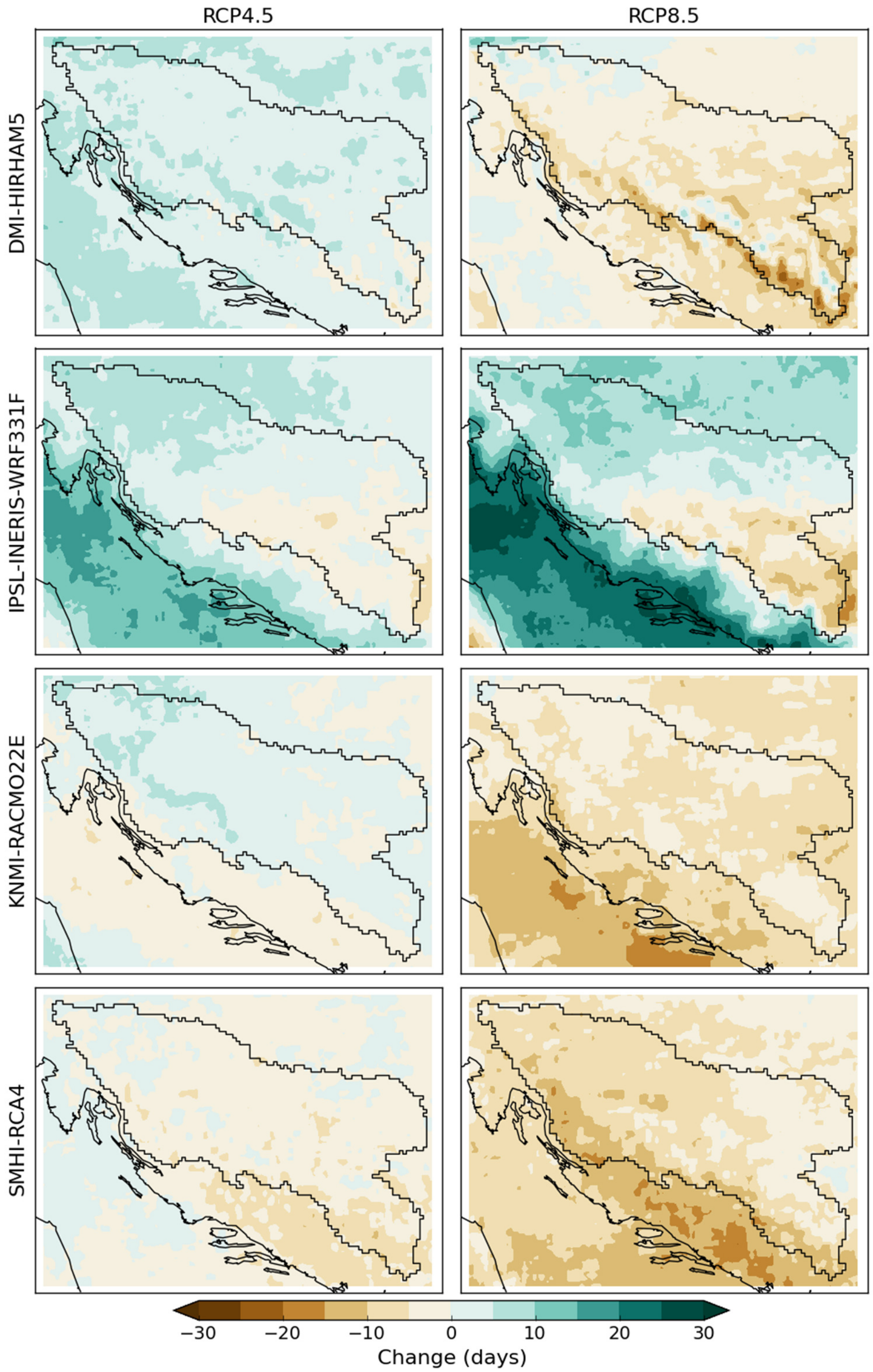

Figure 25 Average daily change in the number of precipitation days (>0.1mm) as simulated by the RCMs at the end of the century (2071-2099) for both the RCP4.5 and RCP8.5 scenario. The temperature change is relative to the present RCM reference climate (1981-2010).

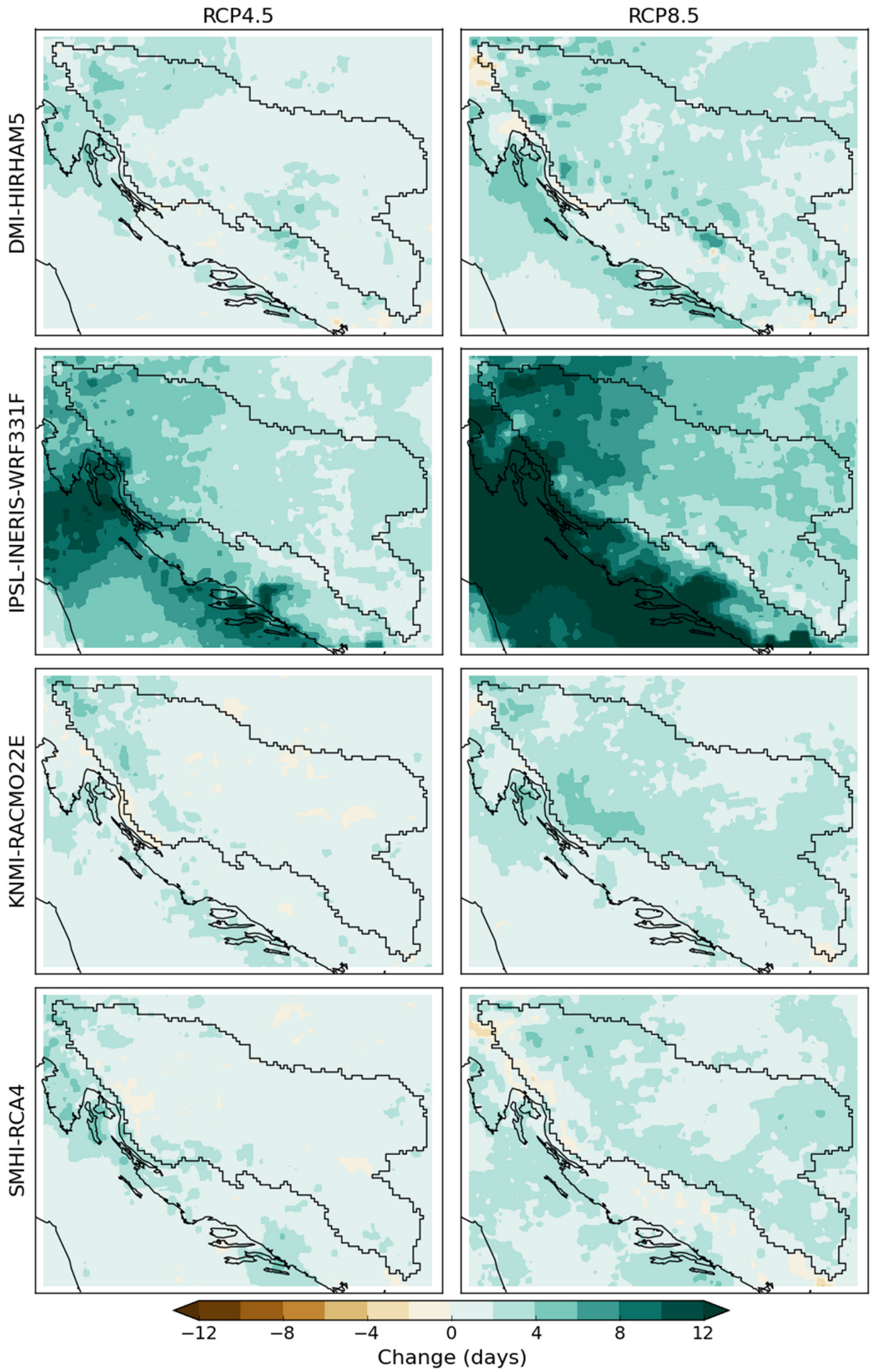

Figure 26 Average daily change in the number of precipitation days (> 20mm) as simulated by the RCMs at the end of the century (2071-2099) for both the RCP4.5 and RCP8.5 scenario. The temperature change is relative to the present RCM reference climate (1981-2010)

4.2 Scenarios of future land use

At present, project land use data are only available for EU28 countries, thus including Slovenia and Croatia. The other countries of the Sava basin are not yet included. Work is underway to establish land use projections for Serbia, Bosnia and Herzegovina and Montenegro as well. Therefore, in this study, urban and forest area in Serbia, Bosnia and Herzegovina and Montenegro are kept as in 2006. In the increased irrigated area scenarios, shifts are introduced from rainfed agriculture towards irrigated agriculture.

With regard to Croatia, three significant changes are immediately apparent (see Figure 1). On the one hand, forest areas are expected to increase substantially between 2010 and 2050 until 50% of the country's modelled land surface is forested; while on the other hand, areas of arable land and semi-natural vegetation are expected to decrease substantially. Industrial and urban land uses are expected to increase by respectively 22% and 1%, but the total effect is relatively minor due to the relatively small area that those land-uses occupy in 2010.

The trend in forest area between 2006 and 2050 depends, among other factors, on the projected afforestation/deforestation rates, based on country data reported in the frame of UNFCCC (country declarations). The main driver for the agricultural uses is the CAPRI model, which indeed forecasts a decrease in arable land.

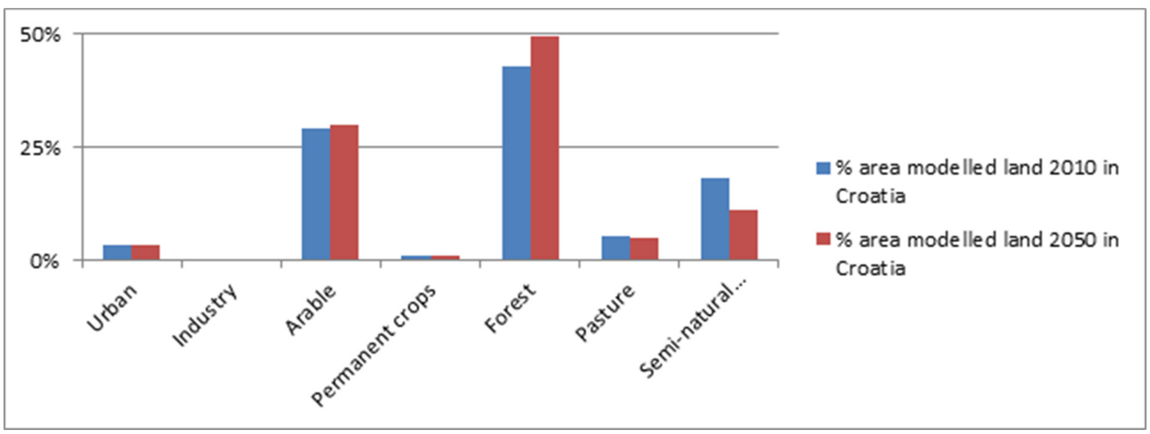

Figure 27 Projected land use changes in Croatia from 2010 towards 2050 (Source: JRC LUISA model, version 2015)

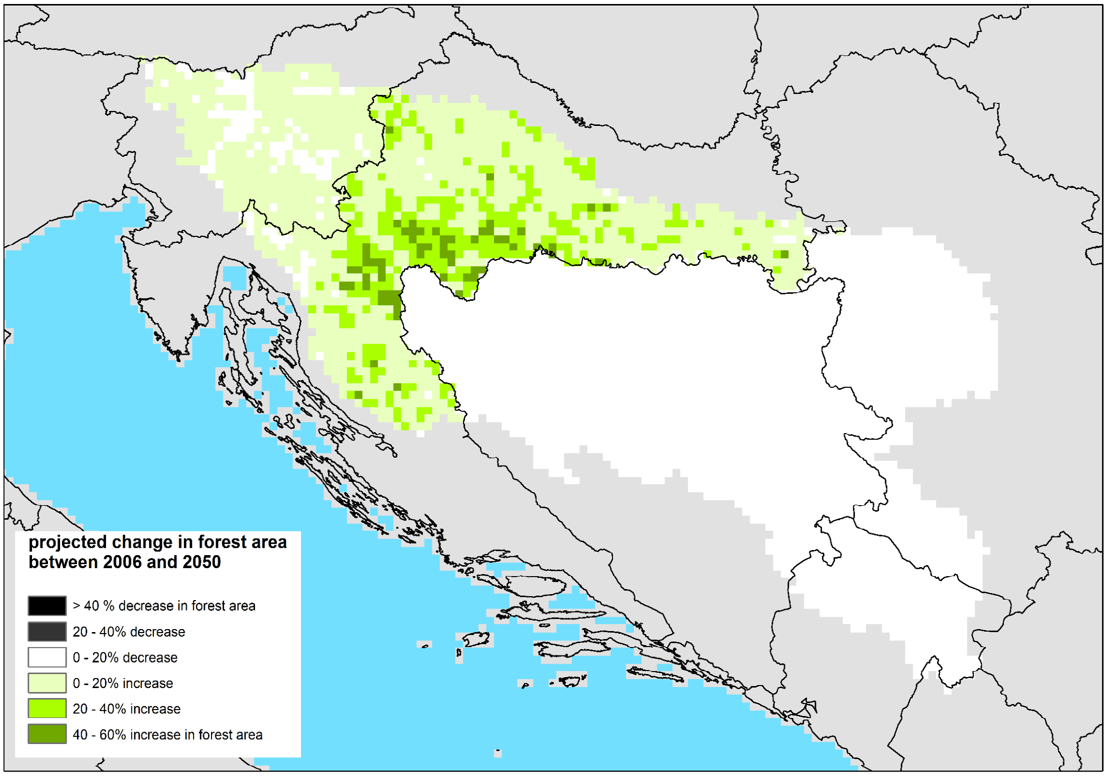

Figure 28 Change in forested area by 2050 as compared to 2006, simulated by the LUISA model (Source: JRC 2015).

With regard to Slovenia the expected land-use changes are roughly similar: again, the LUISA modelling results demonstrate a substantial increase of forested area between 2010 and 2050 at the expense of arable land and semi-natural vegetation (see Figure 2). In fact, the area of semi-natural vegetation is almost completely gone by 2050 according to these results. The slight decrease in arable land is consistent with the projections provided by the CAPRI model results that are fixed inputs for LUISA. Compared with Croatia, growth in urban and industrial land uses has a more clearly noticeable impact on land-use patterns in Slovenia. Urban land use is expected to increase by roughly 22%; industrial land use is expected to increase by roughly 27%.

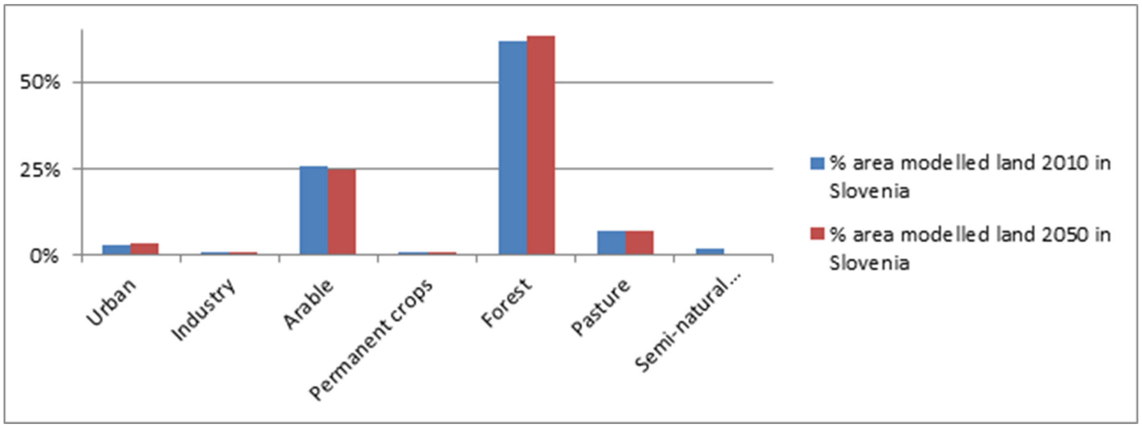

Figure 29 Projected land use changes in Slovenia from 2010 towards 2050 (source: JRC LUISA model).

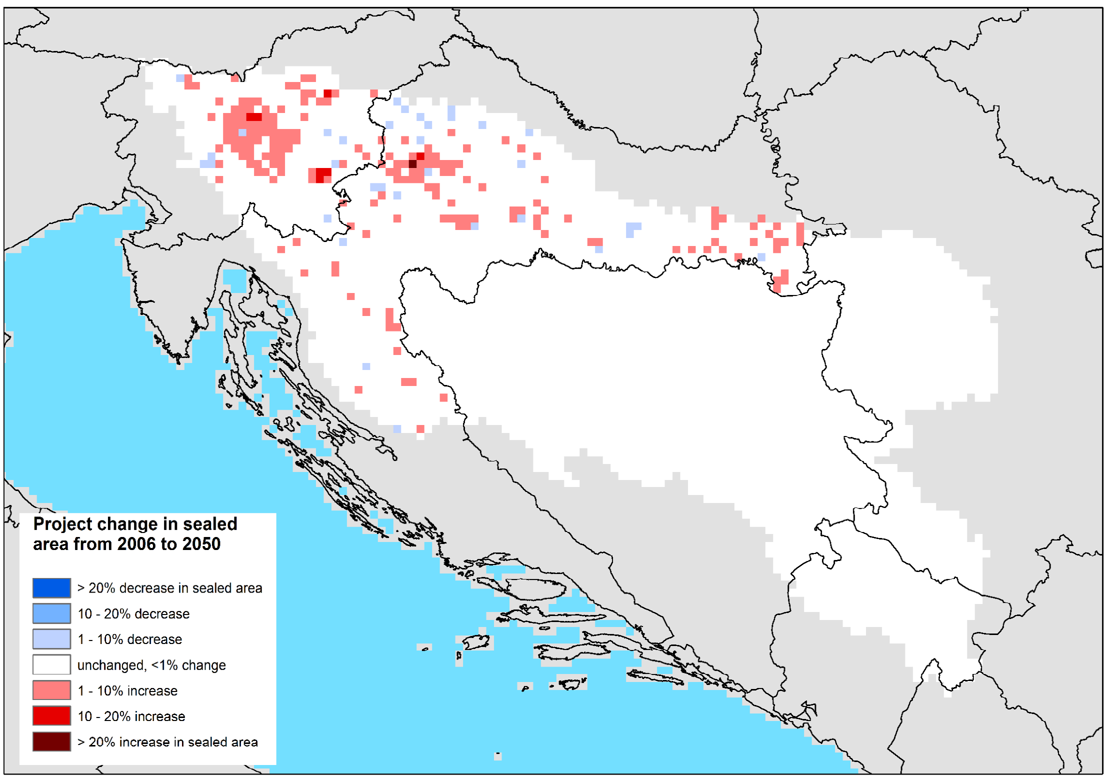

Figure 30 Change in urban area in 2050 as compared to 2006, as simulated with the LUISA model.

For this study, the following land use scenarios will be used in the scenario combinations:

- Baseline land use 2006
- Land use 2010
- Land use 2030
- Land use 3050

4.3 Scenarios of increased irrigation

For crop irrigation, a number of scenarios have been defined:

- Baseline 2006: irrigated areas as in 2006, with optimum crop irrigation water gift.
- Increase of irrigation including the areas indicated by FAO as "equipped for irrigation" (available from FAO Aquastat), added with planned Worldbank funded irrigation areas in Bosnia Herzegovina and Montenegro (information from ISBRC national facilitators) (referred to in this study as 'MaxIrrigation')
- A variation of the previous 'MaxIrrigation' scenario, using increased abstraction from groundwater, and reduced abstraction from reservoirs and surface water (referred to in this study as 'MaxIrrigationLZ')
- Hypothetical scenario by which all current maize arable land is irrigated if weather and soil conditions require to obtain maximum possible maize production (referred to as 'EpicMax').

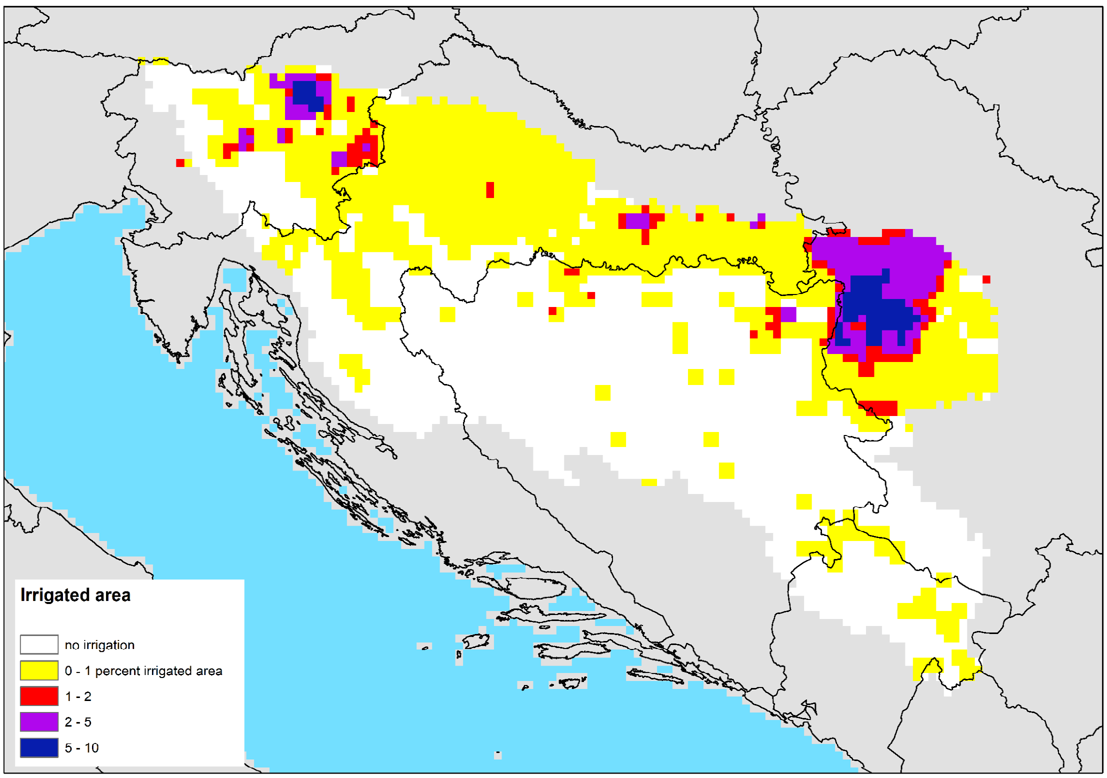

Figure 31 Maximized irrigation while using areas mentioned by FAO/Aquastat as equipped for irrigation.

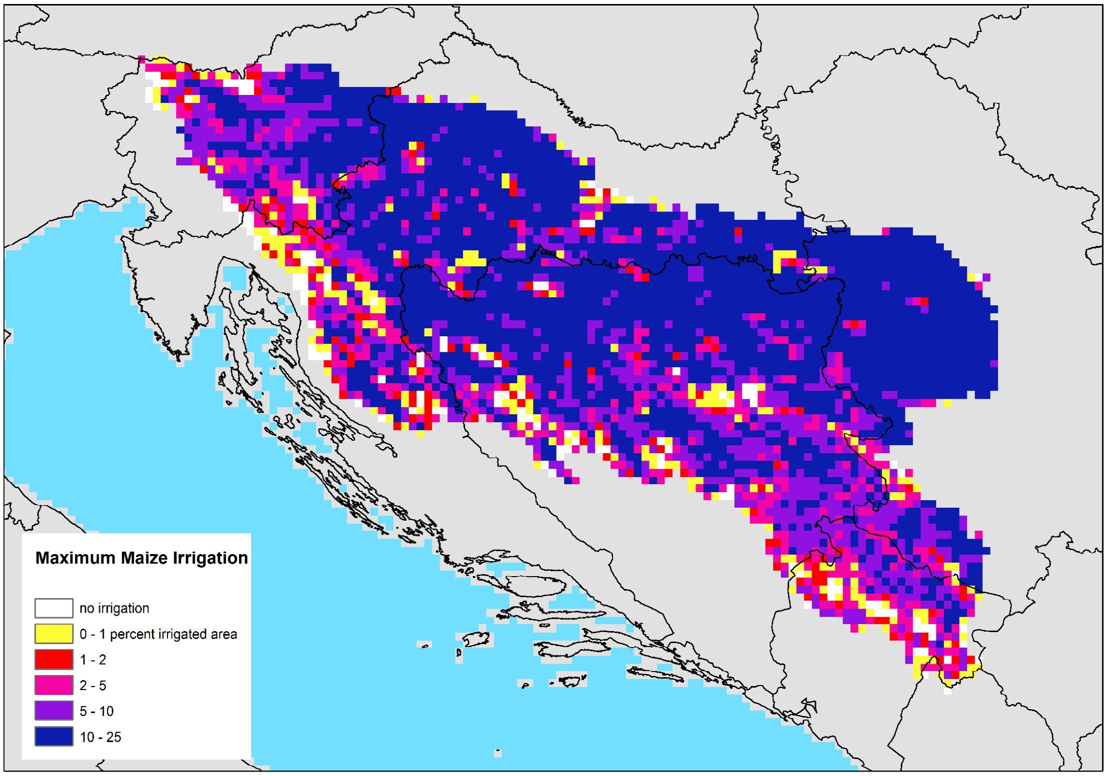

Figure 32 Maximized irrigation assuming all arable land irrigated for maize production.

For this hypothetical scenario we selected the crop maize as it is one of the dominant crops in the Sava River Basin (about 30 % of agricultural area) followed by wheat, other cereals and fodder crops, and also because it is a crop with moderate/high water requirements that can benefit from higher irrigation water input. Also the crop currently is not widely irrigated in the basin (Portmann et al., 2010).

We performed a crop yield gap analysis by comparing the difference between potential maize crop yield under no water constraints and the actual yield. For this purpose we setup the EPIC model to run under two alternative setups.

The first setup is the baseline scenario and it is representative of current irrigation (current area of maize irrigated) and fertilization management practices. Under these conditions, maize currently irrigated can obtain sufficient water whenever a water stress occurs.

The hypothetical scenario is the "irrigation potential" with no limitation for irrigation: all areas cultivated with maize are irrigated accordingly to estimated requirements. This scenario aims at assessing potential production, while assuming to potentially extend irrigation to all maize cropped areas. This study aims to evaluate if the water requirements of this maize production scenario can be met in the Sava basin.

5. Results

This chapter describes the results obtained with the LISFLOOD and EPIC modelling. Some of the results are summarized at country level, where Croatia, Serbia and Bosnia-Herzegovina have been divided in a high and low altitude area (Figure 33).

170 Simulations with the LISFLOOD water resources for 30-year periods with various combinations of land use change and climate change have been evaluated for their impact on the water-food-energy-environment nexus in the Sava river basin.

The model was first calibrated and validated against observations, and results are given below. Next, in chapter 5.3 the results are discussed first on the land use changes and irrigation changes simulated with current weather conditions. In chapter 5.4 the results are discussed of the simulations adding the climate change projections to the land use change projections. Chapter 5.5 discusses specific influences on the various sectors such as agriculture, energy production, environment and navigation.

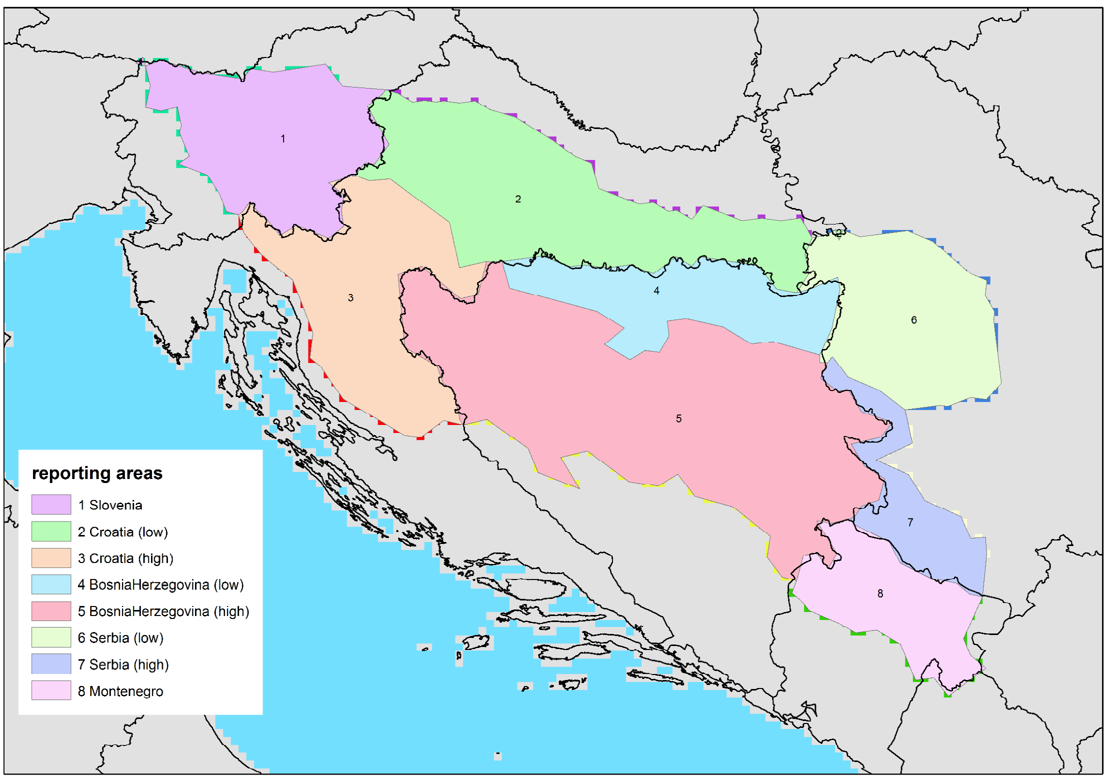

Figure 33 Reporting areas used in this report to summarize some of the model results.

5.1 LISFLOOD calibration

The calibration of the Sava river basin has been done for 38 sub-basins, using the data received from the Sava Commission yearbooks, as well as data from the Global Runoff Data Centre. The calibration of the model was done taking the reservoirs and current water use into account. The number of generations was limited to 13, as this was found to be sufficient to achieve convergence in most cases. This resulted in 832 model runs and objective-function evaluations per catchment. The calibration of all 38 catchments lasted about 7 days on a workstation equipped with two Intel Xeon E5-2640 CPUs (total 16 cores and 32 threads).

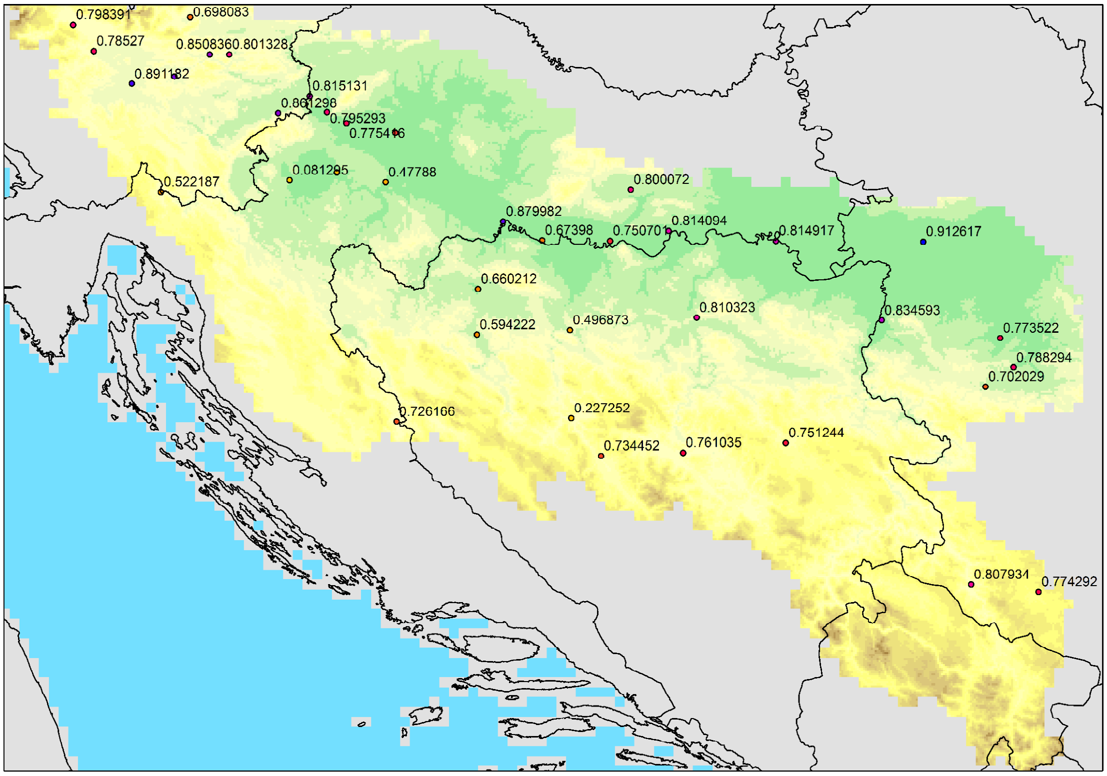

Figure 34 Kling-Gupta Efficiency (KGE) scores for the 38 Sava sub-basins (calibration).

Figure 34 shows a map of KGE scores obtained for the calibration of the 38 catchments. The score obtained for the most downstream station (upstream area 88,000 km2) for the calibration period was 0.91, suggesting that the model performance was excellent overall. However, somewhat lower scores were obtained for the Kupa and Vrbas tributaries. The median calibration scores obtained for the 38 catchments for the calibration and validation periods were relatively high at 0.77 and 0.75, respectively. The small decrease from calibration to validation scores demonstrates the robustness of the obtained parameters. The interquartile ranges in calibration scores obtained for the validation and validation periods were 0.11 and 0.23, respectively, indicating that the performance was relatively consistent amongst catchments.

Two station examples are given in the figures below.

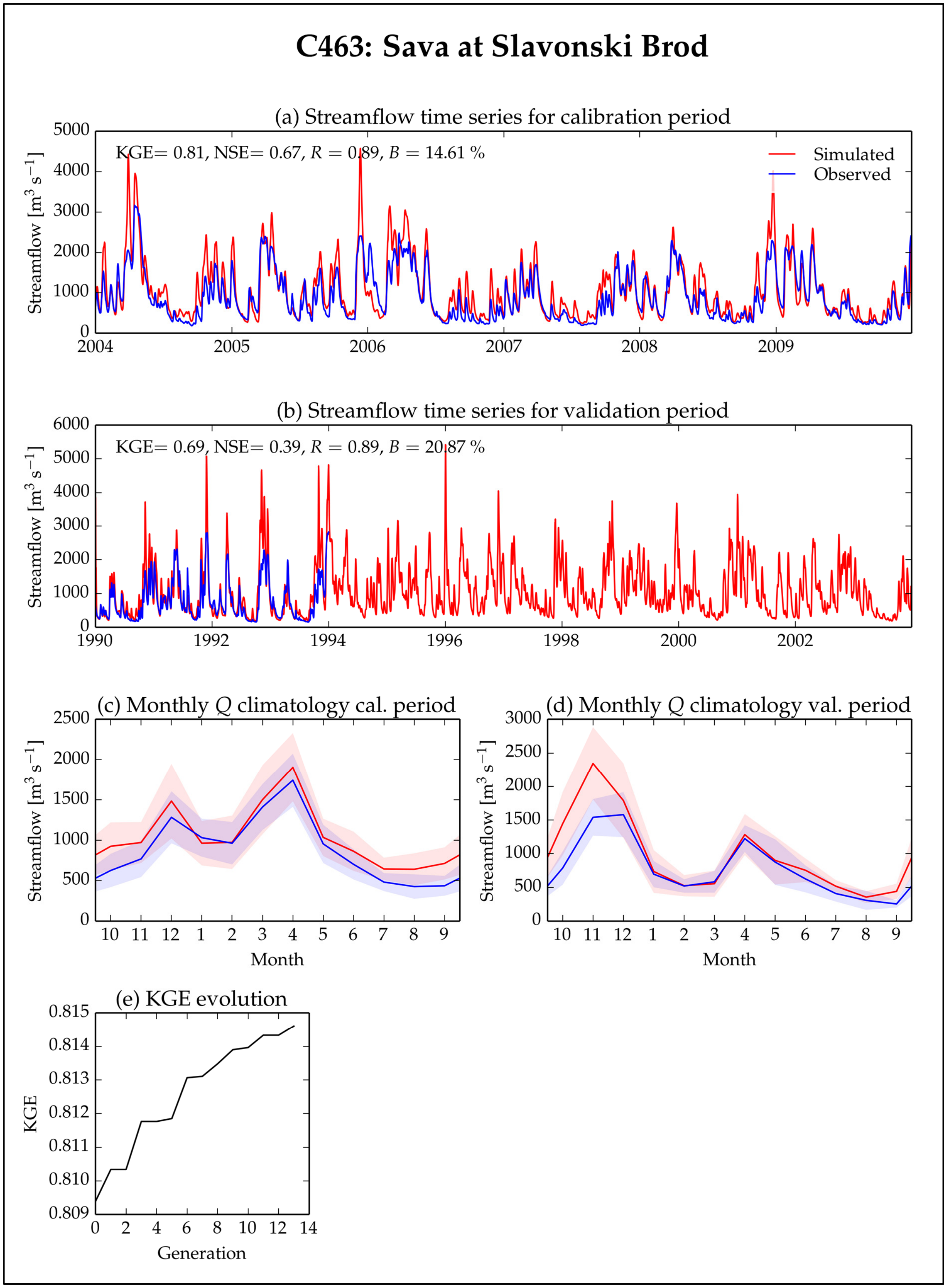

Figure 35 LISFLOOD calibration for Slavonski Brod (Sava).

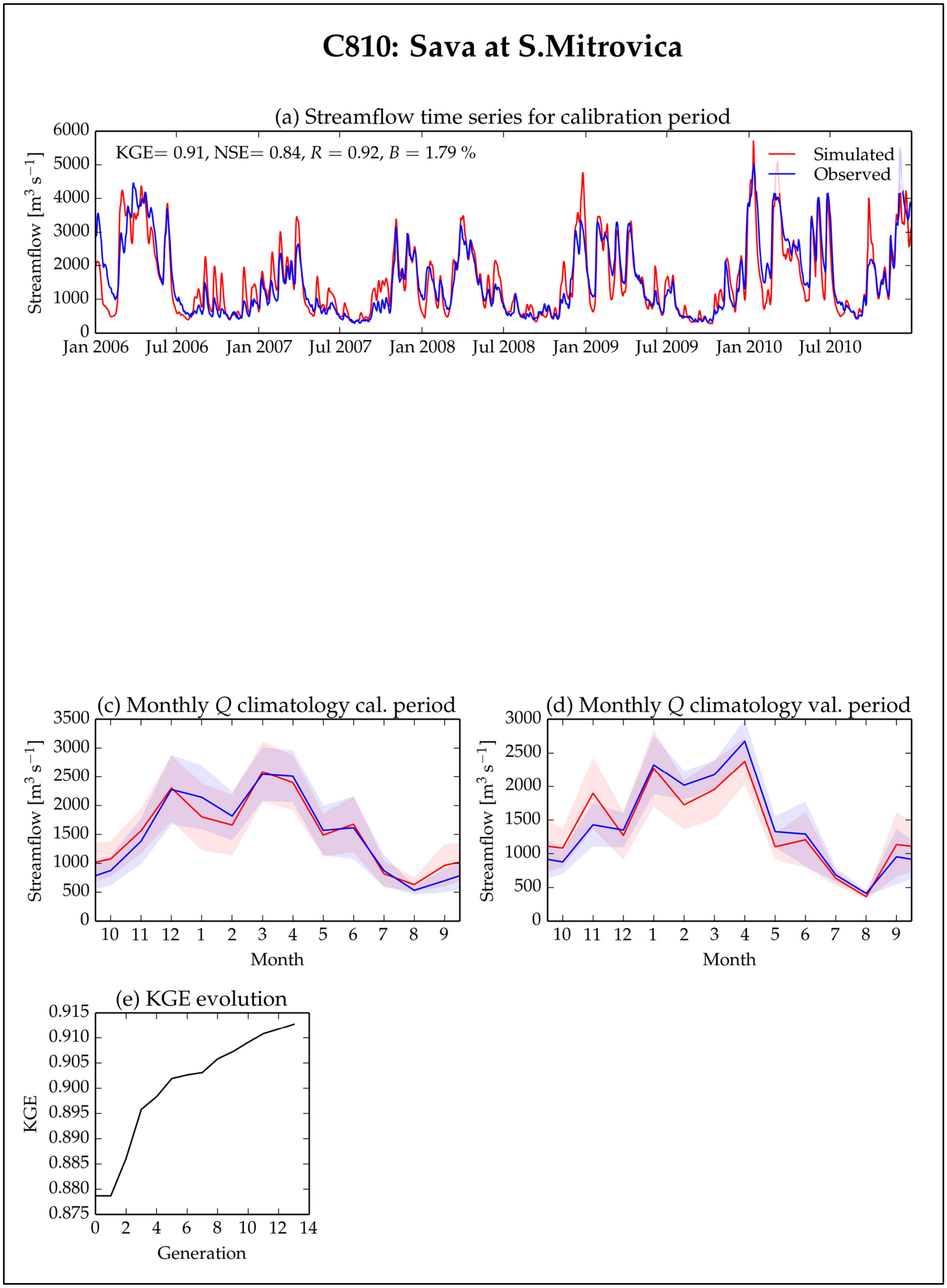

Figure 36 LISFLOOD calibration at S. Mitrovica (Sava).

5.2 The human influence on hydrology in the Sava basin

River flow in the Sava basin is altered by the presence of humans. Humans have changed land use, introduced reservoirs, and are abstracting water. Two additional model runs were executed to examine how large this human influence possibly is. This is also important for considerations of ecological flow conditions in a catchment. The following three model runs are compared below:

- *Use2006: land use as in 2006, hydropower reservoirs and water abstractions*
- *NoWaterUse: land use as in 2006, no hydropower, no water abstractions*
- *Natural: land use is 100% forest, no hydropower, no water abstractions*

These runs were done with LISFLOOD for the observed weather 1990-2013. The figure below gives the results for several gauging stations along the Sava river and its tributaries.

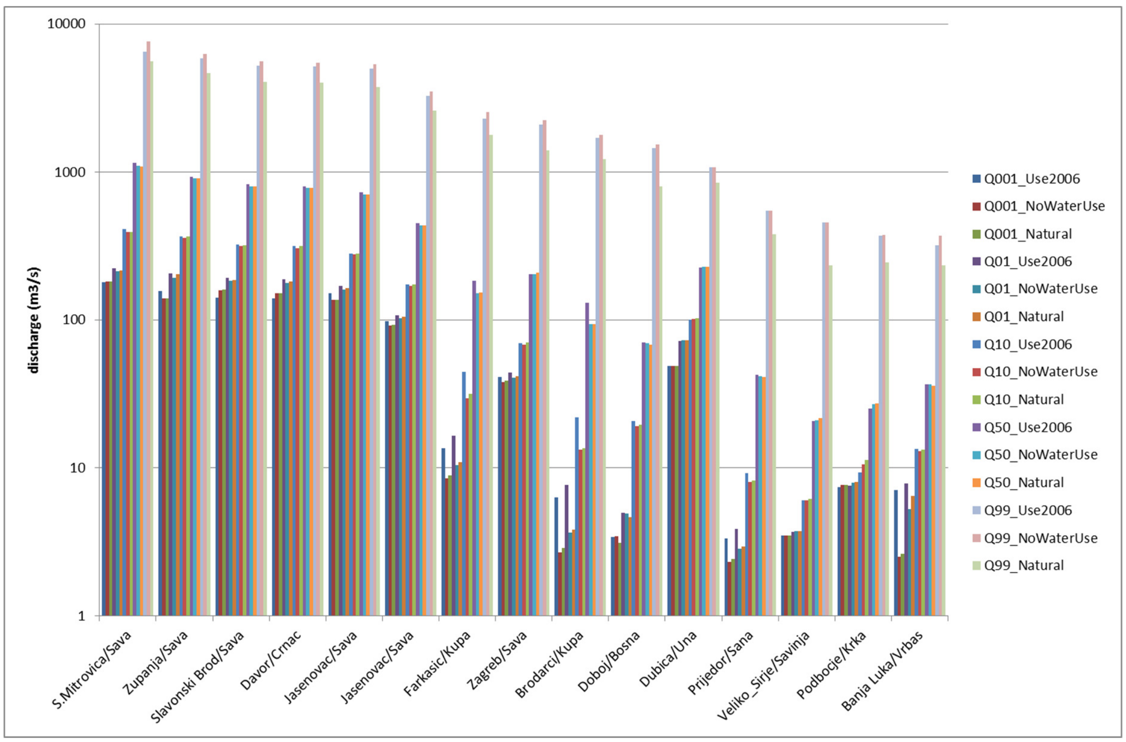

Figure 37 Discharges (m3/s) in the Sava basin under present (2006) conditions, without reservoirs and water use, and under complete natural (forested) conditions. Several percentiles are shown: Q0.1, Q1, Q10 (low flows), Q50 (median discharge), and Q99 (high flows).

From these runs it can be deducted that reservoirs alter low flow conditions in some tributaries such as the Kupa, the Sana, and the Vrbas: the reservoirs cause a more gradual outflow of the water, visible in Q001 and Q01 mainly. It should be noted that these specific model results depend strongly on the steering parameters of these reservoirs, which have been estimated. Thus results are uncertain.

A clear effect can be seen in the high flows (Q99) in all tributaries and the main Sava river. Under natural conditions peak discharges would be 15-50% lower than under present land use (note that the scale in the graph is a log-scale).

5.3 Projected changes in water resources due to land use

This chapter summarizes the single effect of projected land use changes until 2050 under present day / observed weather conditions 1990-2013.

5.3.1 Water demand and use

As a result of the LUISA land use projections presented in Chapter 4, together with projected changes in population and GDP, the water demands are also projected to change.

Public sector water demands are simulated by estimating water use per capita from historic data. For future projections, water use per capita is multiplied with projected population amounts. A further correction is made to account for seasonal influences due to weather and tourism.

Again, unfortunately only for EU28 countries, population projects were available. Work is underway to include the non-EU countries as well.

From the available population projections, it is remarkable that for Croatia population is projected to decrease from 2014 until 2050 with 10%, and further until 2080 with 18%. For Slovenia, a first projected increase in the 2020's is followed by a decrease. Net change in population in 2050 is +1%, but by 2080 projections indicate a decrease of 3%.

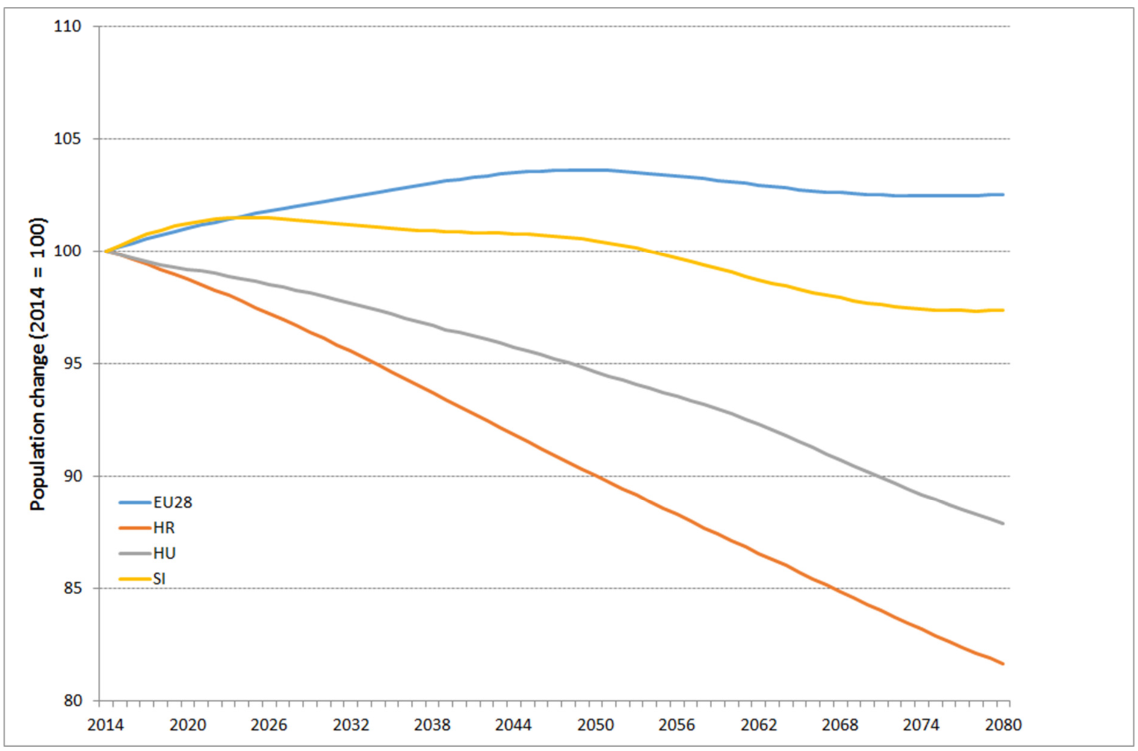

Figure 38 Projected population changes in HR, SI and HU as compared to EU28; RS, BA and ME not available (Source: EuroPop 2013). 2014=reference. Hungary (not part of the Sava basin) is included for reasons on comparison.

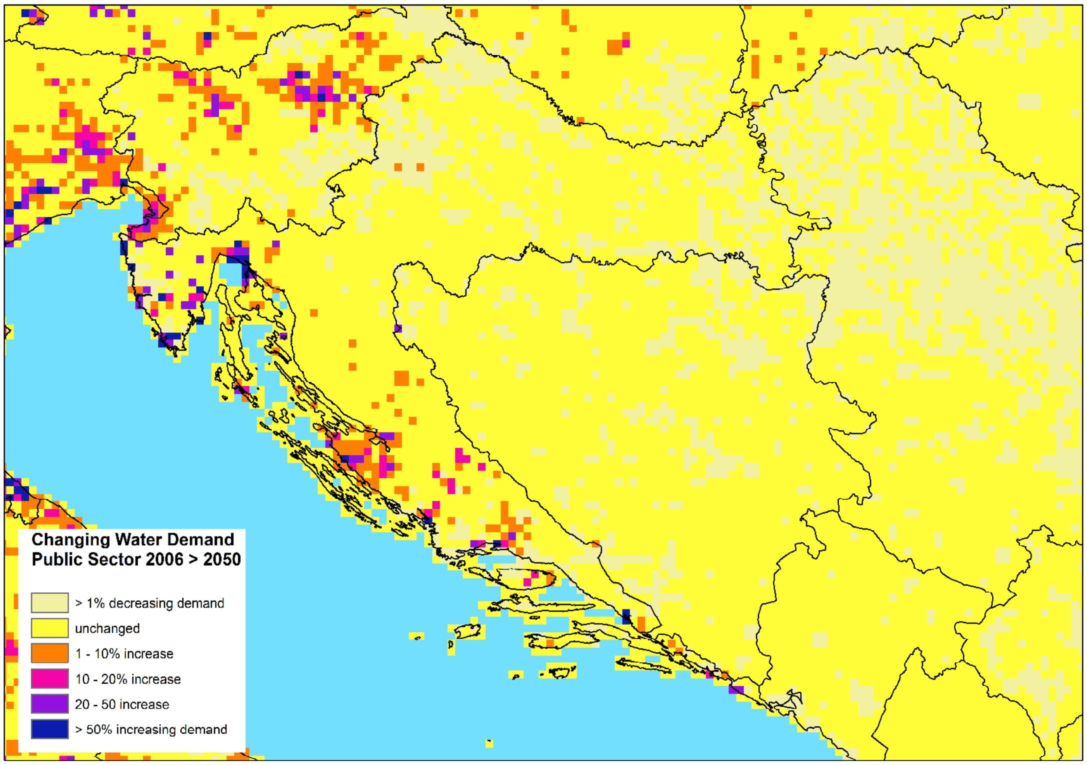

Figure 39 Projected changes in water demand for households from 2006 towards 2050. Note: insufficient data for projections for non-EU countries.

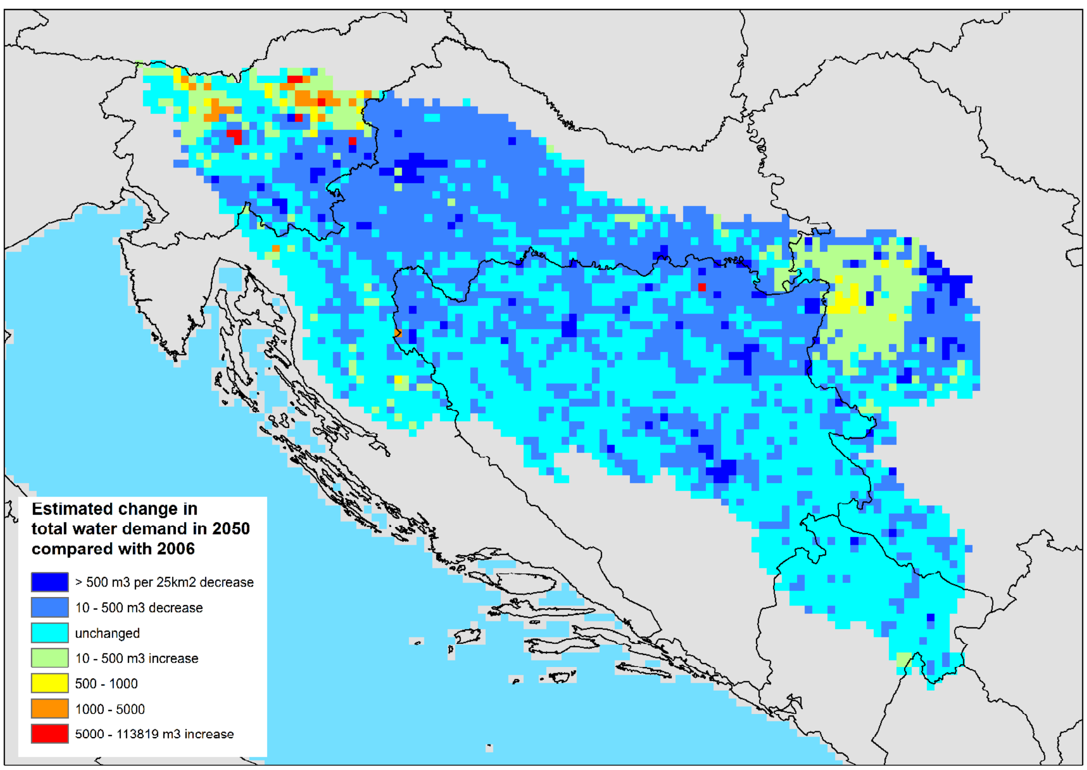

Figure 40 Projected changes in total water demand including increased irrigation by 2050, as compared with 2006.

These changes in population are reflected in the projected water demand for the public sector. Where Slovenia shows in increase in water demand, for Croatia a decrease is estimated for several regions, except the coastal region.

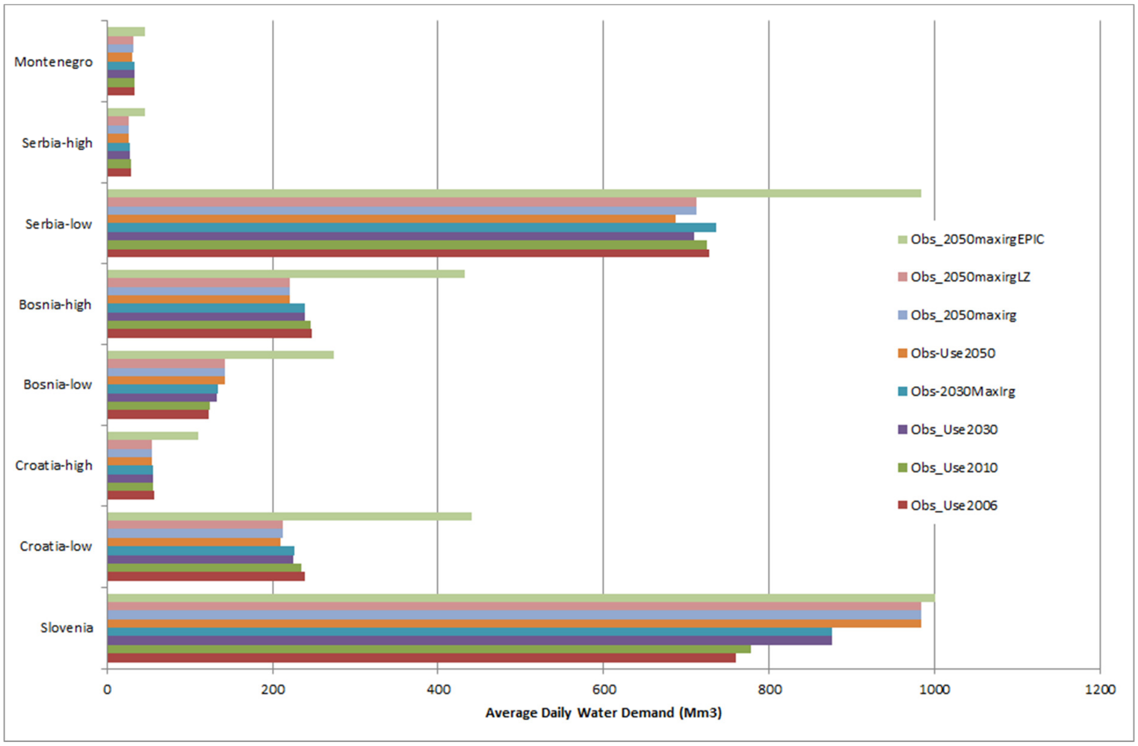

Figure 41 Average annual water demand (million m3) for the Sava countries, under present conditions and projections for 2050 scenarios.

Name	Obs_Use2006	Obs_Use2010	Obs_Use2030	Obs-2030MaxIrg	Obs-Use2050	Obs_2050maxirg	Obs_2050maxirgLZ	Obs_2050maxirgEPIC
Slovenia	760.1	777.4	876.2	876.6	983.4	983.9	983.9	1000.9
Croatia-low	238.5	235.0	225.4	227.2	210.2	212.0	212.0	441.2
Croatia-high	57.0	55.1	55.5	55.5	54.1	54.1	54.1	110.7
Bosnia-low	123.3	124.6	133.4	133.5	141.9	142.0	142.0	274.6
Bosnia-high	247.3	245.9	239.4	239.5	220.5	220.6	220.6	432.8
Serbia-low	727.9	724.2	709.6	735.6	686.8	712.7	712.7	984.4
Serbia-high	28.8	28.6	27.6	27.7	26.2	26.3	26.3	46.5
Montenegro	33.0	33.0	32.8	32.9	31.3	31.3	31.3	45.5
Total Sava	2215.9	2223.8	2300.0	2328.4	2354.4	2382.9	2382.9	3336.7

Table 2 Presented and projected annual water demands (million m3) in the Sava basin until 2050 (Source: JRC LISFLOOD model estimates, based on LUISA land use projections and Eurostat current reported water demands)

The projected water demand data show considerable increases for Slovenia until 2050. If the hypothetical maize irrigation scenario (EpicMax) would be implemented, water demands would increase considerably in the lower parts of Serbia, and Croatia and Bosnia Herzegovina.

Projected total water demand by 2050 in the Sava increases with 6.25%, but this is only due to projected changes in Slovenia. The other countries show a decreasing trend in water demand. Note that only Croatia and Slovenia are included in the LUISA land use projections. For Serbia, Bosnia-Herzegovina and Montenegro some estimates are made based on projected GDP changes for these countries.

The increased irrigation scenarios indicate especially for the Serbia Sava-basin territory an increase in water demand of 3.67%, 1.2% on the total Sava water demand.

The hypothetical EpicMax increased maize irrigation scenario would lead to further increases in water demand of 1.7% for Slovenia, 107% for Croatia , 95% for Bosnia Herzegovina, 39.5% for Serbia, 45% for Montenegro, and an overall 40% for the Sava basin.

5.3.2 Low-flow and Ecological flow

Simulated results for low-flow (Q001, Table 3) show negligible changes until 2050 as a consequence of land use change. Increased sealed areas and increasing forested areas seem to balance each other out in their effect on hydrology. Modest irrigation plans give the same result. Only intensive irrigation (MaxEpic scenario) would lead to increasing lowflow conditions, with the Q001 decreasing by 45% at the Sava mouth in Belgrade.

Name	River	Obs_Use2006	Obs_Use2010	Obs_Use2030	Obs-2030MaxIrg	Obs-Use2050	Obs_2050maxirg	Obs_2050maxirgLZ	Obs_2050maxirgEPIC
Belgrade	Sava	203.0	203.9	203.7	205.5	203.6	205.2	203.5	112.6
Brodarci	Kupa	6.3	6.5	6.6	6.6	6.6	6.6	6.6	6.2
Davor	Crnac	139.9	140.0	140.1	140.2	140.2	140.3	140.2	115.5
Dubica	Una	48.8	48.8	48.8	48.8	48.8	48.8	48.8	43.9
Farkasic	Kupa	13.6	13.6	13.6	13.6	13.6	13.6	13.6	8.3
Hrastnik	Sava	25.5	25.5	25.4	25.4	25.4	25.4	25.4	25.1
Jamnicka Kiselica	Kupa	7.9	7.9	7.9	7.9	7.9	7.9	7.9	6.6
Jasenovac	Sava	98.2	98.6	100.4	100.3	100.4	100.4	100.4	60.2
Jasenovac	Sava	150.6	150.5	151.7	151.9	151.6	151.8	151.9	111.1
Litija I	Sava	24.0	24.0	23.9	23.9	23.9	23.9	23.9	23.6
Pleternica	Orljava	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Podsused/Ž	Sava	41.1	41.0	40.8	41.1	40.8	41.0	41.0	38.9
Rugvica	Sava	41.6	41.6	41.3	41.6	41.3	41.5	41.4	38.7
S.Mitrovica	Sava	179.0	179.1	179.1	179.3	179.2	179.3	179.3	115.8
Slavonski Brod	Sava	141.6	141.6	142.0	142.0	142.0	142.0	142.1	115.3
Stara Gradiska	Sava	151.9	151.9	153.1	153.3	153.0	153.2	153.2	111.2
Zagreb	Sava	41.2	41.1	40.8	41.2	40.9	41.1	41.0	38.6
Zupanja	Sava	157.5	157.5	157.6	157.6	157.6	157.6	157.6	117.8

Table 3 Projected low flow discharge (The 0.1% percentile discharge) in m3/s under various land use changes until 2050.

As for ecological or environmental flows – in this report referred to as Eflow – the model simulations indicate a slight improvement for Croatia, due to land use change, caused by the projected decreases in population and therefore public water demands: in general unchanged until 2050. Bosnia and Serbia also indicate improvements in Eflow likely due to decreasing water demands. Slovenia shows also an improvement, but here the likely cause is increased urban area producing more runoff.

Under the hypothetical EpicMax increased maize irrigation scenario, E-flow conditions are estimated to deteriorate considerably in lower Serbia, Croatia and Bosnia-Herzegovina.

Region	Obs_Use2006	Obs_Use2010	Obs_Use2030	Obs-2030MaxIrg	Obs-Use2050	Obs_2050maxirg	Obs_2050maxirgLZ	Obs_2050maxirgEPIC
Slovenia	REF	-0.68	-0.58	-1.10	-0.63	-1.10	-0.96	0.05
Croatia-low	REF	-1.30	-1.24	-1.90	-1.29	-1.96	-1.73	3.89
Croatia-high	REF	-0.64	-2.04	-2.04	-2.31	-2.29	-2.24	4.46
Bosnia-low	REF	-0.13	-0.18	-0.25	-0.31	-0.37	-0.75	0.93
Bosnia-high	REF	-0.03	-0.05	-0.05	-0.08	-0.08	-0.08	7.27
Serbia-low	REF	-0.39	-0.62	-11.36	-0.73	-11.77	2.72	38.08
Serbia-high	REF	0.00	-0.02	-0.14	-0.04	-0.16	-0.16	-0.54
Montenegro	REF	0.00	0.00	0.01	-0.01	0.01	0.01	0.03

Table 4 Projected changes in number of days with e-flow conditions not met in the Sava basin as a consequence of land use, compared to land use 2006 as a reference (percentage change compared to 2006)

It makes a difference if increased irrigation is taken from surface water, groundwater or lakes and reservoirs. Simulations in which more groundwater is used as a source for irrigation (scenarios 'maxirrigationLZ'), show an increased number of days that eflow conditions cannot be met, especially in the lower Sava region in Serbia.

5.3.3 Flood hazard

The projected land use changes do not seem to influence extreme peak discharges, as it is reflected in the table below. Extreme flood hazard (Q9995) - as a consequence of land use change only - is basically unchanged until 2050, with marginal changes locally only.

Location	River	Obs_Use2006	Obs_Use2010	Obs_Use2030	Obs-2030MaxIrg	Obs-Use2050	Obs_2050maxirg	Obs_2050maxirgLZ
Belgrade	Sava	8448.8	8453.5	8457.9	8463.1	8458.7	8463.8	8462.1
Brodarci	Kupa	1832.5	1831.9	1823.8	1823.8	1824.1	1824.1	1824.0
Brodarevo	Lim	548.8	548.8	548.8	548.8	548.8	548.8	548.8
Davor	Crnac	5451.7	5411.7	5386.0	5386.2	5386.8	5387.0	5386.6
Doboj	Bosna	1644.9	1644.9	1644.9	1644.9	1644.9	1644.9	1644.9
Dubica	Una	1139.8	1139.9	1139.8	1139.8	1139.8	1139.8	1139.8
Farkasic	Kupa	2582.8	2547.4	2512.7	2512.7	2510.8	2510.8	2510.8
Gorazde	Drina	927.9	927.9	927.9	927.9	927.9	927.9	927.9
Hrastnik	Sava	1360.0	1367.0	1372.2	1372.2	1374.3	1374.2	1374.2
Jamnicka K	Kupa	2534.5	2506.6	2499.4	2499.4	2497.8	2497.9	2497.8
Jasenovac	Sava	3776.1	3745.4	3767.0	3767.0	3764.4	3764.4	3764.3
Kozluk Jajc	Vrbas	411.8	411.9	411.9	411.9	411.9	411.9	411.9
Litija I	Sava	1329.8	1335.9	1360.7	1360.7	1362.9	1362.9	1362.9
Merdani	Lašva	225.1	225.1	225.1	225.1	225.1	225.1	225.1
Olovo	Krivaja	148.0	148.0	148.0	148.0	148.0	148.0	148.0
Pleternica	Orljava	92.8	93.6	94.7	94.7	94.8	94.9	94.9
Podsused/	Sava	2417.9	2417.3	2424.3	2424.6	2427.4	2427.7	2427.5
Prijedor	Sana	573.9	573.9	573.9	573.9	573.9	573.9	573.9
Radalj	Drina	1558.8	1558.8	1558.8	1558.8	1558.8	1558.8	1558.8
Rugvica	Sava	2479.5	2480.0	2487.4	2487.8	2490.9	2491.2	2491.0
S.Mitrovic	Sava	7523.3	7524.7	7521.0	7522.3	7521.3	7522.6	7522.2
Slavonski E	Sava	5529.0	5517.6	5486.3	5486.6	5472.8	5473.1	5472.7
Stara Grad	Sava	5375.6	5363.0	5333.8	5334.1	5316.1	5316.5	5316.3
Vrbanja	Vrbanja	142.8	142.8	142.8	142.8	142.8	142.8	142.8
Zagreb	Sava	2450.4	2450.4	2457.5	2457.8	2460.8	2461.0	2460.9
Zupanja	Sava	6182.1	6182.8	6180.8	6181.1	6181.2	6181.5	6181.3

Table 5 Changes in flood hazard (Q99.95, in m3/s) for selected gauges in the Sava basin, for changing land use scenarios

5.3.4 Water availability for power stations

Electricity generation is important within the Sava basin, as has been also made clear in the UNECE report on the Water-Food-Energy Nexus (UNECE, 2015). Water is needed for the generation of hydropower, but also for cooling thermal and nuclear power stations.

Changing water availability could seriously affect power production or cooling possibilities, forcing thermal plants to a potential shutdown.

As the table below shows, land use changes alone until 2050 as projected here, do not have an impact on the median discharge in the power stations in the Sava basin.

HPP/TPP	Obs_Use2006	Obs_Use2010	Obs_Use2030	Obs-2030MaxIrg	Obs-Use2050	Obs_2050maxirg	Obs_2050maxirgLZ
Brezice	185.9	186.4	186.3	186.7	186.7	186.9	186.8
CHP Sremska Mitrovica	1155.4	1158.1	1159.2	1161.2	1159.3	1161.0	1159.8
CHP TE TO Zagreb	205.3	206.2	206.7	207.0	207.1	207.3	207.1
CHP Toplarna Ljubljana	54.9	54.9	54.9	54.9	54.9	54.9	54.9
HPP Arto-Blanco	154.2	154.6	154.7	154.9	154.7	155.1	154.9
HPP Bajina Basta RoR	95.2	95.2	95.2	95.3	95.3	95.3	95.3
HPP Bistrica	36.8	36.8	36.9	36.9	36.8	36.9	36.9
HPP Bocac	31.9	31.9	32.0	32.0	32.0	32.0	32.0
HPP Bostanj	153.5	153.6	153.7	154.0	153.8	154.1	154.0
HPP Gojak	81.2	81.5	81.1	81.1	80.9	80.9	80.9
HPP Jajce I	25.2	25.2	25.2	25.2	25.2	25.2	25.2
HPP Jajce II	28.7	28.7	28.7	28.7	28.7	28.7	28.7
HPP Krsko	155.4	155.6	155.7	155.9	155.9	156.1	156.0
HPP Lesce	82.7	82.8	82.4	82.4	82.4	82.4	82.4
HPP Mavcice	42.6	42.6	42.6	42.6	42.6	42.7	42.7
HPP Medvode	53.8	53.8	53.8	53.8	53.9	53.9	53.9
HPP Moste	11.9	11.9	11.9	11.9	11.9	11.9	11.9
HPP Piva	9.7	9.7	9.7	9.7	9.6	9.6	9.6
HPP Potpec	37.1	37.1	37.1	37.2	37.1	37.1	37.1
HPP Visegrad	94.2	94.2	94.2	94.2	94.2	94.2	94.2
HPP Vrhovo	148.2	148.4	148.6	148.8	148.6	148.9	148.7
HPP Zvornik	105.1	105.1	105.1	105.1	105.1	105.1	105.1
Modrac	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Mokrice	191.3	191.8	192.0	192.3	192.5	192.7	192.5
Ozalj	36.9	37.1	37.1	37.1	37.1	37.1	37.1
TPP Brestanica	154.8	155.1	155.3	155.6	155.4	155.7	155.5
TPP Kakanj	19.5	19.5	19.5	19.5	19.5	19.5	19.5
TPP Nikola Tesla A	1178.8	1181.4	1180.9	1184.6	1181.1	1185.5	1181.9
TPP Nikola Tesla B	1166.1	1170.0	1170.7	1174.0	1172.0	1175.3	1172.4
TPP/CHP Sisak	201.9	202.6	202.8	202.8	202.9	202.9	202.9

Table 6 Changes in Q50 (median discharge, in m3/s) at the major power-stations in the Sava basin, as a consequence of land use projections.

5.3.5 Soil water stress

The Sava river basin consists of drier and wetter parts. The Slovenian part is relatively wet with high soil moisture contents, and very few days a year when transpiration may get limited by available soil moisture. Downstream Zagreb and the Sava plain near Belgrade appear to be areas where moisture conditions get limited more often.

Land use change as simulated here does not affect these number of soil water stress days. Soil moisture stress is mainly driven by the weather forcing data and soil texture and hydraulic conditions.

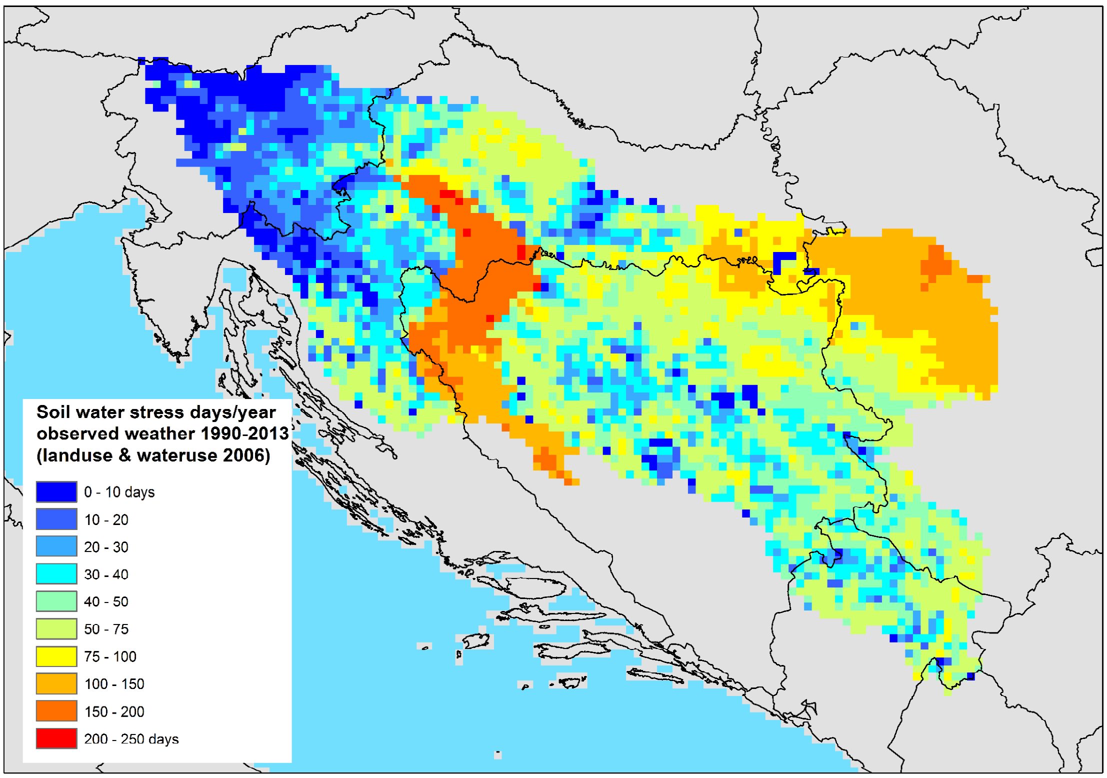

Figure 42 Average number of days per year with soil moisture stress, where vegetation/crop transpiration is limited, for observed weather 1990-2013, 2006 land use and water use.

5.3.6 Groundwater

Groundwater resource estimates (LZavg) are slightly decreasing in Slovenia under the projected land use changes. Due to the projected land use changes, simulations for Croatia show an increase in groundwater in the higher altitudes, and a decreasing amount in the Sava floodplain area

Bosnia-Herzegovina displays a small increase, as does lower Serbia. The higher areas in Serbia and Montenegro remain unchanged. However, if changes are made in water abstraction towards more groundwater abstraction instead of surface water abstraction, the decrease in groundwater resources are much larger, especially in the lower areas along the Sava in Croatia and Serbia.

Region	Obs_Use2010	Obs_Use2030	Obs-2030MaxIrg	Obs-Use2050	Obs_2050maxirg	Obs_2050maxirgLZ
Slovenia	REF	-5.64E+06	-5.23E+06	-7.82E+06	-7.39E+06	-9.09E+06
Croatia-low	REF	-1.57E+06	-1.44E+06	-1.29E+06	-1.16E+06	-4.67E+06
Croatia-high	REF	5.55E+05	5.34E+05	1.05E+06	1.03E+06	5.08E+04
Bosnia-low	REF	3.03E+04	4.45E+04	1.15E+05	1.29E+05	-4.27E+05
Bosnia-high	REF	2.09E+04	2.33E+04	1.46E+05	1.49E+05	3.08E+03
Serbia-low	REF	4.90E+04	1.13E+06	9.91E+04	1.18E+06	-5.60E+06
Serbia-high	REF	0.00E+00	1.98E+03	0.00E+00	1.98E+03	1.98E+03
Montenegro	REF	0.00E+00	1.80E+03	0.00E+00	1.80E+03	1.80E+03

Table 7 Projected groundwater changes in the Sava basin under the land use scenarios (average m3 change in groundwater resources; 2010 land use is reference here)

5.3.7 The Water Exploitation Index

The Water Exploitation Index (WEI) (withdrawal ratio) - defined as the mean annual total abstraction of fresh water divided by the freshwater resources – will obviously reflect the demand changes discussed earlier in the report.

Name	Obs_Use2006	Obs_Use2010	Obs_Use2030	Obs-2030MaxIrg	Obs-Use2050	Obs_2050maxirg	Obs_2050maxirgLZ	Obs_2050maxirgEPIC
Slovenia	0.0872	0.0889	0.0996	0.0997	0.1110	0.1111	0.1111	0.1148
Croatia-low	0.0099	0.0097	0.0094	0.0096	0.0089	0.0092	0.0092	0.0207
Croatia-high	0.0228	0.0220	0.0227	0.0228	0.0225	0.0225	0.0225	0.1049
Bosnia-low	0.0061	0.0061	0.0060	0.0064	0.0059	0.0063	0.0063	0.0139
Bosnia-high	0.0320	0.0318	0.0309	0.0310	0.0286	0.0286	0.0286	0.0840
Serbia-low	0.0574	0.0569	0.0549	0.0565	0.0518	0.0534	0.0534	0.1321
Serbia-high	0.0366	0.0365	0.0358	0.0361	0.0341	0.0343	0.0343	0.1624
Montenegro	0.0440	0.0439	0.0432	0.0434	0.0412	0.0414	0.0414	0.1720

Table 8 Average monthly WEI (abstraction ratio) for the Sava regions, for the various land use scenarios (WEI varies between 0 and 1, with values close to 1 indicating unsustainable demands).

WEI is projected to increase in Slovenia until 2050, but would increase everywhere under the hypothetical EpicMax increased maize irrigation scenario. Note that these are average monthly WEI values. Individual months may be more extreme.

The related Water Exploitation Index Plus (WEI+) (consumption ratio), is the total water consumption divided by the freshwater resources of a region and shows similar tendencies.

Name	Obs_Use2006	Obs_Use2010	Obs_Use2030	Obs-2030MaxIrg	Obs-Use2050	Obs_2050maxirg	Obs_2050maxirgLZ	Obs_2050maxirgEPIC
Slovenia	0.0052	0.0052	0.0057	0.0058	0.0060	0.0061	0.0061	0.0106
Croatia-low	0.0020	0.0019	0.0019	0.0021	0.0018	0.0020	0.0020	0.0131
Croatia-high	0.0036	0.0035	0.0036	0.0036	0.0035	0.0036	0.0036	0.0471
Bosnia-low	0.0015	0.0015	0.0015	0.0019	0.0015	0.0019	0.0019	0.0091
Bosnia-high	0.0056	0.0055	0.0053	0.0054	0.0049	0.0049	0.0049	0.0566
Serbia-low	0.0082	0.0081	0.0077	0.0094	0.0071	0.0088	0.0088	0.0717
Serbia-high	0.0052	0.0052	0.0051	0.0053	0.0047	0.0049	0.0049	0.1128
Montenegro	0.0060	0.0060	0.0058	0.0060	0.0054	0.0056	0.0056	0.1223

Table 9 Average monthly WEI+ (consumption ratio) for the Sava regions, for the various land use scenarios (WEI+ varies between 0 and 1, with values over 0.20 being critical).

5.4 Projected changes in water resources due to climate change

In this chapter the various effects of climate projections on water resources are discussed.

5.4.1 Water demand and use

The projections on water demand are basically constant for all the climate projections, and consistent with the observed weather control run, so no bias here.

As a consequence of land use change and irrigation increases, water demands are projected to increase, mainly in Slovenia (Table 10).

Under climate change projections especially the water demand for the hypothetical maize irrigation scenario increases even more than due to the irrigation change itself (Table 10). The land use change itself would lead to an increase in water demand from 2216 Mm3/year to 3337 Mm3/year. The additional climate forcing, likely due to the warmer temperatures and thus likely increased crop water needs, increases the water demand of this scenario to around 6000 Mm3/year. Impact on the water resources will be discussed in the following paragraphs.

Name	Obs_Use2006	Obs-Use2050	Obs_2050maxirg	Obs_2050maxirgEPIC	KNMI_RCP45_20712100_2050MaxEpic	KNMI_RCP85_20712100_2050MaxEpic	SMHI_RCP45_20712100_2050MaxEpic	SMHI_RCP85_20712100_2050MaxEpic	DMI_RCP45_20712100_2050MaxEpic	DMI_RCP85_20712100_2050MaxEpic	IPSL_RCP45_20712100_2050MaxEpic	IPSL_RCP85_20712100_2050MaxEpic
Slovenia	760.1	983.4	983.9	1000.9	1122.6	1166.5	1186.8	1241.3	1096.0	1146.6	1129.9	1131.1
Croatia-low	238.5	210.2	212.0	441.2	976.7	1095.1	1127.6	1214.9	812.6	976.4	1008.8	990.8
Croatia-high	57.0	54.1	54.1	110.7	277.9	336.4	323.5	370.2	226.9	306.7	253.1	249.0
Bosnia-low	123.3	141.9	142.0	274.6	585.6	653.5	695.6	724.4	494.9	605.3	608.7	593.5
Bosnia-high	247.3	220.5	220.6	432.8	925.9	1045.4	1235.3	1313.1	860.7	1061.0	1008.7	1039.0
Serbia-low	727.9	686.8	712.7	984.4	1449.8	1574.6	1628.3	1645.2	1326.4	1499.4	1513.7	1554.4
Serbia-high	28.8	26.2	26.3	46.5	99.4	118.2	138.6	147.5	95.9	131.7	124.8	141.6
Montenegro	33.0	31.3	31.3	45.5	85.3	96.7	118.3	125.2	83.9	107.9	93.3	106.8
Sum (m3)	2215.9	2354.4	2382.9	3336.7	5523.1	6086.5	6454.0	6781.7	4997.1	5834.9	5741.1	5806.2

Table 10 Projected changes in water demands for the hypothetical maize irrigation scenario (Mm3/year)

5.4.2 Overall water resources

Median discharge is projected to change only slightly for the 2011-2040, but is projected to increase by the end of the century with around 20% (Table 11). On average, the RCP4.5 scenario is a bit drier, and the RCP8.5 scenarios a bit wetter.

Name	River	Obs_Use2006	Obs-Use2050	Hist_Use2006	RCP45_20112040_Use2030	RCP85_20112040_Use2030	RCP_RCP45_20712100_Use2050	RCP_RCP85_20712100_Use2050		Dif RCP45_20112040_Use2030	Dif RCP85_20112040_Use2030	Dif RCP45_20712100_Use2050	Dif RCP85_20712100_Use2050
Banja Luka	Vrbas	37	37	15	14	15	17	19		-4	-3	16	27
Belgrade	Sava	1206	1209	586	576	600	692	735		-2	2	18	26
Brodarci	Kupa	131	131	56	49	54	68	70		-12	-2	22	27
Brodarevo	Lim	33	33	13	13	13	14	14		-2	0	13	13
Cedovo	Vapa	2	2	1	0	0	1	1		-11	-18	25	29
Cemanov most	Tamnava	1	1	0	0	0	0	0		7	50	78	104
Daljan	Vrbas	11	11	6	6	6	7	7		-6	-1	12	18
Davor	Crnac	806	810	445	432	453	526	549		-3	2	18	23
Doboj	Bosna	71	71	30	29	30	35	38		-3	-1	17	27
Donja Suvaja	Una	12	12	8	7	8	8	8		-3	0	8	8
Dubica	Una	227	227	164	161	161	178	181		-1	-2	9	10
Farkasic	Kupa	184	186	77	70	77	98	101		-9	0	27	31
Gorazde	Drina	36	36	7	6	6	7	7		-16	-4	8	6
Hrastnik	Sava	121	122	72	67	70	83	84		-7	-2	16	17
Jamnicka Kiselica	Kupa	166	167	73	66	73	92	95		-10	-1	26	30
Jasenovac	Sava	456	458	274	265	272	316	326		-3	-1	15	19
Jasenovac	Sava	732	735	418	403	424	491	512		-4	1	17	22
Kamanje	Kupa	37	37	16	15	16	20	21		-8	-2	28	32
Kozluk Jajce	Vrbas	25	25	13	12	12	14	15		-5	-3	13	18
Kupari	Kupa	8	8	3	3	3	4	4		-5	-3	27	28
Lesnica	Jadar	3	3	1	1	1	2	3		32	78	141	336
Litija I	Sava	115	116	69	64	67	80	80		-7	-2	16	16
Merdani	Lašva	12	12	6	6	6	7	7		-5	-2	15	20
Moste	Ljubljanica	37	37	19	17	18	23	23		-11	-2	21	24
Nazarje	Savinja	8	8	5	5	5	5	5		-3	-4	5	7
Olovo	Krivaja	4	4	1	1	1	1	1		-5	-6	-11	14
Pleternica	Orljava	3	3	0	0	0	1	0		-2	25	91	77
Podbocje	Krka	25	26	16	15	16	20	20		-4	0	24	24
Podsused/Ž	Sava	202	203	110	104	113	131	136		-6	3	19	23
Prijedor	Sana	43	43	20	20	20	23	24		-3	-2	12	16
Radalj	Drina	103	103	35	34	33	35	36		-1	-6	-1	4
Radovljica_I	Sava	29	29	23	22	22	24	24		-3	-2	8	6
Rakovec	Sotla	4	4	1	1	1	1	3		-6	10	25	182
Rugvica	Sava	209	211	114	108	118	137	142		-5	3	20	24
S.Mitrovica	Sava	1153	1156	553	542	566	653	692		-2	2	18	25
Sanski Most	Sana	30	30	15	14	14	16	17		-3	-3	12	13
Slavonski Brod	Sava	826	830	448	435	456	530	554		-3	2	18	23
Slovac	Kolubara	4	4	2	2	3	3	3		13	57	63	79
Stara Gradiska	Sava	738	742	419	404	425	493	514		-4	2	18	23
Suha	Sora	8	8	5	5	5	5	6		-7	-7	7	13
Valjevo	Kolubara	1	1	0	1	1	1	1		19	76	104	98
Veliko_Sirje_I	Savinja	21	21	9	8	9	11	12		-11	-1	18	29
Vrbanja	Vrbanja	4	4	2	2	2	2	2		-7	12	14	42
Zagreb	Sava	205	206	112	105	115	133	139		-6	3	19	24
Zupanja	Sava	931	935	494	481	503	583	615		-3	2	18	24
Sum		9017	9054	4754	4591	4815	5592	5846		-3	1	18	23

Table 11 Projected changes in median discharge (Q50, in m3/s) for the Sava basin. Averages of 4 climate models. The last 4 columns are the percentage change relative to the historic/control run 1981-2010.

5.4.2 Low-flow and Ecological flow

Low-flow simulations are reasonable consistent between the climate projections. There is a general bias (Table 12), as the control climate runs simulate Q01 (1 percentile discharge) around 32% lower than in the runs with observed weather forcing 1990-2013.

Name	River	Obs_Use2006	Obs_2050maxirgEPIC	Hist_Use2006	RCP45_20112040_Use2030	RCP85_20112040_Use2030	RCP45_20112040_2030MaxIrg	RCP85_20112040_2030MaxIrg	RCP45_20712100_Use2050	RCP85_20712100_Use2050	RCP45_20712100_2050MaxIrg	RCP85_20712100_2050MaxIrg	RCP45_20712100_2050MaxEpic	RCP85_20712100_2050MaxEpic
Banja Luka	Vrbas	7.8	7.4	1.7	1.3	1.6	1.3	1.6	2.1	2.1	2.1	2.1	0.4	0.3
Belgrade	Sava	240.0	160.2	170.5	155.7	166.3	161.9	173.4	190.9	191.4	197.8	200.3	60.2	44.9
Brodarci	Kupa	7.7	7.8	2.2	1.7	2.0	1.7	2.0	3.4	4.4	3.4	4.4	2.6	1.9
Brodarevo	Lim	2.7	0.7	2.9	3.0	3.1	3.0	3.1	3.1	3.1	3.1	3.1	0.2	0.2
Daljan	Vrbas	0.6	0.3	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1
Davor	Crnac	187.5	147.9	132.7	117.8	128.3	118.0	128.6	142.8	141.4	143.2	141.8	73.7	57.0
Doboj	Bosna	5.0	2.0	4.5	4.3	4.7	4.3	4.7	5.4	6.0	5.4	6.0	0.7	0.7
Donja Suvaja	Una	3.4	2.5	3.2	3.2	3.2	3.2	3.2	3.5	3.3	3.5	3.3	2.0	1.6
Dubica	Una	71.7	53.4	69.8	68.2	69.1	68.2	69.1	75.1	72.9	75.1	72.9	41.3	35.7
Farkasic	Kupa	16.4	11.5	3.5	3.2	3.2	3.2	3.2	6.4	6.2	6.4	6.2	2.9	2.1
Gorazde	Drina	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Hrastnik	Sava	27.5	27.0	14.5	13.4	14.7	13.4	14.7	17.6	15.5	17.6	15.6	13.0	11.3
Jamnicka Kiselica	Kupa	10.1	8.9	3.1	2.8	2.9	2.8	2.9	5.0	4.4	5.0	4.4	2.4	1.9
Jasenovac	Sava	107.6	76.7	88.7	80.9	83.1	80.8	83.1	96.4	94.6	96.3	94.5	46.1	36.0
Jasenovac	Sava	170.0	137.7	125.0	111.6	120.9	112.0	121.2	137.1	136.0	137.3	136.3	73.7	56.6
Kamanje	Kupa	3.2	3.2	0.7	0.5	0.7	0.5	0.7	1.3	1.3	1.3	1.3	0.8	0.5
Kozluk Jajce	Vrbas	2.5	0.8	0.8	0.6	0.7	0.6	0.7	1.0	0.8	1.0	0.8	0.3	0.2
Kupari	Kupa	1.5	1.5	0.4	0.1	0.3	0.1	0.3	0.7	0.5	0.7	0.5	0.7	0.5
Litija I	Sava	25.8	25.4	14.3	13.2	14.4	13.2	14.4	17.2	15.2	17.3	15.3	13.2	11.4
Merdani	Lašva	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.6	0.6	0.6	0.6	0.1	0.1
Moste	Ljubljanica	2.1	0.9	0.5	0.3	0.4	0.4	0.5	0.7	0.6	0.7	0.7	0.3	0.3
Nazarje	Savinja	3.7	3.0	2.4	2.0	2.3	2.0	2.3	2.6	2.4	2.6	2.4	1.4	1.0
Podbocje	Krka	7.6	4.9	5.7	5.5	5.6	5.5	5.6	6.7	6.2	6.7	6.2	1.5	0.8
Podsused/Ž	Sava	43.7	41.5	24.8	21.0	26.0	21.2	26.1	30.7	27.4	30.8	27.6	16.7	13.4
Prijedor	Sana	3.9	1.0	2.8	2.6	2.7	2.6	2.7	3.2	2.4	3.2	2.4	0.3	0.3
Radalj	Drina	4.8	1.8	5.1	4.7	5.3	4.7	5.3	5.4	5.2	5.4	5.2	0.5	0.4
Radovljica_I	Sava	8.1	6.3	4.1	4.0	4.0	4.0	4.0	4.2	4.1	4.2	4.1	5.2	5.1
Rugvica	Sava	44.4	41.6	25.2	21.4	26.6	21.6	26.7	31.4	28.0	31.6	28.3	16.2	12.9
S.Mitrovica	Sava	222.8	166.7	158.1	142.8	153.3	144.9	155.4	174.7	171.1	177.4	174.8	65.2	46.5
Sanski Most	Sana	1.4	0.5	1.1	0.9	0.9	0.9	0.9	1.1	0.9	1.1	0.9	0.2	0.2
Slavonski Brod	Sava	193.3	147.5	133.4	118.6	129.2	119.0	129.6	143.1	143.4	143.3	143.8	72.1	55.3
Stara Gradiska	Sava	171.7	139.4	125.8	111.8	121.6	112.1	121.8	138.1	136.4	138.2	136.7	73.5	56.5
Suha	Sora	1.3	1.3	0.3	0.1	0.3	0.1	0.3	0.5	0.3	0.5	0.3	0.2	0.1
Veliko_Sirje_I	Savinja	3.7	3.9	2.6	2.2	2.5	2.2	2.6	2.8	2.6	2.9	2.7	0.6	0.2
Zagreb	Sava	43.8	41.4	24.9	21.2	26.2	21.3	26.4	30.9	27.5	31.1	27.8	16.7	13.4
Zupanja	Sava	206.7	155.6	144.9	131.7	143.0	132.1	143.2	163.8	164.5	163.9	164.9	68.8	52.6
SUM		2967.4	2309.5	2021.3	1817.7	1978.3	1842.0	2004.3	2276.6	2221.9	2306.0	2260.1	1026.1	799.3
change				REF	-10.07	-2.125	-8.867	-0.839	12.63	9.928	14.09	11.82	-49.23	-60.5

Table 12 Low-flow (Q01, 1 percentile discharge) for selected gauges in the Sava basin under various land use and climate scenarios (averages of 4 models).

Likely cause of this bias is that the E-obs dataset which has been used for the Cordex bias-correction of climate scenarios for Europe, does not contain all the mountain precipitation that is available in the JRC gridded observed meteorological dataset.

For the 2011-2040 scenarios, a moderate decrease of lowflow is projected, where RCP8.5 is again a little wetter than RCP4.5 by. For the end of the century 2071-2100, lowflow values are projected to moderately increase as compared to the control 1981-2010 climate. The EpicMax scenario would result in a severe decrease of the lowflow discharges with 50-60%, even when a considerable amount of water would not be available, as discussed later in this report.

Name	Obs_Use2006	Obs_2050maxirgEPIC	Hist_Use2006	RCP45_20112040_2030	RCP85_20112040_2030	RCP45_20712100_2050	RCP85_20712100_2050	RCP45_20712100_MaxEpic	RCP85_20712100_MaxEpic
Slovenia	REF	0.05	REF	7.15	2.09	-17.87	-14.68	-15.37	-11.11
Croatia-low	REF	3.89	REF	-1.29	-3.38	-12.87	-20.36	-11.83	-18.00
Croatia-high	REF	4.46	REF	3.01	0.45	-13.65	-15.56	-8.75	-10.05
Bosnia-low	REF	0.93	REF	-1.04	-1.41	-8.22	-15.69	-13.05	-19.10
Bosnia-high	REF	7.27	REF	2.96	2.75	-11.13	-15.30	1.97	1.27
Serbia-low	REF	38.08	REF	-6.81	-7.22	-15.88	-20.51	33.93	31.67
Serbia-high	REF	-0.54	REF	-1.25	-0.73	-7.74	-11.17	-10.54	-12.33
Montenegro	REF	0.03	REF	3.67	2.61	-2.47	-0.57	-3.18	-1.32
TOTALS		4.96		0.97	-0.56	-10.92	-14.23	-6.73	-8.77

Table 13 E-flow percent changes under land use and climate change projections in the Sava basin (averages of 4 climate models). The Eflow indicator reflects the average number of days per year that minimum flow conditions are not reached.

Table 13 shows that E-flow is not significantly changing until 2030, where RCP4.5 is again slightly drier and thus producing more days that fellow cannot be met, than RCP 8.5. Projections for end of the century are wetter, leading to 11% decreases of eflow breaching days (RCP4.5) up to 14% for the wetter RCP8.5 scenario.

The excessive irrigation scenario (EpicMax) would increase Eflow breaching days with 5% under current climate. Under end of the century climate, Eflow issues for the Sava basin would reduce also under this scenario. An exception would be the lower Serbia Sava floodplain, where Eflow issues would worsen by around 33%.

5.4.3 Flood hazard

The Sava basin is vulnerable for flooding, as the events in 2014 clearly demonstrated. Therefore, knowledge about future prospects is extremely important, to raise awareness and facilitate adequate planning measures.

As discussed earlier, land use change until 2050 alone as projected for the Sava basin does not seem to influence flood peaks very clearly.

When we add however the climate signal with the various scenarios, we do simulate an overall increase in the Q99.95 flood peaks with 13% for the 2011-2040 period (both RCP4.5 and RCP8.5) and a 23% increase for the 2071-2100 period (also both RCP's).

We have averaged the outcomes of the 4 different climate models, as they do vary, and sometimes vary considerably. It should also be noted that the baseline historic 1981-2010 climate runs, which should reflect current weather, do simulate considerably less (35%) Q99.95 peak discharge than the control run 2006 with observed weather 1990-2013, even though some bias correction was carried out.

Results for gauges should not be interpreted too rigidly, as the spatial resolution of the climate models is rather coarse, and there is variability among the climate models, but we have enclosed the results for a selection of gauges in the Sava basin in the enclosed table 12.

The maps on the consecutive pages give a spatial image of the changing flood risk.

Name	River	Obs_Use2006	Obs-Use2050	Hist1981-2010	RCP45_20112040_Use2030	RCP85_20112040_Use2030	RCP45_20712100_Use2050	RCP85_20712100_Use2050		Dif RCP45_20112040_Use2030	Dif RCP85_20112040_Use2030	Dif RCP45_20712100_Use2050	Dif RCP85_20712100_Use2050
Banja Luka	Vrbas	373	373	159	191	184	166	184		20	15	4	16
Belgrade	Sava	8449	8459	4721	5147	5083	5405	5654		9	8	14	20
Brodarci	Kupa	1833	1824	1232	1366	1306	1411	1466		11	6	15	19
Brodarevo	Lim	549	549	207	235	269	264	283		13	30	27	36
Cedovo	Vapa	39	39	29	32	34	36	36		9	15	25	23
Cemanov r	Tamnava	66	66	19	22	31	31	41		13	61	65	113
Daljan	Vrbas	271	271	133	159	145	162	177		19	9	22	34
Davor	Crnac	5452	5387	3675	4477	4380	4861	4463		22	19	32	21
Doboj	Bosna	1645	1645	793	941	892	937	1254		19	13	18	58
Donja Suva	Una	100	99	55	56	51	55	57		3	-8	0	4
Dubica	Una	1140	1140	740	773	778	846	938		4	5	14	27
Farkasic	Kupa	2583	2511	1688	1991	1968	2109	2018		18	17	25	20
Gorazde	Drina	928	928	426	473	503	499	473		11	18	17	11
Hrastnik	Sava	1360	1374	1358	1289	1333	1470	1607		-5	-2	8	18
Jamnicka K	Kupa	2534	2498	1664	1933	1878	2025	1957		16	13	22	18
Jasenovac	Sava	3776	3764	2388	2725	2582	2862	2767		14	8	20	16
Jasenovac	Sava	5351	5256	3569	4336	4321	4681	4297		21	21	31	20
Kamanje	Kupa	653	647	451	488	535	609	621		8	19	35	38
Kozluk Jajc	Vrbas	412	412	198	235	207	238	245		19	5	20	24
Kupari	Kupa	178	178	148	150	158	159	187		1	7	7	26
Lesnica	Jadar	181	181	73	101	97	151	167		38	33	105	128
Litija I	Sava	1330	1363	1325	1262	1314	1434	1577		-5	-1	8	19
Merdani	Lašva	225	225	101	120	117	123	156		18	16	22	54
Moste	Ljubljanica	391	395	344	372	369	434	483		8	7	26	41
Nazarje	Savinja	210	210	154	153	182	178	206		-1	18	16	33
Olovo	Krivaja	148	148	70	68	77	68	91		-4	9	-3	29
Pleternica	Orljava	93	95	25	25	27	32	35		-2	7	26	39
Podbocje	Krka	401	402	306	367	377	446	472		20	23	46	54
Podsused/	Sava	2418	2427	1804	1941	2066	2243	2463		8	15	24	37
Prijedor	Sana	574	574	336	350	351	367	468		4	4	9	39
Radalj	Drina	1559	1559	650	721	694	701	701		11	7	8	8
Radovljica	Sava	325	325	446	426	436	477	515		-4	-2	7	16
Rakovec	Sotla	94	94	96	93	98	123	158		-2	2	29	65
Rugvica	Sava	2480	2491	1816	2002	2108	2264	2490		10	16	25	37
S.Mitrovic	Sava	7523	7521	4595	5114	4940	5291	5351		11	8	15	16
Sanski Mo	Sana	425	425	219	230	222	230	266		5	1	5	21
Slavonski B	Sava	5529	5473	3694	4485	4406	4887	4511		21	19	32	22
Slovac	Kolubara	226	222	106	149	151	184	208		40	42	74	96
Stara Grad	Sava	5376	5316	3555	4267	4305	4712	4302		20	21	33	21
Suha	Sora	266	266	279	267	275	313	358		-4	-1	12	28
Valjevo	Kolubara	72	72	30	39	44	53	66		32	48	79	120
Veliko_Sirj	Savinja	544	548	419	435	470	542	581		4	12	29	39
Vrbanja	Vrbanja	143	143	102	114	96	103	135		12	-6	0	32
Zagreb	Sava	2450	2461	1809	1971	2082	2266	2474		9	15	25	37
Zupanja	Sava	6182	6181	4061	4680	4615	4985	4669		15	14	23	15
Sum		76853	76535	50070	56770	56555	61435	61631		13	13	23	23

Table 14 Changing Q99.95 discharges (m3/s) for selected gauges in the Sava basin, as a consequence of climate and land use change, averaged for the 4 climate models. The last 4 columns give the percentage change as compared to the control runs 1981-2010.

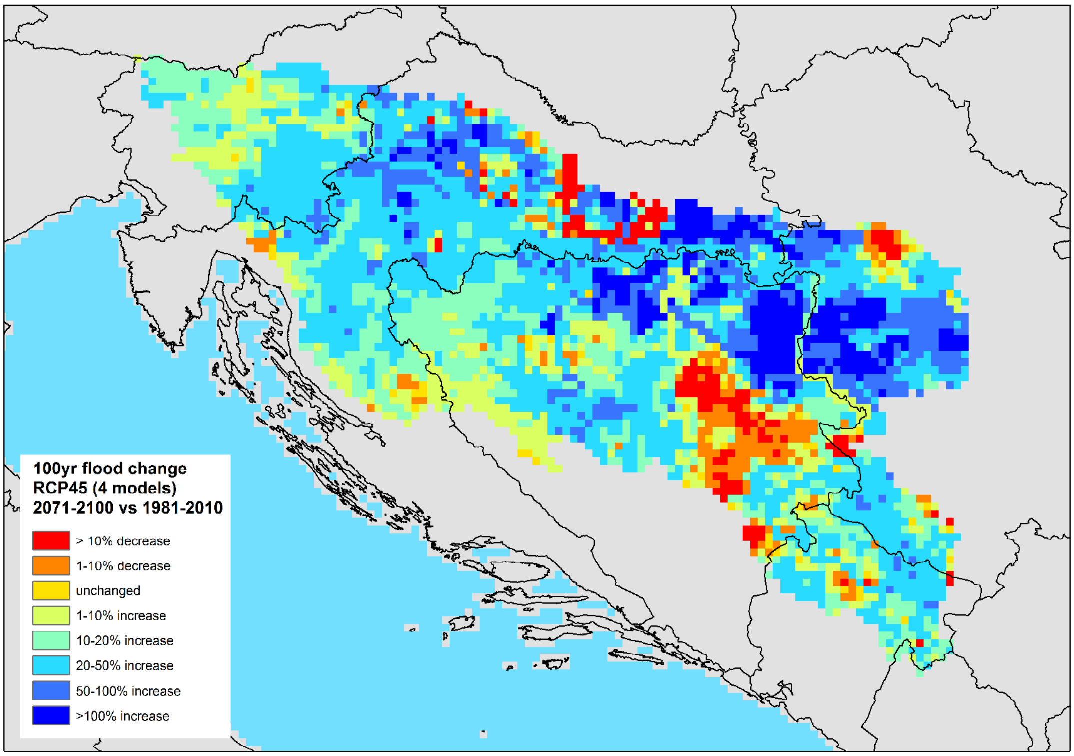

Figure 43 Projected changes in extreme flooding (HQ100) for the RCP45 scenario: 2071-2100 vs 1981-2010 (average of KNMI, SMHI, IPSL and DMI models).

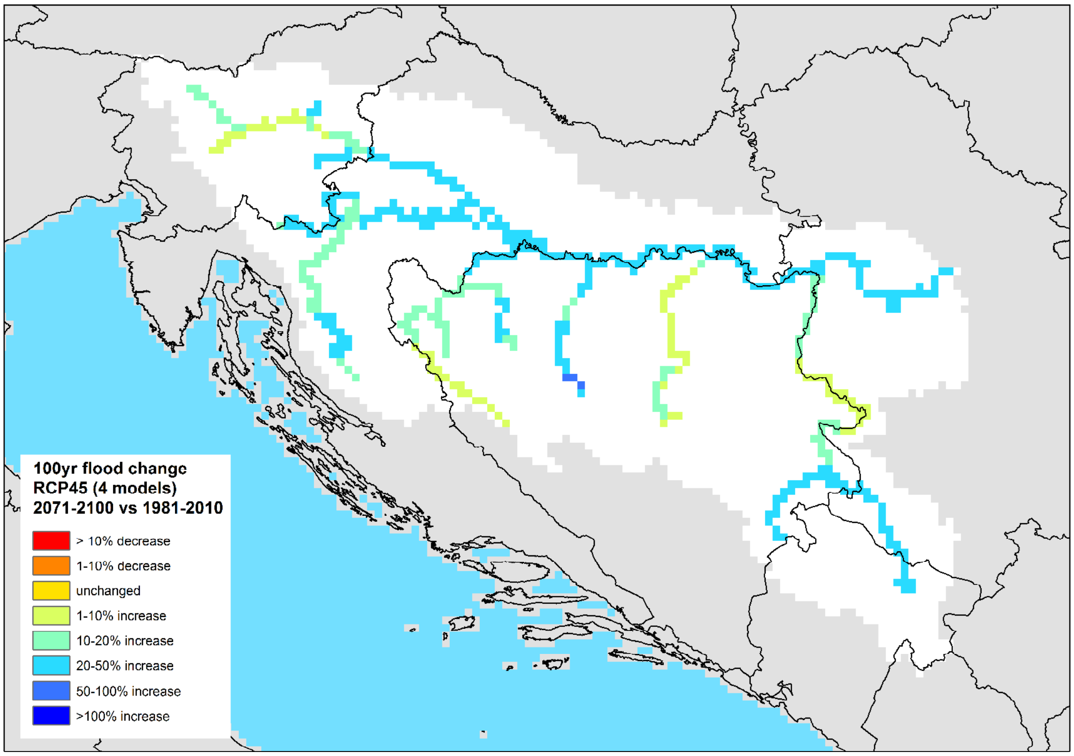

Figure 44 Projected changes in extreme flooding (HQ100) for the RCP45 scenario: 2071-2100 vs 1981-2010 (average of KNMI, SMHI, IPSL and DMI models) (main rivers displayed only).

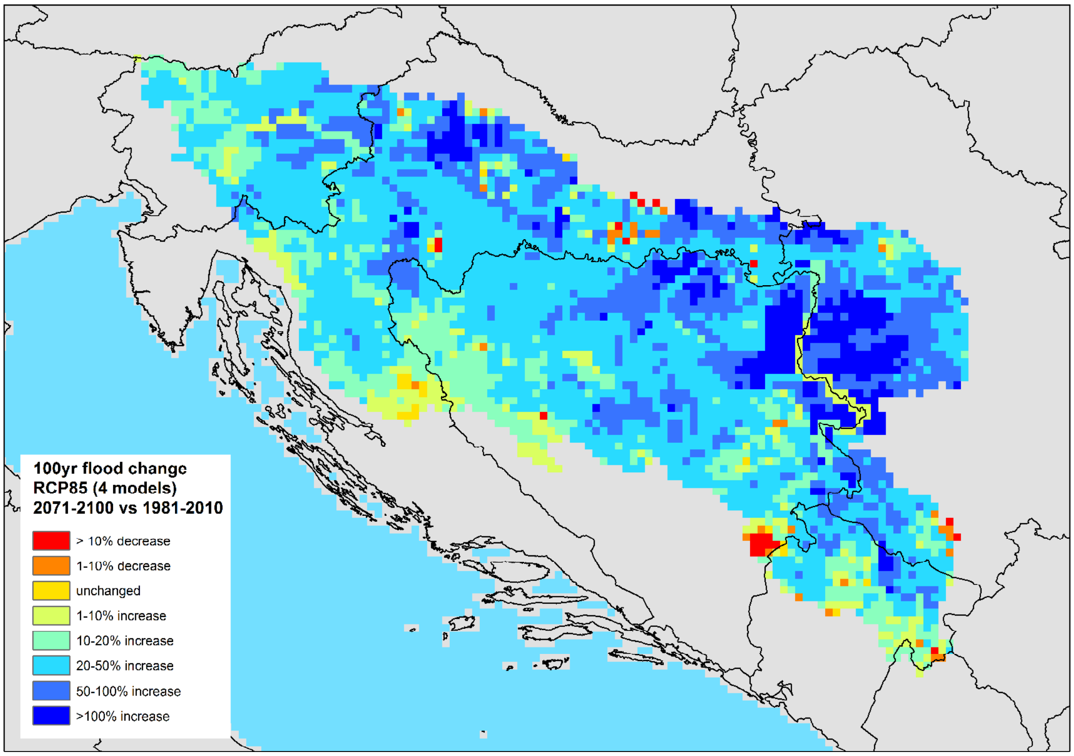

Figure 45 Projected changes in extreme flooding (HQ100) for the RCP85 scenario: 2071-2100 vs 1981-2010 (average of KNMI, SMHI, IPSL and DMI models).

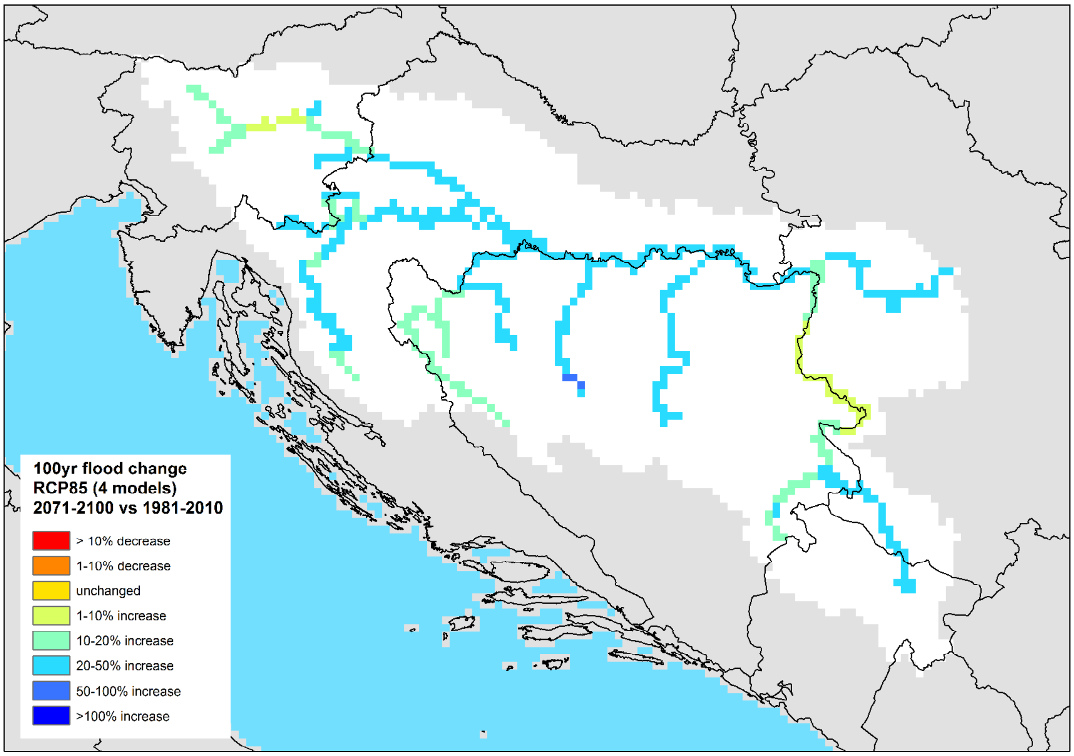

Figure 46 Projected changes in extreme flooding (HQ100) for the RCP85 scenario: 2071-2100 vs 1981-2010 (average of KNMI, SMHI, IPSL and DMI models) (main rivers displayed only).

5.4.4 Water availability for power stations

As energy production is essential in the Sava basin, the changes in water availability for several hydropower stations and thermal power stations have been examined as well.

Name	Obs_Use2006	Hist_Use2006	RCP45_20112040_2030	RCP85_20112040_2030	RCP45_20712100_2050	RCP45_20712100_MaxEpic	RCP85_20712100_2050	RCP85_20712100_MaxEpic
Brezice	185.9	105.9	99.2	103.9	125.2	126.0	128.3	127.6
CHP Sremska Mitrovica	1155.4	554.1	543.9	568.4	655.2	642.0	694.8	683.0
CHP TE TO Zagreb	205.3	112.3	106.1	116.0	134.2	135.8	139.5	139.5
CHP Toplarna Ljubljana	54.9	36.7	34.3	35.3	40.7	41.3	40.7	40.7
HPP Arto-Blanco	154.2	85.3	80.1	84.3	99.9	100.9	101.8	103.0
HPP Bajina Basta RoR	95.2	30.4	31.4	30.6	31.2	30.2	31.2	30.3
HPP Bistrica	36.8	15.0	14.9	15.1	17.1	17.7	17.4	17.9
HPP Bocac	31.9	13.8	13.1	13.3	15.9	16.5	17.1	17.9
HPP Bostanj	153.5	85.1	80.0	84.1	99.5	100.6	101.5	102.6
HPP Gojak	81.2	35.4	30.8	33.9	41.2	45.1	42.5	46.3
HPP Jajce I	25.2	12.7	12.0	12.2	14.4	14.8	15.0	15.6
HPP Jajce II	28.7	13.5	12.9	13.0	15.4	15.9	16.4	17.1
HPP Kokin Brod	4.9	1.8	1.8	1.8	1.9	1.7	1.9	1.8
HPP Krsko	155.4	85.7	80.2	84.6	100.5	101.3	102.5	103.7
HPP Lesce	82.7	35.5	31.0	33.9	41.7	45.7	43.1	47.1
HPP Mavcice	42.6	30.0	28.6	29.1	33.1	33.2	32.5	32.9
HPP Medvode	53.8	35.7	33.5	34.4	39.6	40.3	39.8	39.8
HPP Moste	11.9	11.4	11.0	11.3	11.6	11.5	12.7	12.6
HPP Piva	9.7	2.6	2.6	2.6	2.6	2.6	2.6	2.5
HPP Potpec	37.1	14.7	14.5	14.8	16.9	17.5	17.2	17.8
HPP Uvac	3.6	1.5	1.6	1.5	1.6	1.5	1.6	1.6
HPP Visegrad	94.2	29.4	28.8	28.2	30.3	31.4	31.8	33.3
HPP Vrhovo	148.2	83.2	78.1	81.9	96.8	97.6	98.9	99.8
HPP Zvornik	105.1	32.5	33.4	31.6	33.0	32.9	33.8	33.3
Modrac	7.5	2.8	2.9	2.8	5.4	4.9	5.0	4.8
Mokrice	191.3	107.4	100.6	111.1	127.4	128.7	130.9	131.5
Ozalj	36.9	15.9	14.7	15.6	20.4	21.1	21.1	21.6
TPP Brestanica	154.8	85.6	80.3	84.5	100.2	101.1	102.2	103.3
TPP Kakanj	19.5	10.6	9.9	9.9	11.6	11.3	12.6	12.3
TPP Kolubara	2.4	1.6	1.6	1.6	1.9	1.9	1.9	1.9
TPP Nikola Tesla A	1178.8	570.0	562.0	586.0	675.6	654.7	717.4	698.2
TPP Nikola Tesla B	1166.1	560.9	553.5	577.4	665.8	649.0	705.7	689.5
TPP Tuzla	1.0	0.7	0.6	0.5	1.3	1.3	0.9	0.9
TPP/CHP Sisak	201.9	89.7	83.7	90.4	113.0	111.4	118.2	116.7
Sum	5917.7	2909.2	2813.8	2945.8	3421.9	3389.5	3580.2	3548.3
Change		REF	-3.278	1.2564	17.622	16.51	23.066	21.968

Table 15 Median discharge (Q50, in m3/s) for several hydropower and thermal power stations in the Sava basin (average of 4 climate models).

Table 15 shows again the bias for the climate runs versus the observed weather simulations. When we take the Climate control runs 1981-2010 as a reference, we find an average decrease of Q50 of 3.3% for 2030 under RCP4.5, whereas RCP8.5 would result in a 1.3% increase. End of the century simulations yield a 17.6% higher Q50 for RCP4.5 and 23.1% higher for RCP8.5. The extreme EpicMax irrigation scenario would result in a reduction of water available to the power stations, assuming that parts of the water would be taken from the reservoirs. However, if reservoirs are made multifunctional, the irrigation water needed downstream can first be used to produce energy upstream.

5.4.5 Soil water stress

Soil water stress conditions are an important indicator for rain-fed agriculture. Severe and or frequent water stress conditions limit the transpiration potential of the crop or vegetation, especially during crucial stages in the growing season, and will lead to decreases in crop yield.

Under current climate the lower parts of Bosnia-Herzegovina, Croatia and Serbia most frequently experience soil water stress. Climate models again show a bias as compared to the observed weather model run 2006. If we take the climate models control period 1981-2010 as a reference, we see an increase of soil water stress of 9% for 2030, both for RCP4.5 and RCP8.5. For the end of the century, RCP4.5 shows a 1% increase, whereas RCP8.5 shows a 7% increase in soil water stress. This might indicate stronger needs for irrigation in the future to maintain current crop yields.

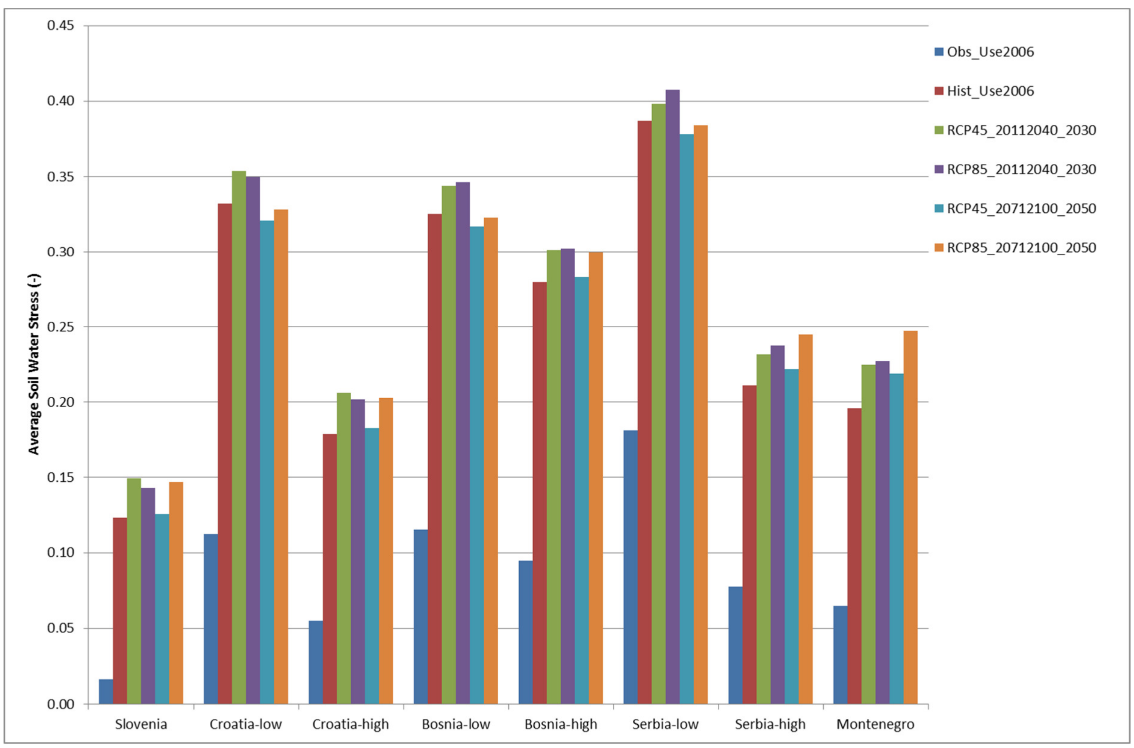

Figure 47 Changes in average soil water stress (0= no stress, 1= always stress) for the various land use and climate change runs (average of 4 climate models).

Name	Obs_Use2006	Hist_Use2006	RCP45_20112040_2030	RCP85_20112040_2030	RCP45_20712100_2050	RCP85_20712100_2050
Slovenia	0.016	0.123	0.149	0.143	0.126	0.147
Croatia-low	0.112	0.332	0.353	0.350	0.321	0.328
Croatia-high	0.055	0.179	0.206	0.202	0.183	0.203
Bosnia-low	0.115	0.325	0.344	0.346	0.317	0.323
Bosnia-high	0.095	0.280	0.301	0.302	0.283	0.300
Serbia-low	0.181	0.387	0.398	0.408	0.378	0.384
Serbia-high	0.078	0.211	0.232	0.238	0.222	0.245
Montenegro	0.065	0.196	0.225	0.227	0.219	0.247
Sum	0.717	2.034	2.209	2.216	2.048	2.177
Perc. Change		REF	8.65	8.98	0.73	7.05

Table 16 Changes in Soil water stress under various land use and climate model projections (average of 4 climate models). The indicator varies between 0 (never soil water stress) and 1 (always completely stressed, no transpiration possible all year)

5.4.6 Groundwater

Groundwater is simulated in a simplified way in LISFLOOD, but includes recharge, pumping for irrigation where appropriate, and baseflow, as well as local groundwater flow to neighbouring cells.

For the climate runs (figure 47) we simulate a moderate decrease of groundwater resources for Slovenia and the higher parts of Croatia and Bosnia Herzegovina until 2030, both for RCP45 and RCP85, where RCP85 is again a bit wetter. For the end of the century runs we observe increases in groundwater resources.

Increased irrigation practices (scenarios indicated MaxEpic) would seriously reduce groundwater resources again, and also if relatively more groundwater is used for irrigation replacing surface water, groundwater resources decrease as well (scenarios indicated 2050LZ).

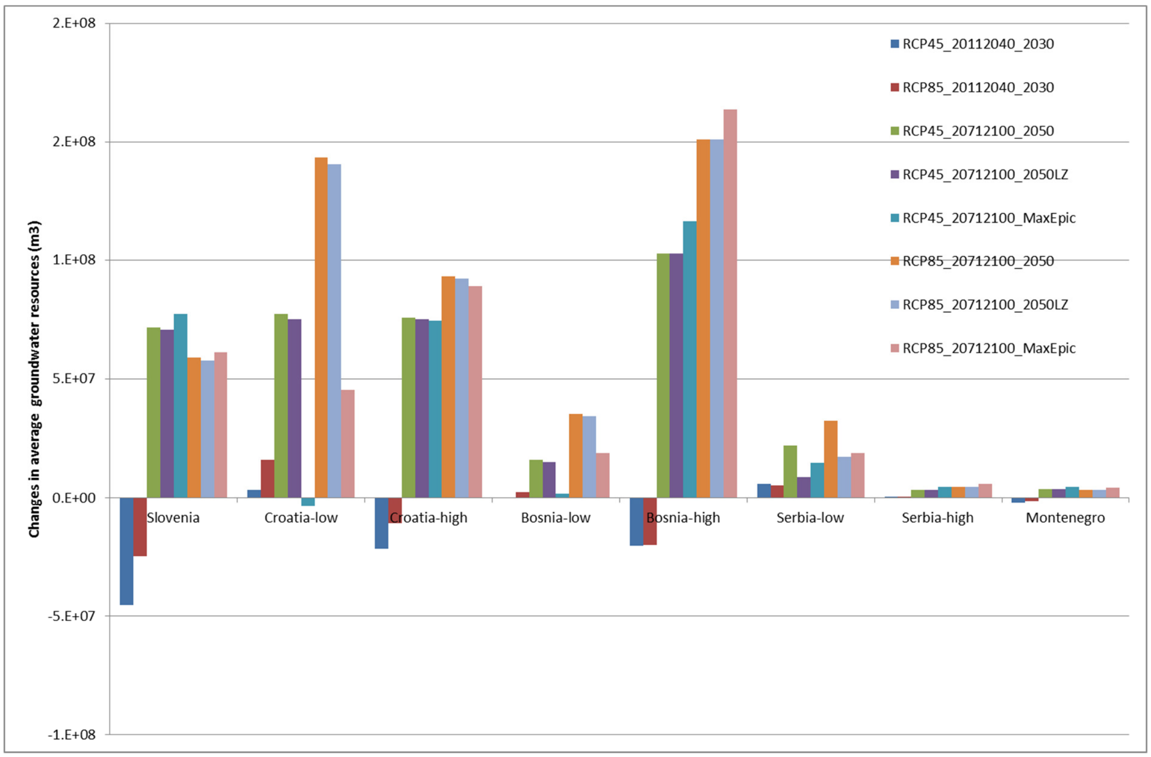

Figure 48 projected changes in average groundwater resources (m3) for the Sava river basin. Averages of 4 climate models.

5.4.7 The Water Exploitation Index

The Water Exploitation Index (WEI+) values, representing net water consumption versus available water (local flow, and upstream inflow if present), is relatively low in the Sava basin, indicating the still limited water consumption versus availability.

The WEI+ is projected to increase until 2030, and even more so if irrigated areas are extended. But, still, values are relatively low when compared to other international areas.

For the end of the century, water availability increases considerably. Therefore, WEI+ decreases, although it must be noted here that (urban, industrial and forest) landuse changes are projected for Slovenia and Croatia only.

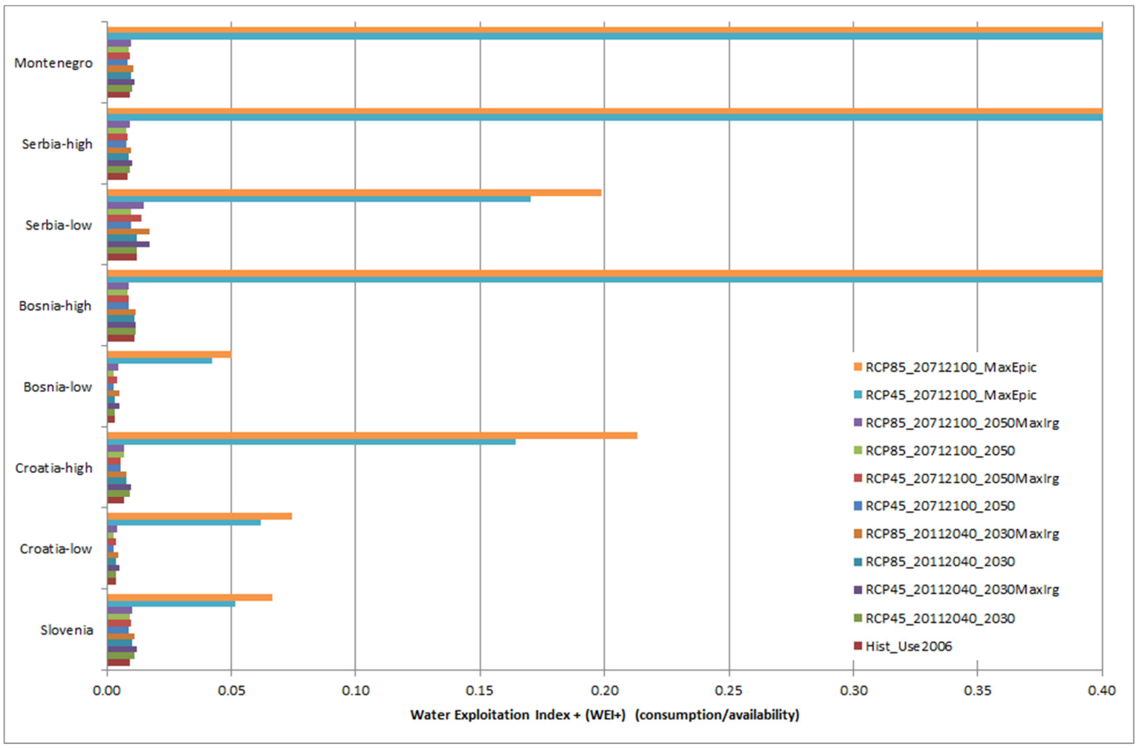

Figure 49 Changes in the Water Exploitation Index (WEI+) due to land use and climate change (averages of 4 climate models).

The excessive irrigation scenario (EpicMax) is unfeasible for Montenegro and the higher parts of Bosnia Herzegovina and Serbia. The freshwater is simply not available to meet the crop requirements, should maize be irrigated in those areas. Close to the Sava river, while using the Sava river water, the WEI would stay within the 0.20 limit, which is often used to indicate water scarcity. However, it should be noted that what is displayed here, are average WEI+ values. Monthly WEI+ show a larger variability, and indicate water scarce seasons.

Name	Hist_Use2006	RCP45_20112040_2030	RCP45_20112040_2030MaxIrg	RCP85_20112040_2030	RCP85_20112040_2030MaxIrg	RCP45_20712100_2050	RCP45_20712100_2050MaxIrg	RCP85_20712100_2050	RCP85_20712100_2050MaxIrg	RCP45_20712100_MaxEpic	RCP85_20712100_MaxEpic
Slovenia	0.0092	0.0109	0.0120	0.0103	0.0112	0.0087	0.0095	0.0092	0.0102	0.0515	0.0663
Croatia-low	0.0037	0.0038	0.0048	0.0036	0.0046	0.0029	0.0037	0.0029	0.0039	0.0619	0.0746
Croatia-high	0.0069	0.0094	0.0096	0.0077	0.0079	0.0056	0.0057	0.0067	0.0069	0.1644	0.2133
Bosnia-low	0.0032	0.0034	0.0051	0.0032	0.0050	0.0027	0.0042	0.0028	0.0044	0.0421	0.0504
Bosnia-high	0.0111	0.0115	0.0117	0.0113	0.0115	0.0087	0.0088	0.0085	0.0087	0.5675	0.9036
Serbia-low	0.0120	0.0118	0.0169	0.0118	0.0169	0.0095	0.0139	0.0097	0.0147	0.1704	0.1985
Serbia-high	0.0085	0.0091	0.0100	0.0090	0.0098	0.0076	0.0084	0.0080	0.0090	1.6612	2.9199
Montenegro	0.0094	0.0101	0.0109	0.0099	0.0107	0.0084	0.0092	0.0088	0.0097	1.6757	2.9825
Average	0.0080	0.0087	0.0101	0.0083	0.0097	0.0068	0.0079	0.0071	0.0085	0.5493	0.9262
Percentage Change		9.3	26.5	4.3	21.1	-15.6	-1.0	-11.6	5.7	6760	11466

Table 17 Changes in the Water Exploitation Index (WEI+) due to land use and climate change (averages of 4 climate models).

5.5 Sectorial impacts of future land use, climate, and water demand changes

Below we aim to summarize projected impacts for various sectors in the Sava basin.

5.5.1 Irrigated Agriculture

According to simulations done at JRC with the EPIC model, there is a potential in the Sava river basin to optimize and increase the yield of for example maize with increased irrigation.

Under a baseline scenario analysis (figures 49 & 50) - considering only area currently cultivated with maize and the relative share irrigated - 6.5 Mm3 water is currently used for irrigation. When the maize crop is irrigated , 200-300 mm irrigation water per year is required.

In the potential scenario (EpicMax, figures 51 & 52), irrigation requirements would be still quite limited in the North-western part of the Sava basin, moderate in mostly of the basin and high in other small regions (already equipped for irrigation). Under this scenario the total use of irrigation water is about 1600 Mm3, instead of the 6.5 Mm3 currently used.

In the northwestern region because of limited water stress, high maize crop yields are achieved also under current management strategies (however, always < 9 tons ha-1). Medium level of productivity has been observed mainly in the Croatian region of the Sava River Basin.

With the introduction of extended use of water irrigation all regions in the Sava River basin resulted in a medium high crop yield productivity with values ranging between 9-11 tons ha-1. The average simulated maize yield in the basin is 10 tons ha-1.

Land mostly cultivated with maize is currently located in the North-eastern part of the River basin and we estimated the highest level of total production in this region (mainly in Bosnia and Herzegovina part of the basin). In this area the current production is already quite high but by increasing the irrigation an increase of +80 - + 120% can be reached (Figure 51).

The average simulated maize yield could increase from 5.7 tons/ha at present conditions to 9.9 tons/ha in case of optimum irrigation. To realise this potential crop yield increase, 200-300 mm water would be needed for the newly irrigated areas.

However, this maize irrigation scenario (EpicMax) is unfeasible for large parts of the Sava basin. Should all maize be irrigated in those areas, there is simply insufficient freshwater to meet the crop requirements (figure 54). There would be also widespread issues with low-flow and breaching e-flow conditions. Figure 54 shows the annual water shortage for this scenario under current weather conditions, 4 baseline climate runs, 4 runs for RCP45, and 4 runs for RCP85. The climate runs in any case simulate more water shortage than the run with the observed weather. Largest water shortages would occur in Croatia. Close to the Sava river in Croatia, Bosnia Herzegovina and Serbia, while using the Sava river water, there would be more possibilities for this scenario, but seasonal water scarcity will occur.

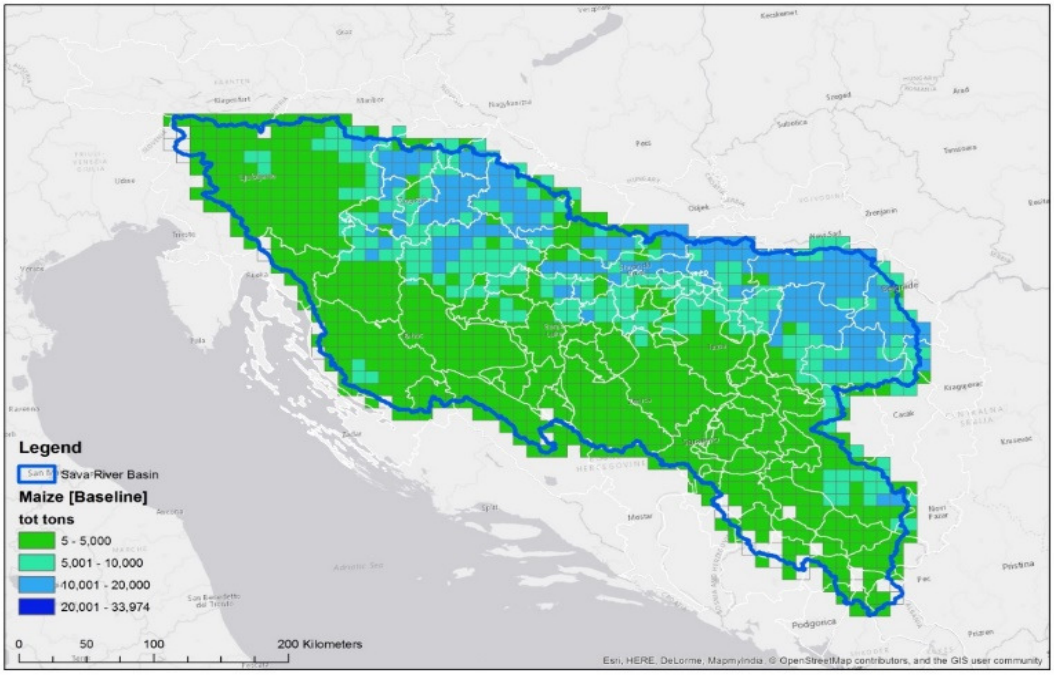

Figure 50 Current estimated maize crop yield (source: JRC EPIC model)

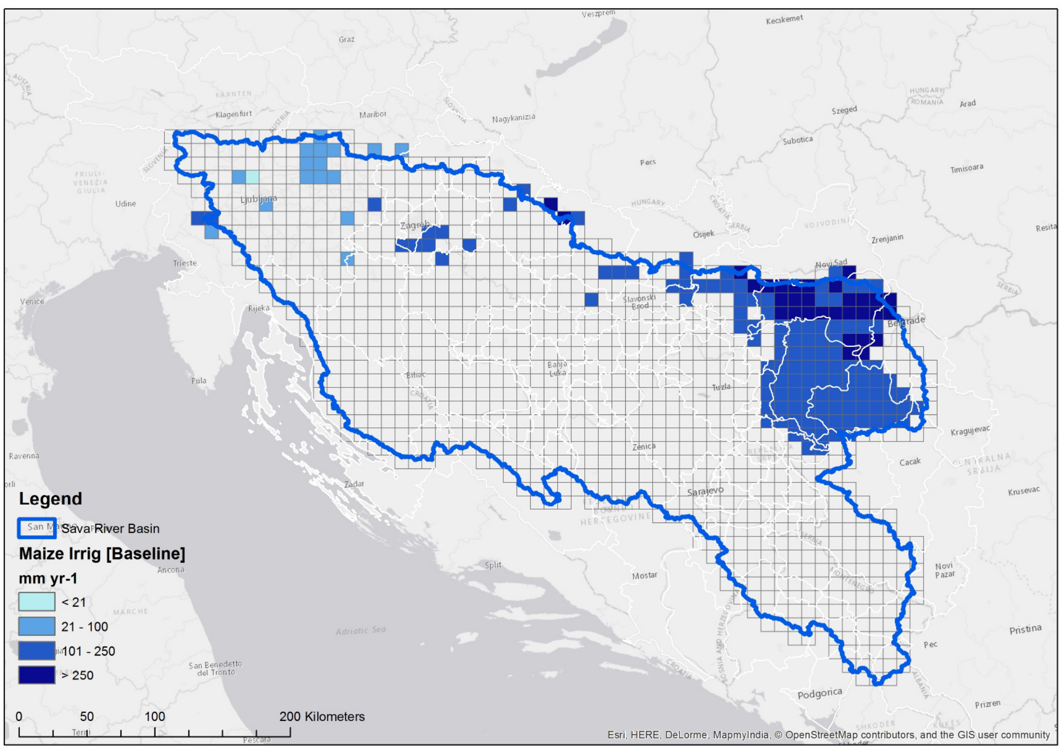

Figure 51 Current water requirements for maize irrigation (source: JRC EPIC model)

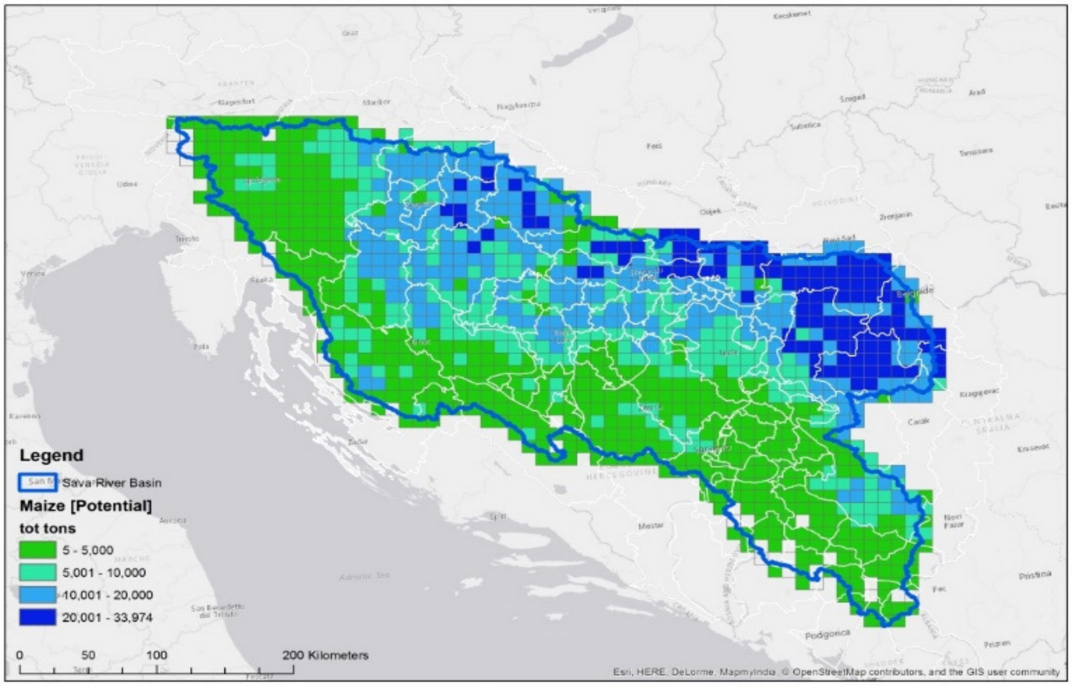

Figure 52 Possible maize yield under maximum irrigation of all maize cultivated areas (source: JRC EPIC model)

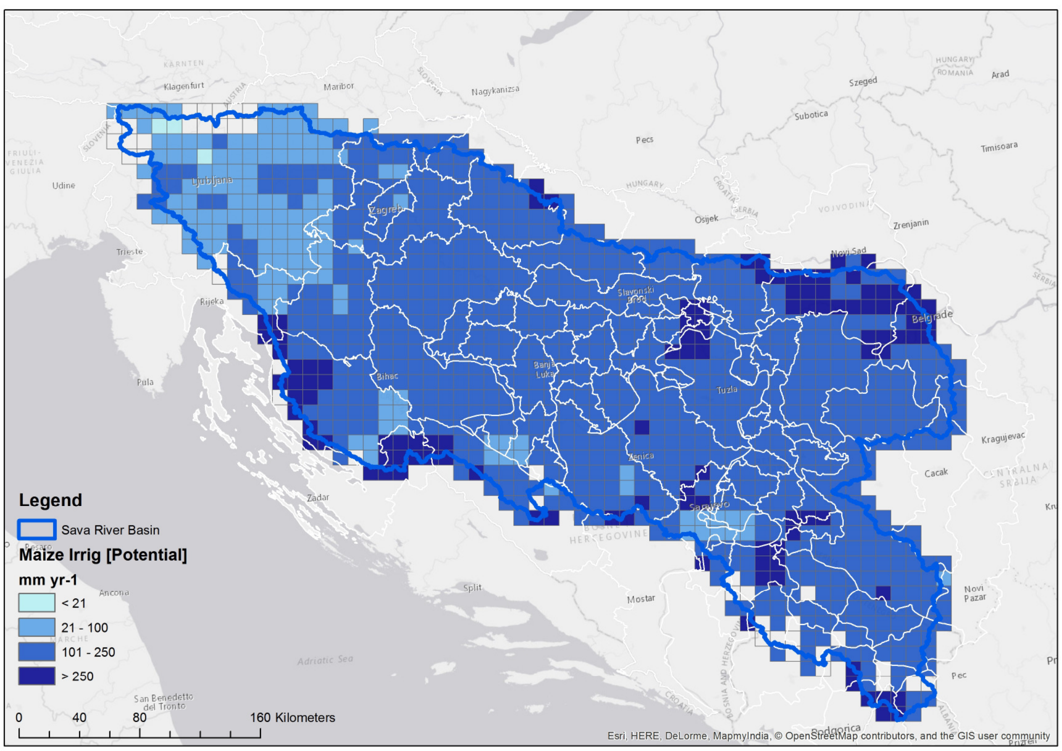

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Figure 53 Water requirements for maximized maize irrigation in the Sava basin (source: JRC EPIC model).

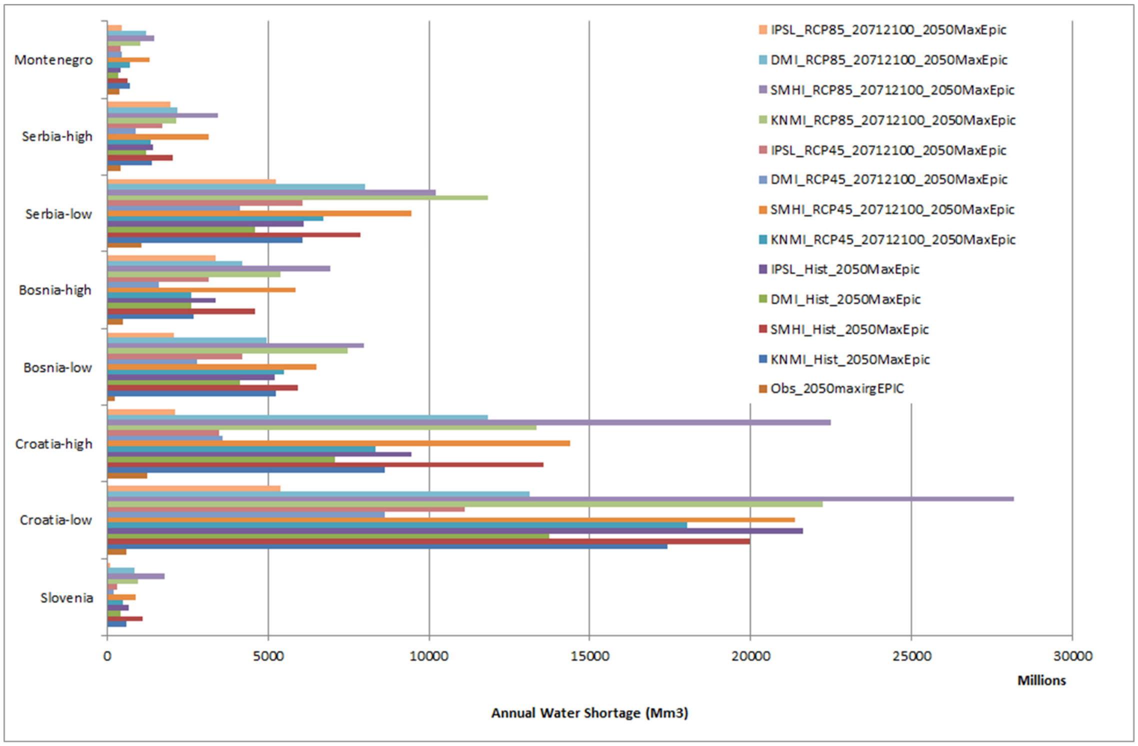

Figure 54 Annual water shortage (Mm3) simulated for the EpicMax scenario.

Existing irrigation plans and irrigating the areas which were previously equipped for irrigation (according to FAO) seems more feasible from a water resources perspective.

5.5.2 Rain-fed Agriculture

Severe and or frequent soil water stress conditions limit the transpiration potential of the crop or vegetation, especially during crucial stages in the growing season, and will lead to decreases in crop yield. An increase of soil water stress of 9% is projected for 2030, which may have an impact on agricultural crop yields.

For the end of the century, RCP4.5 shows a 1% increase, whereas RCP8.5 shows a 7% increase in soil water stress. This might indicate stronger needs for irrigation in the future to maintain current crop yields.

5.5.3 Energy

Water availability for energy production - hydropower and cooling water for thermal and nuclear power stations – is projected to decrease by an average of 3.3% for 2030 under RCP4.5, whereas RCP8.5 would result in a 1.3% increase. End of the century simulations yield a 17.6% higher Q50 for RCP4.5 and 23.1% higher for RCP8.5. Excessive irrigation could affect the water availability for power production, especially for cooling thermal power stations.

As suggested earlier by UNECE (2015) as well, hydropower reservoirs could be turned into multi-functional reservoirs, also serving downstream irrigation needs and flood control, and thus serve multiple purposes.

5.5.4 Flood hazard and risk

Flood hazard is increasing. Flood peaks are projected to remain unchanged as a consequence of projected land use changes until 2050 for the Sava basin. However, with climate change projections we do simulate an overall increase in the flood peaks with 13% for the 2011-2040 period and a 23% increase for the 2071-2100 period.

Floods might impact hydropower dams and downstream thermal stations.

Since exposure to flooding is also likely increasing, given the projected increases in urban area (chapter 4.2) e.g. around Zagreb and in Slovenia, overall flood risk is expected to increase considerably.

5.5.5 Environment: ecological flow

Environmental flow conditions are not significantly changing until 2030. Projections for end of the century are wetter, leading to 11% decreases of eflow breaching days (RCP4.5) up to 14% for the wetter RCP8.5 scenario.

Excessive increases in irrigation would increase the number of Eflow breaching days with 5% under current climate. Under end of the century climate, Eflow issues for the Sava basin would reduce also under this scenario. An exception would be the lower Serbia Sava floodplain, where Eflow issues are projected to get worse by around 33% under the extreme irrigation scenario.

5.5.6 Navigation

River low-flows decrease moderately for the 2011-2040 scenarios. This could influence navigation in the main Sava river.
For the end of the century 2071-2100, lowflow values are projected to moderately increase as compared to the control 1981-2010 climate, which could positively influence navigation.
Excessive irrigation would result in a severe decrease of the lowflow discharges with 50-60%, which would likely impact navigation in a negative way.

Conclusions

Assessing the water-food-energy-ecosystems nexus in the Sava river basin is crucial to understand the inter-linkages between various water resources components, agriculture, energy production, navigation and the environment. This understanding is necessary for the definition of appropriate programs of measures.

For the Sava river basin, we found in this study that more intense irrigated agriculture does have the potential to increase crop yields considerably, but there are not sufficient water resources available to realise this. Also, if irrigation would be increased drastically, other sectors would be negatively influenced, such as the energy sector (reduced cooling water availability, potentially less water at times produce hydropower), navigation (more frequent and lower low-flows), and the environment (breaches of environmental or minimum flow conditions).

With respect to most of the water resources indicators, the projected land use changes until 2050 balance each other out, and the net effect is only marginal. Land use projections for Slovenia until 2050 show a substantial increase of forested area at the expense of arable land and semi-natural vegetation. Urban land use is expected to increase by roughly 22% as compared to present day; industrial land use is expected to increase by roughly 27%. For Croatia, forest areas are expected to increase substantially between 2010 and 2050 until 50% of the country's land surface is forested. Areas of arable land and semi-natural vegetation are expected to decrease substantially. Industrial and urban land uses are expected to increase by respectively 22% and 1%.

Effects on water resources would be more significant with increased irrigation to increase the crop yield of e.g maize. This would lead to an increase in water demand from 2216 Mm3/year to 3337 Mm3/year. Overall water demand in the Sava basin would further increase to around 6000 Mm3/year if we combine both increased irrigation and climate projections until 2100. The average simulated maize yield could increase from 5.7 tons/ha at present conditions to 9.9 tons/ha in case of increased and optimum irrigation. These substantial increases in irrigation, which would lead to substantial crop yield increases as well, would lead to water scarcity in parts of the Sava basin. Also, there just is not sufficient water to irrigate all areas which are water-limited for crop growth.

Existing irrigation plans and irrigating the areas which were previously equipped for irrigation (according to FAO) seems more feasible from a water resources perspective.

Flood peaks are projected to remain unchanged as a consequence of projected land use changes until 2050 for the Sava basin. However, with climate change projections we do simulate an overall increase in the flood peaks with 13% for the 2011-2040 period and a 23% increase for the 2071-2100 period.

River low-flows decrease moderately for the 2011-2040 scenarios. For the end of the century 2071-2100, lowflow values are projected to moderately increase as compared to the control 1981-2010 climate. Excessive irrigation would result in a severe decrease of the lowflow discharges with 50-60%. As for ecological flows, similar observations can be made.

Navigation in the main Sava river may be affected by these trends.

Water availability for energy production - hydropower and cooling water for thermal and nuclear power stations – is projected to decrease by an average of 3.3% for 2030 under RCP4.5, whereas RCP8.5 would result in a 1.3% increase. End of the century simulations yield a 17.6% higher Q50 for RCP4.5 and 23.1% higher for RCP8.5. Excessive irrigation could affect the water availability for power production, especially for cooling thermal power stations. Hydropower reservoirs could be turned into multi-functional reservoirs, also serving downstream irrigation needs and flood control, and thus serve multiple purposes.

Soil water stress conditions, which would potentially reduce agricultural crop yields, are especially affecting the lower parts of Bosnia-Herzegovina, Croatia and Serbia under current climate. Climate impact simulations show an increase of soil water stress of 9% for 2030. For the end of the century, RCP4.5 shows a 1% increase, whereas RCP8.5 shows a 7% increase in soil water stress. This might indicate stronger needs for irrigation in the future to maintain current crop yields.

Our climate impact simulations show a moderate decrease of groundwater resources for Slovenia and the higher parts of Croatia and Bosnia Herzegovina until 2030. For the end of the century runs we observe increases in groundwater resources. Increased irrigation practices would seriously reduce groundwater resources again. Also, if relatively more groundwater is used for irrigation replacing surface water, groundwater resources decrease as well.

Policy implications:

This study demonstrates the nexus character of water resources, with feedbacks and linkages to food production, energy production, navigation, and environmental issues. Policy measures should therefore consider the impact on all these sectors, while also keeping an eye on the effects of extreme events such as floods.

Climate adaptation measures need to go hand in hand with water resource management policy measures, and the integrated effects should be studied.

Recommendations:

This study shows first of all that integrated water nexus studies are essential to graps interlinkages and feedbacks to other sectors. Involvement of energy and agricultural specialists should be intensified, which is underway already with JRC-Petten.

There is also a need for further work. Bias correction of the climate models is not adequate yet, and observational data series need to be improved. This is the aim of the current JRC initiative to extend the CarpatClim gridded meteorological dataset 1960-210 to include more countries, including the Sava basin.

Also, the land use modelling with LUISA needs to go beyond EU28 to cover the entire Sava and Danube river basins. This is currently underway at JRC with the help of Sava regional experts. Results will be included in the forthcoming Danube Water Nexus report.

Projections of water demand changes in industry are also uncertain, and are under current further study at JRC (Bernhard et al, 2016).

The Eobs meteorological dataset, which is used for bias-correction in this study, still needs improvements in several locations, e.g. the Serbian-Montenegran mountains, where precipitation is underestimated in Eobs. This affects the conclusions in that area.

The irrigation water requirement estimates in this LISFLOOD version need improvement to meet the quality of the EPIC model estimates; Integration of the LISFLOOD and EPIC model is envisaged.

Streamlining sectorial fluxes with the EEA Water accounts database needs to take place.

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List of abbreviations and definitions

CAPRI	Common Agricultural Policy Regionalised Impact Model
CLUE	Conversion of Land Use and its Effects modelling framework
CORDEX	Coordinated Regional Climate Downscaling Experiment
EPIC	Environmental Policy Integrated Climate Model
FAO	Food and Agriculture Organization
FD	EU Floods Directive
GDP	Gross Domestic Product
ICPDR	International Commission for the Protection of the Danube River
ISRBC	International Sava River Basin Commission
JRC	EC Joint Research Centre
KNMI	Royal Netherlands Meteorological Institute
KTH	Royal Institute of Technology, Stockholm, Sweden
LISFLOOD	JRC's water resources model
LUISA	JRC's Land-Use-based Integrated Sustainability Assessment Modelling.
NUTS	Nomenclature of Territorial Units for Statistics
RCP	Representative Concentration Pathways, greenhouse gas emissions scenarios
Q1	1^{st} percentile river discharge
Q50	5^{th} percentile (median) river discharge
Q9995	99.95^{th} percentile river discharge
RWS	Root Water Stress Index
SYNOP	Surface synoptic observations
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
WDI	Water Dependency Index
WEI	Water Exploitation Index
WFD	EU Water Framework Directive

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