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Water & Climate Adaptation Plan for the Sava River Basin

ANNEX 2 - Guidance Note on Adaptation to Climate Change for – Flooding

August 2015

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Water & Climate Adaptation Plan for the Sava River Basin

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GUIDANCE NOTE ON ADAPTATION TO CLIMATE CHANGE FOR THE SAVA RIVER BASIN – FLOODING

1 Background

This report provides guidance note for decision making on the adaptation needs related to floods in the Sava River Basin (SRB). This guidance note is one of the components of the Water and Climate Adaptation Plan (WATCAP) being prepared by the Consultant for the International Sava River Basin Commission (ISRBC) under World Bank funding.[1] It builds on the main WATCAP report (World Bank, 2013b), the report on the development of future climate scenarios (Vujadinovic and Vukovic, 2013) and on the report on development of the hydrologic model for the Sava River basin (World Bank, 2013a).

Furthermore, there are essentially three recent studies that have been undertaken by the University of Ljubljana under the title "*Pilot project on climate change: Building the link between flood risk management planning and climate change assessment In The Sava River Basin (SRB), Component A3: Compilation of various existing climate change scenarios for the region, their expected impacts on water cycle and more specifically on frequency and magnitude of extreme flood events*". These studies are:

- Part 1: Report on meteorological part of development of climate projections for the SRB, University of Ljubljana, Faculty for mathematics and physics
- Part 2: Climate change impact on flood discharge of the Sava River, hydrology report, University of Ljubljana, Faculty of civil engineering and geodesy
- Part 3: Assessment whether additional modelling of climate change impact on flood vulnerability is needed, preliminary identification and description of possible adaptation measures, selection of a package of prevention, preparedness, resilience, response and recovery measures, University of Ljubljana, Faculty of civil engineering and geodesy.

The above reports support the Program for development of the Flood Risk Management Plan in the SRB, a requirement of the International Save River Basin Commission (ISRBC). The reports also draw upon other important documents including:

- University of Split Report on Vulnerability Analysis,
- ISRBC, 2009, Sava River Basin Analysis Report and
- ICPDR, 2012, Danube Study – Climate Change Adaptation

2 Part 1 – Meteorology

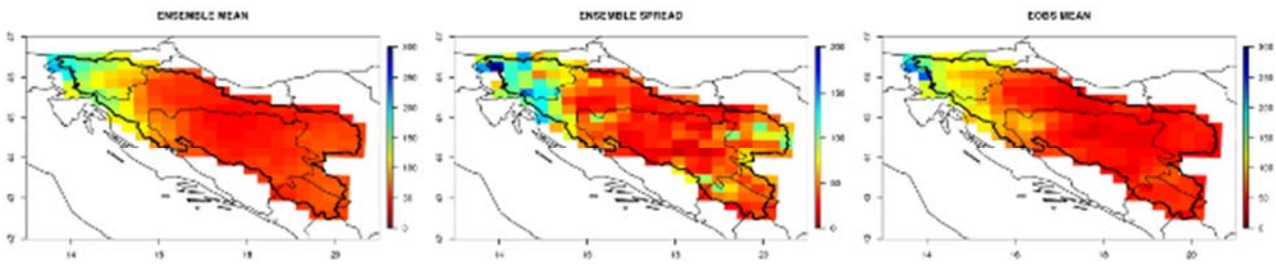
Meteorological data from simulations of 16 different ENSEMBLES GCM/RCM model runs were used for preparation of projections. All simulations for the 21st Century were done using only the IPCC SRES A1B emission scenario, since it has been recognized that the choice of the emission scenario is less relevant until the middle of the 21st Century. The A1B scenario assumes a future world of rapid economic growth, low population growth and rapid introduction of new and more efficient technologies. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. It is assumed that under the A1B scenario, people pursue personal wealth rather than environmental quality.

[1] COWI AS of Norway were contracted by the World Bank to undertake the development of the hydrologic model – World Bank Contract No - 7162102

Simulations generally cover a time period between 1961 and 2100. Simulations of two different meteorological variables were used in study: daily precipitation and daily mean air temperature. E-OBS data (daily precipitation) were used as a reference (observational) dataset for comparison and derivation of transfer functions. These data have been designed to provide the best estimate of grid box averages to enable a direct comparison with RCMs. The E-OBS dataset was defined on the same 0.25 degree grid resolution. The E-OBS dataset covers the period between 1950 and 2011.

ENSEMBLES climate model runs were used to produce climate projections for the SRB. Statistical bias correction was used to correct raw model simulations for systematic biases. Validation procedure showed that statistical bias correction improved quality of daily precipitation and temperature simulations over the majority of the basin area and was also dependent on the season.

Climate projections for the Sava river basin were calculated, based on derived transfer functions for the period 1961-2000. Transfer functions were applied to climate projections for the 21st Century from RCM simulations. Three periods were used for assessing future climate change: 2011-2040, 2041-2070 and 2071-2100. For each of the periods, absolute values for seasonal precipitation and extreme precipitation were determined as well as the differences from the reference period (1971-2000) values. Results are provided in forms of images, where spatial distributions for the Sava river basin for each of the variables are shown. Results for the 100-year return period autumn daily precipitation are given in Figure 1.



Note: Units on all images are in mm.

Figure 1: Ensemble mean, spread (from 16 different model runs) and observed values for autumn daily precipitation intensity with return period 100 years for the reference period (1971-2000).

In general, temperature was expected to increase over the basin area in all seasons (the most pronounced increase can be observed for summer and winter). On the other hand, precipitation is expected to decrease in spring, summer and autumn (with the most pronounced decrease in summer), whereas an increase in the winter is expected, especially in north-western part of the basin.

In general, the highest model simulation spread was observed over the most complex orography (e.g. Julian Alps, Kamniško-Savinjske Alps and Dinaric Alps). This introduced some level of uncertainty in the simulation results over that area. Consequently it is recommended that climate model simulations of large scale circulation patterns, which influence the weather and climate in the basin, should be verified in the future. This will enable determination of the primary causes of systematic model biases when simulating large scale precipitation and other meteorological variables.

Furthermore, a sensitivity study on convective parameterization schemes that are used in climate models to simulate sub-grid scale convective precipitation would enable a better understanding and help evaluate the abovementioned uncertainty, related to extreme precipitation events over the basin area. In addition, the impact of changing model resolution should be analysed in the future climate modelling experiments.

3 Part 2 – Climate Change Impact on Flood Discharge

The WB trends report (Meerbach et al 2010) did not analyse peak flood flows and droughts; whilst the report from the Exeter University (Jupp et all 2011) was not useful for flood prediction. Furthermore, floods are also not substantially mentioned in the UNFCCC national communications from the SRB countries. Whenever they are mentioned, there is a general concern that climate change is causing more extreme events to occur, such as floods.

Flood runoff generation is a complex non-linear process that cannot be easily estimated from precipitation data. Hence for the transformation of extreme precipitation data into flood runoff, a hydrological model is needed that is capable of reproducing the basin response during extreme precipitation rather than runoff from moderate precipitation amounts. Such a hydrological model was developed for the Sava River Basin (Brilly et al 2011) and the extreme precipitation data from different climate projections was used as input for the model (along with the temperature projections).

The Hydrologiska Byrans Vattenbalansavdelning (HBV) model is a conceptual model developed by the Swedish Meteorological and Hydrological Institute for continuous runoff simulation and is often used in hydrological forecasting (IHMS, 1999). The model structure is presented schematically in Figure 2 and is based on the water balance equation:

$$P - E - Q = \frac{d}{dt}\left[SP + SM + UZ + LZ + lakes\right]$$

where: *P* is precipitation, *ET* is evapotranspiration, *Q* is runoff, *SP* is snowpack, *SM* is soil moisture, *UZ* is water storage in upper reservoir, *LZ* is water storage in lower reservoir and *lakes* is water storage in lakes.

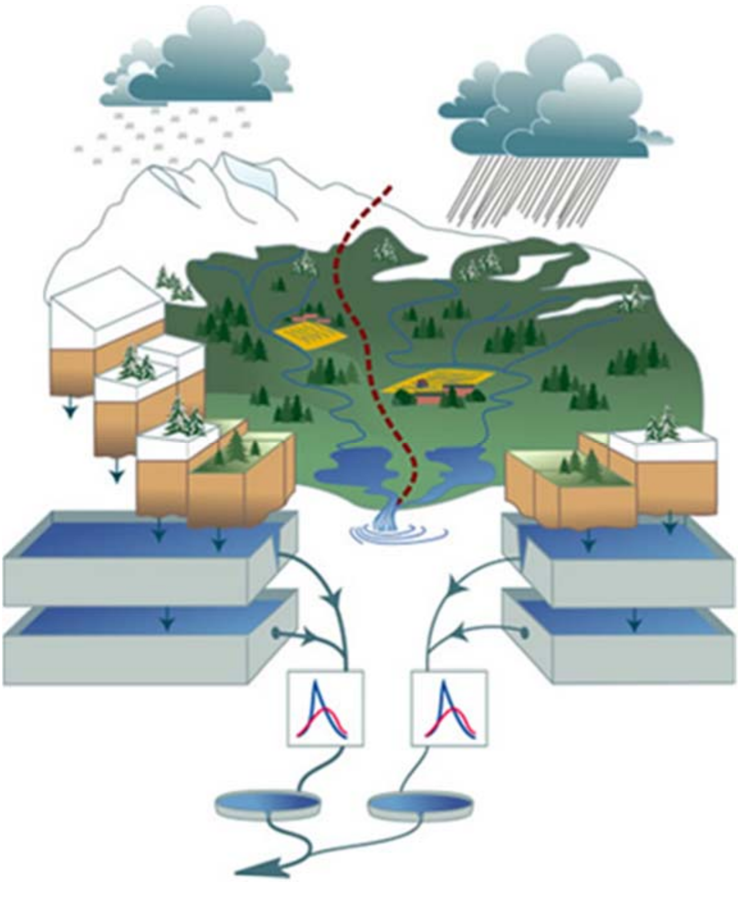


Figure 2: Schematic representation of the HBV model (IHMS, 1999)

For the purpose of modelling, the SRB was divided into elevation and vegetation zones, especially important for calculating snowfall and snowmelt. The basin is divided into sub-basins as shown in Table 1 and Figure 3.

Table 1: List of Sub-Basins

#	Sub-basin number	Sub-basin name	River	Sub-basin area [km^2]
1	I.	Sava I	Sava	10.073
2	II.	Sava II	Sava	3.481
3	III.	Kolpa/Kupa	Kolpa/Kupa	9.501
4	IV.	Sava III	Sava	6.701,5
5	V.	Una	Una	9.907
6	VI.	Sava IV	Sava	1.880
7	VII.	Vrbas	Vrbas	5.295
8	VIII.	Sava V	Sava	4.403
9	IX.	Bosna	Bosna	10.261
10	X.	Sava VI	Sava	5.021
11	XI.	Drina I	Drina	13.781
12	XII.	Drina II	Drina	5.979
13	XIII.	Sava VII	Sava	8.424,72
			All sub-basins	**94.708,22**

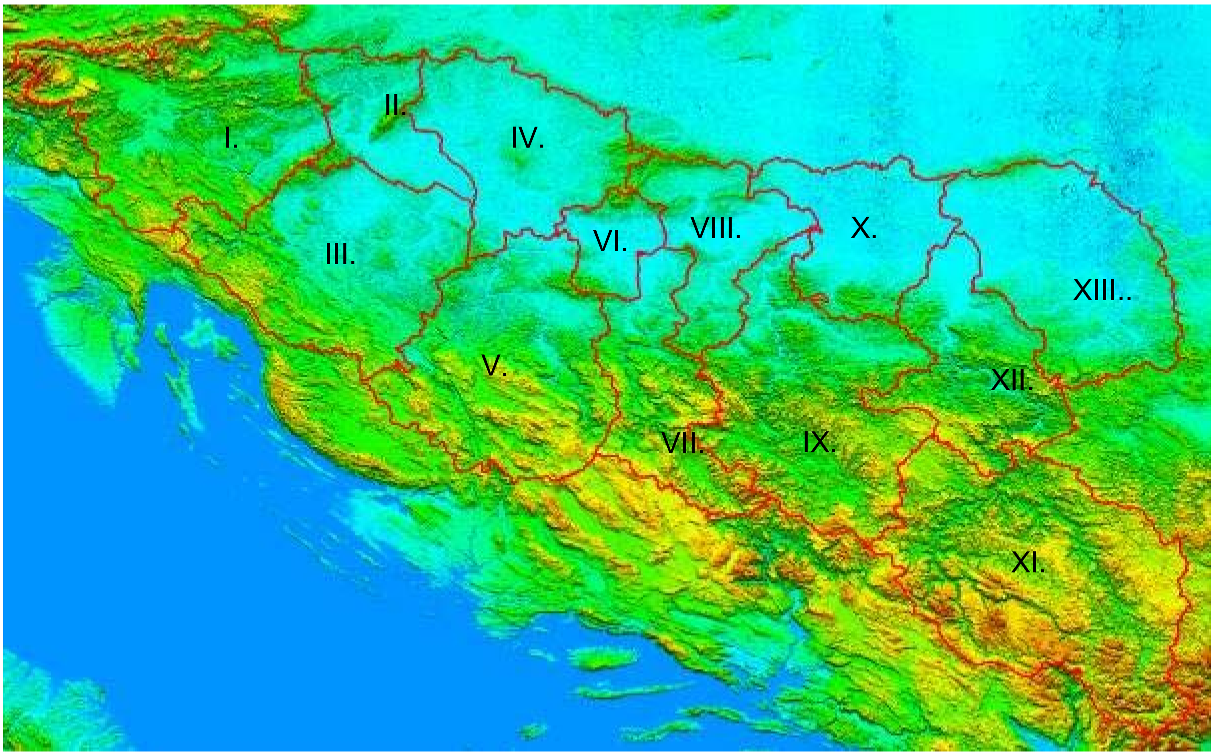


Figure 3: The SRB relief and division into sub-basins

The following input data were used to calibrate and run the model:

- precipitation from 32 measurement stations (Figure 4),
- temperatures from 8 measurement stations,
- discharge data from 12 measurement stations (Figure 5),
- potential evapotranspiration from 8 measurement stations.

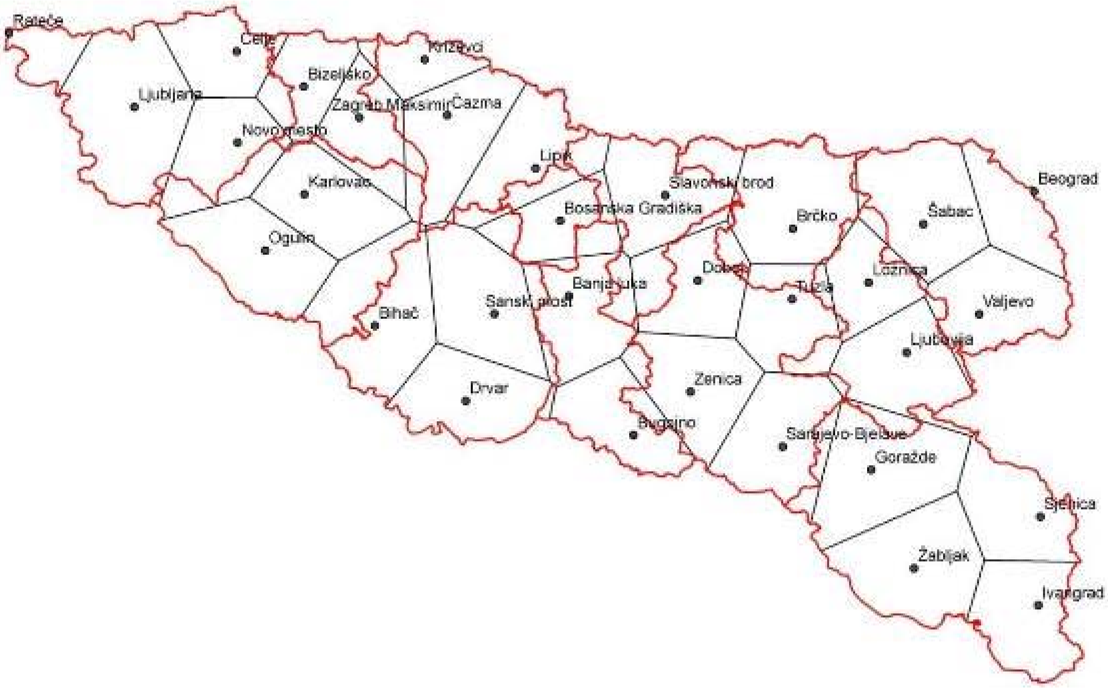


Figure 4: Sava River basin with precipitation stations and Thiessen polygons used to define station representative areas

Figure 5: Sava River Basin with hydrologic stations used for model calibration.

Input data for calibration (precipitation, temperature, evapotranspiration, discharge) was collected for the period from June 1 to December 31, 1974. This corresponded to the period of the 1974 flood event, which is regarded as the last major flood to take place in the SRB before major flood protection construction works were put in place in the Sava River valley (Posavina). An important characteristic of the 1974 flood event was major rainfall that moved with time from the east to the west part of the Sava River Basin. Maximum precipitation on the Drina River basin occurred two days after maximum precipitation in Slovenia and the resulting flood peaks from Slovenia and the right tributaries coincided at the confluence of the Sava River and the Drina River.

The verification period was from 1st September, 1978 to 30th November, 1978. During this event the peak discharges were quite high, but lower than during the 1974 event; another advantage was that data from the weather stations were available for modelling. The results of calibration and verification of the model are not impressive, especially for sub-basins. This is because the sub-basins were modelled as homogeneous areas except the Drina River Basin. The main goal of the calibration was to reproduce flood peaks and not water balance (Table 2).

Table 2: Model calibration peak discharges in m^3/s (1974).

Sub-basins	Water station	measured	calibrated	difference
		[m^3/s]	[m^3/s]	%
Sava I	Čatež	2294	2308	0.6
Kolpa	Šišinec	1250	1419	13.5
Sava II	Crnac	2147	2295	6.9
Una	Kostajnica	1370	1445	5.4
Sava III	Jasenovac	2580	2515	-2.5
Vrbas	Delibašino selo	691	762	10.3
Sava IV	Slavonski Brod	3460	3422	-1.1
Bosna	Doboj	1095	753	-31.3
Sava V	Županja	3930	4057	3.2
Drina I	Bajina Bašta	3359	2715	-19.2
Drina II	Kozluk	3041	2640	-13.2
Sava VI	Sremska Mitrovica	6275	6540	4.2
Confluence with Danube			**6653**	

In order to utilize information on extreme precipitation data from the available climate scenarios as an input to the hydrologic model and to make it possible to predict hydrological response to climate change, precipitation and temperature data from the climate scenarios were taken from the raster data set based on the position of rain gauge stations and transformed in order to be used for hydrological modelling. The transformation was derived based on the differences between precipitation observed at meteorological stations and gridded precipitation in the E-OBS data.

The maximum daily values of the precipitation measured in 1974 are mainly slightly lower than the values of E-OBS. A high discrepancy between the E-OBS data and the measurements is present in the area of the Dinaric Mountains, especially in Montenegro. The value at the Žabljak station is two times higher than that in the E-OBS data with the 20-year return period and even the 100-years return period (Table 3). There is a concern that for the E-OBS data set the precipitation from Montenegro was not considered.

Table 3 shows that maximum summer daily precipitation is slightly higher than in autumn. However, runoff in the autumn season is much higher due to less evaporation than in summer, so for further analysis the autumn values were chosen.

Table 3: Daily maximum of seasonal precipitation: 20-year return period E-OBS data for 1971–2010 vs. 1974 measured data (in mm).

Longitude	Latitude	Station	Max. prec. observed 1974*	Spring E-OBS	Summer E-OBS	Autumn E-OBS	Winter E-OBS
13° 43' E	46° 30' N	Rateče	42.6	98.2	99.0	131.9	99.6
14° 31' E	46° 04' N	Ljubljana	95.8	69.0	90.9	88.5	75.4
15° 15' E	46° 15' N	Celje	66.7	62.3	82.4	85.4	58.2
15° 42' E	46° 01' N	Bizeljsko	68	47.0	62.9	64.3	49.2
15° 11' E	45° 48' N	Novo mesto	55	57.6	75.0	79.7	62.8
16° 33' E	46° 02' N	Križevci	26.5	34.2	47.0	47.1	38.6
15° 14' E	45° 16' N	Ogulin	63.2	58.0	85.6	86.6	70.9
15° 33' E	45° 30' N	Karlovac	42.5	46.3	61.0	62.0	52.1
16° 02' E	45° 49' N	Zagreb - Maksimir	34.5	34.6	47.2	43.6	36.4
16° 38' E	45° 45' N	Čazma	29.3	28.2	43.6	40.1	36.6
17° 10' E	45° 25' N	Lipik	49.3	27.2	39.9	32.3	35.1

Longitude	Latitude	Station	Max. prec. observed 1974*	Spring E-OBS	Summer E-OBS	Autumn E-OBS	Winter E-OBS
18° 00' E	45° 10' N	Slavonski brod	31.6	25.9	30.6	31.1	27.2
17° 16' E	45° 09' N	Bosanska Gradiška	38.4	27.7	33.5	31.7	31.4
15° 53' E	44° 49' N	Bihač	82.9	45.8	58.3	69.7	58.1
16° 24' E	44° 23' N	Drvar	58.6	39.9	47.9	54.9	42.3
16° 42' E	44° 46' N	Sanski most	61.5	32.4	37.7	47.9	35.5
17° 13' E	44° 47' N	Banja Luka	56.2	25.2	29.9	34.0	29.0
17° 28' E	44° 04' N	Bugojno	40.4	25.9	32.6	38.0	30.1
17° 54' E	44° 13' N	Zenica	21.4	23.8	29.2	34.7	31.9
18° 06' E	44° 44' N	Doboj	24.2	25.5	30.2	30.7	28.9
18° 42' E	44° 33' N	Tuzla	21.5	25.9	33.5	31.7	29.7
18° 50' E	44° 53' N	Brčko	23.5	28.7	36.4	33.3	29.8
18° 26' E	43° 52' N	Sarajevo - Bjelave	36	26.2	34.6	37.6	38.2
18° 59' E	43° 40' N	Goražde	29.2	27.3	34.3	42.2	41.2
19° 14' E	44° 33' N	Loznica	26.5	33.5	50.5	34.6	32.9
19° 23' E	44° 11' N	Ljubovija	50.9	31.8	42.5	35.5	36.5
19° 41' E	44° 46' N	Šabac	46.8	34.4	52.2	36.0	31.5
19° 55' E	44° 17' N	Valjevo	49	39.5	49.7	39.3	38.5
20° 28' E	44° 48' N	Beograd	39.4	39.6	51.7	36.0	32.9
20° 01' E	43° 16' N	Sjenica	45.1	32.6	51.9	42.9	34.3
19° 08' E	43° 09' N	Žabljak	83.9	27.1	37.5	37.1	34.3
19° 52' E	42° 50' N	Ivangrad	39.2	31.5	48.6	44.0	33.5
		Average	**46.2**	**37.9**	**49.6**	**49.5**	**42.0**
		Max	**95.8**	**98.2**	**99.0**	**131.9**	**99.6**
		Min	**21.4**	**23.8**	**29.2**	**30.7**	**27.2**

* from the Federal Hydrometeorological Service of Yugoslavia yearbook

Climate scenarios for 2011–2040, 2041–2070 and 2071–2100 show interesting dynamics. The autumn precipitation for some stations increase with time, while with other stations there is first an increase and then a decrease. Average values of precipitation having a 20-year return period across the basin show a very small increase between periods 2041–2070 and 2071–2100, and even a slight decrease for the 100-year return period precipitation (Table 4).

Table 4: Autumn maximum daily precipitation (in mm) of 20- and 100-year return periods based on the E-OBS data and climate scenarios.

Station	EOBS	EOBS	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100
	20 yr.	100 yr.	20 yr.	20 yr.	20 yr.	100 yr.	100 yr.	100 yr.
Rateče	131.9	171.1	149.6	**147.5**	155.7	206.5	**191.3**	201.9
Ljubljana	88.5	110.0	99.1	**110.0**	113.3	131.1	**148.0**	153.2
Celje	85.4	105.3	92.7	**105.9**	111.1	122.4	**140.1**	149.8
Bizeljsko	64.3	77.1	71.1	**83.2**	86.8	94.5	**119.5**	126.9
Novo Mesto	79.7	101.5	86.4	**100.7**	108.4	117.8	**148.6**	164.3
Križevci	47.1	55.9	50.3	**56.5**	59.7	61.9	**73.1**	80.4
Ogulin	86.6	103.8	89.8	**102.6**	110.8	108.8	**138.6**	148.7
Karlovac	62.0	71.9	67.0	**74.1**	82.0	81.9	**94.5**	111.7
Zagreb - Maksimir	43.6	50.3	46.0	**52.0**	56.3	56.2	**67.4**	80.4
Čazma	40.1	45.5	42.5	**47.2**	50.1	48.5	**56.7**	62.4
Lipik	32.3	34.3	36.4	**37.9**	37.3	40.5	**42.4**	38.9
Slavonski Brod	31.1	38.6	36.2	**36.3**	36.8	48.1	**47.8**	45.0
Bosanska Gradiška	31.7	39.2	36.4	**37.0**	37.1	47.3	**48.1**	46.2
Bihač	69.7	83.4	76.3	**81.0**	88.4	95.8	**101.8**	114.2
Drvar	54.9	69.3	60.0	**65.6**	64.7	78.0	**91.5**	86.6
Sanski Most	47.9	68.6	53.8	**55.6**	56.5	81.5	**84.3**	82.1
Banja Luka	34.0	44.0	38.2	**38.9**	39.1	51.9	**53.4**	50.7
Bugojno	38.0	50.4	43.1	**44.8**	43.9	61.6	**66.6**	62.2
Zenica	34.7	42.4	41.0	**43.6**	40.3	54.1	**60.9**	51.2
Doboj	30.7	34.9	36.9	**38.2**	35.8	46.4	**51.3**	41.6
Tuzla	31.7	35.2	39.0	**40.7**	39.3	50.1	**51.6**	48.6
Brčko	33.3	39.4	39.6	**40.4**	40.6	50.7	**51.4**	49.0

Sarajevo - Bjelave	37.6	42.6	45.1	**49.6**	44.5	58.8	**66.5**	52.8
Goražde	42.2	52.6	46.7	**52.8**	50.3	61.3	**74.2**	66.5
Ložnica	34.6	37.5	41.5	**44.7**	41.6	51.0	**54.6**	46.0
Ljubovija	35.5	39.5	42.1	**48.0**	42.5	52.2	**64.6**	50.6
Šabac	36.0	43.4	43.9	**47.2**	43.3	59.5	**62.1**	53.0
Valjevo	39.3	47.2	43.5	**51.1**	47.2	55.1	**70.3**	59.4
Beograd	36.0	46.1	41.9	**46.4**	44.8	58.3	**66.7**	61.0
Sjenica	42.9	51.3	44.9	**55.9**	52.6	54.6	**77.6**	66.1
Žabljak	37.1	45.7	40.4	**49.3**	44.1	54.1	**75.0**	61.6
Ivangrad	44.0	53.1	49.8	**63.5**	58.5	62.2	**98.7**	76.6
Average	49.5	60.3	55.4	**60.9**	61.4	72.0	**82.5**	80.9

The probabilities of maximum precipitation are based on the Gumbel probability distribution and were calculated using the observed precipitation data from the trends report (Meerbach 2010), and the results are given in Table 5. The period of observation varied from 1908 or 1951 to 2009. The differences in the 20-year precipitation from the Gumbel distribution and E-OBS vary. At some stations the Gumbel distribution yields higher values than those calculated from E-OBS, and vice versa. For the 100-year precipitation, only the values from Slovenian stations are lower if calculated using the Gumbel distribution than from the E-OBS data. All other stations have higher values. Finally, the 100-year return period projected values for 2041-2070 are lower than the 100-year precipitation for all stations.

Table 5: Maximum daily precipitation (in mm) based on the observed data, values in 1974 and data from Table 4.

	Return period			Max.	V1	V2	V3	V4
Station	**1000**	**100**	**20**	**prec. in 1974**	**EOBS_20**	**EOBS_100**	**2041-2070_20**	**2041-2070_100**
Ljubljana	190.7	106.3	72.2	95.8	88.5	110.0	110.0	148.0
Rateče	214.9	121.2	83.2	42.6	131.9	171.1	147.5	191.3
Zagreb	117.2	65.9	45.2	34.5	43.6	50.3	52.0	67.4
Slavonski Brod	104.1	59.1	40.9	31.6	31.1	38.6	36.3	47.8
Bihač	155.3	89.5	62.8	82.9	69.7	83.4	81.0	101.8
Bugojno	119.9	66.2	44.5	40.4	38.0	50.4	44.8	66.6
Sarajevo	120.0	67.0	45.5	36.0	37.6	42.6	49.6	66.5
Banja Luka	86.0	57.4	45.8	56.2	34.0	44.0	38.9	53.4
Beograd	126.8	66.3	41.9	39.4	36.0	46.1	46.4	66.7
Sjenica	89.9	53.3	38.5	45.1	42.9	51.3	55.9	77.6

Temperature data vary significantly inside the SRB; however, the variation in projections is rather small. For further calculations an increase of 0.8^{o}C in autumn was chosen in the period 2011–2040, 1.8^{o}C for autumn in the period 2041–2070 and 2.9^{o}C in the period 2071–2100 for the watershed as a whole.

The HBV model was used to assess climate change forecasts on the Sava River discharges at selected stations. Input data for these simulations were the same as for the model calibration against the 1974 flood except that daily precipitation data was changed with the maximum precipitation and the increased temperature. Instead of using the measured maximum daily precipitation, projected maximum daily precipitation was used.

Firstly, calculated peak discharges for the E-OBS (1971–2010) data having 20- and 100-year return periods were compared. The calibrated peak discharges in the central part of the watershed down to Sava III are lower than those calculated with the E-OBS data for the 20-year return period. Values of discharge in the lower part of the watershed are between the values calculated for the E-OBS data for 20- and 100-year return periods. The Drina River flood peak discharges are much higher than those calculated with the E-OBS 100-year return period data. The values of the Vrbas River are in-between and the Bosna River has much lower discharges than those calculated.

The results of modelling with the E-OBS data and climate change scenarios (Table 6 and 7) show the projected flood peaks of the 20-year return period will increase in the period 2071–2100 on average from 14 % up to 23 % in the upper part of the basin and on some tributaries. The simulated base flow drops a little due to higher temperatures. The flood peaks along the main stream will increase in the next 60 years from 8 % on the inflow in the Danube to 33 % at the head water part of the catchment. The projected discharges will increase in future due to climate change. However, the predicted discharges on the Drina River and at the downstream Sremska Mitrovica station on the Sava River for 2071–2100 are lower than those for 2041–2070.

Table 6: Flood peaks under climate change and using the E-OBS data of the 20-year return period

Sub-basins	**Water Station**	**E-OBS** m^3/s	**2011-2040** m^3/s	**2041-2070** m^3/s	**2071-2100** m^3/s	**2011-2040 /E-OBS %**	**2041-2070 /E-OBS %**	**2071-2100 /E-OBS %**
Sava I	Čatež	2308	2552	2859	3073	11	24	33
Kolpa/Kupa	Šišinec	1473	1523	1568	1591	3	6	8
Sava II	Crnac	2350	2428	2520	2571	3	7	9
Una	Kostajnica	1382	1637	1726	1718	9	25	24
Sava III	Jasenovac	2561	2630	2717	2742	3	6	7
Vrbas	Delibašino selo	620	676	687	691	9	11	11
Sava IV	Slavonski Brod	3411	3623	3742	3788	6	10	11
Bosna	Doboj	742	912	931	1010	23	25	36
Sava V	Županja	4068	4346	4554	4826	7	12	19
Drina I	Bajina Bašta	2336	2471	2617	2456	6	12	5
Drina II	Kozluk	2276	2427	2586	2425	7	14	7
Sava VI	Sremska Mitrovica	6328	6659	6862	6854	5	8	8
Confluence		**6432**	**6757**	**6960**	**6944**	**5**	**18**	**8**
					average	**8**	**13**	**14**
					max.	**23**	**25**	**36**
					min	**3**	**6**	**5**

Table 7: Flood peaks under climate change and using the E-OBS data of the 100-year return period

Sub-basins	**Water Station**	**E-OBS** m^3/s	**2011-2040** m^3/s	**2041-2070** m^3/s	**2071-2100** m^3/s	**2011-2040 /E-OBS %**	**2041-2070 /E-OBS %**	**2071-2100 /E-OBS %**
Sava I	Čatež	2780	3297	3770	4134	19	36	49
Kolpa/Kupa	Šišinec	1522	1595	1664	1722	5	9	13
Sava II	Crnac	2510	2670	2817	2929	6	12	17
Una	Kostajnica	1407	2060	2245	2188	46	60	56
Sava III	Jasenovac	2718	2863	2993	3086	5	10	14
Vrbas	Delibašino selo	707	813	845	825	15	20	17
Sava IV	Slavonski Brod	3573	3895	4062	4142	9	14	16
Bosna	Doboj	767	985	1025	1103	28	34	44
Sava V	Županja	4227	4699	4957	5270	11	17	25
Drina I	Bajina Bašta	2474	2683	3087	2719	8	25	10
Drina II	Kozluk	2407	2639	3059	2686	10	27	12
Sava VI	Sremska Mitrovica	6603	7143	7580	7409	8	15	12
Confluence		**6715**	**7253**	**7695**	**7509**	**8**	**15**	**12**
					average	**14**	**22**	**23**
					max.	**46**	**60**	**56**
					min	**5**	**9**	**10**

The discrepancies in the peak discharges on the Drina River basin could be the result of fewer climate prediction models used for the 2071–2100 precipitation projections. Also some results of climate change modelling (Rakovec and Ceglar, 2012) which were used for periods 2011–2040 and 2041–2070 were not available for the 2071–2100 projections.

The percentages of increase of flood discharges produced by precipitation of 100-year precipitation indicate a higher increase than the values from the 20-year precipitation. The average increase for the period until 2100 is 14 % and 23 % for the 20- and 100-year precipitation, respectively. The highest increase is observed at the Čatež hydrologic station on the Sava River with 49 %, followed by the Bosna River (44%) and the Una River (56%). The changes in the Drina River and at the Sremska Mitrovica station show similar anomalies as the discharges of the 20-year return period.

The calculated values given are valid for the most downstream stations on the tributaries, but the percentage of increase could be used for the watershed as a whole. The upper part of the watershed at the Čatež station has the greatest increase, up to 49 %. The tributary Kolpa River has a much lower increase, up to 13%. The Una River tributary has a 60% increase in discharge up to year 2070 followed by a smaller increase because of smaller precipitation up to year 2100. The dynamics of the 100-year projected flood peaks for the Vrbas River tributary is similar, i.e. an increase by 20 % followed by a decrease of 17 %. The flood discharge of the Bosna River will increase for 44 % until the end of the century. The Drina River has a similar dynamics to those of the Una River and Vrbas River; however the drop in the last period of projection is more significant. The flood discharge will increase up to 27 % and then drop to 12 % which is similar to the increase in the first period of projection. The projected discharges increase along the Sava River indicating a drop from the Čatež station (49 %) to 17 % at Crnac and to 14 % at Jasenovac which is the same value as that at Slavonski Brod. The percentage of increase downstream at Županja is up to 25 %. Downstream of the Drina River mouth the percentage of increase for 2041–2070 is 15 % at Sremska Mitrovica and a smaller increase of 12 % for 2071–2100.

Uncertainty in the calculated climate predictions of precipitation is estimated at 30 % at the 90 % confidence level. We also designed a model of the Sava River with HBV-Light model and undertook calculations by the same procedure to analyse uncertainties. The analysis showed discrepancies between the models that are less than 10 % (Božek, 2013). Thus, we assume a final overall uncertainty of calculated flood discharges roughly as ± 40% of the values presented in Tables 6 and 7.

A probability analysis was undertaken building on the probability analysis in the report by Prohaska (2009) with data collected in the period 1926–1965. The analysis does not consider the impact of flood protection measures in the Central Posavina, as they were developed later. The floods having 90%, 99% and 99.9% probability of non-exceedance were used to create basic flood-frequency relationships at hydrologic stations. Probability of floods calculated from the E-OBS precipitation of the 20- and 100-year return periods were estimated based on probability from report by Prohaska (2009). We assumed that predicted floods calculated by model with the predicted maximum E-OBS precipitation have the same probability as today floods. We then determined new probability curves of maximum discharges for each future period on the basis of their parallel displacement according to E-OBS projection. In this way we estimated the floods for different probabilities, according to data in the report (Prohaska, 2009).

The calculated results on the current 100-year return period of flood discharges and flood levels at selected hydrologic stations within the SRB show that:

- Floods at Čatež will increase by almost 22% in the first period (2011–2040) and by 55% until the year 2100, implying that the 100-year flood discharge will increase by 1661 m^3/s, while the flood water level will increase by 226 cm in 2100 to a maximum of 9.70 metres (Figure 6).

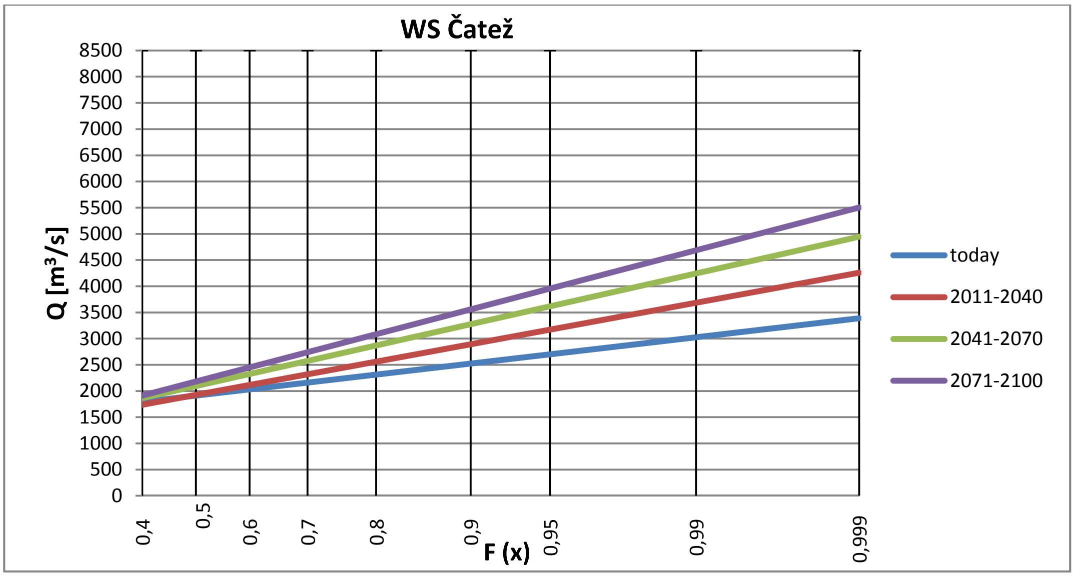


Figure 6: Probability of floods at the Čatež hydrologic station (m³/s).

- Floods at Crnac will increase by 5 % in the first period (2011–2040) and by 13 % until the year 2100, implying that the 100-year flood discharge will increase by 324 m³/s while the flood water level will increase by 82 cm in 2100 to a maximum of 8.84 metres.
- Floods at Slavonski Brod will first increase for 8 % the first period (2011–2040) and then by 15 % from 2071–2100, implying that the 100-year flood discharge will increase by 523 m³/s while the flood water level will increase by 113 cm in 2100 to a maximum of 10.56 metres.
- Floods at Županja will increase from 11 % in the first period (2011–2040) to 24 % in the last period (2071–2100) implying that the 100-year flood discharge will increase by 1020 m³/s while the flood water level will increase by 181 cm in 2100 to a maximum of 12.26 metres.
- Floods at Sremska Mitrovica will increase from 1 % in the first period (2011–2040) and to 3 % in the last period (2071–2100), implying that the 100-year discharge will increase by 193 m³/s while the flood water level will increase by 10 cm in 2100. The increase in the 1000-year flood discharges is quite higher, up to 10% (Figure 7).

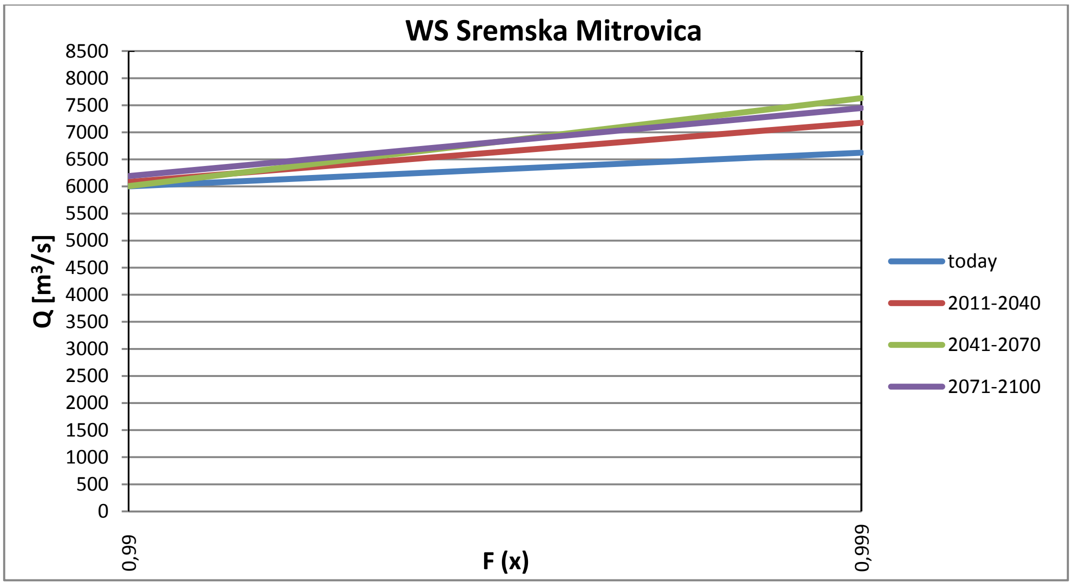


Figure 7: Probability of peak discharges at Sremska Mitrovica (m³/s).

At all hydrologic stations the gradual increase of water levels of the 100-year floods is expected in future. The only exception is Sremska Mitrovica, where, during the first two periods until 2070, the water level rises and then it starts to decrease slightly. The largest increase in the level at the end of the century, i.e. by more than 2 metres, is expected in the upper part of the basin at Čatež. Downstream the Sava River, the water level rise is strongly reduced to 0.82 m at Crnac. Downstream of Crnac, the water level gradually increases up to 1.81 m at Županja. Then, downstream of Županja, the increase of water level strongly drops to 0.10 m at Sremska Mitrovica.

It should be noted that the model was calibrated for the 1974 flood event, i.e. before any major construction on the “Central Posavina” flood protection system was developed. The impact of this system and the impact of hydropower plant Mratinje in the Drina River Basin could not be implemented in the model. Notably, the hydrological model reflects semi-natural conditions, without taking into consideration the structures developed after 1974.

Even though the above estimates for the increase in discharge due to climate change impact are high, they are still much lower than the Probable Maximum Flood of 7081 m^3/s, estimated for the upper Sava when undertaking a study for the Krško Nuclear Power Plant (Brilly et al., 2009) and also lower than the historical flood that occurred in 1896 in the Drina Basin and in the lower part of the Sava River.

There is evidence that the process of reforestation has decreased the mean discharges in the experimental river basin in Slovenia by 35 % (Šraj and Brilly, 2012). Consequently such a process will decrease flood discharges and mitigate the impact of climate change on floods in the SRB. It follows therefore that the process of reforestation should be studied in more detail at selected locations throughout the whole SRB.

4 Part 3 – Flood Vulnerability Assessment

The pilot project on climate change adaptation, building a link between flood risk management planning and climate change assessment in the SRB provides an overview on the vulnerability of the flood-prone areas of the Basin and considers population, economic activities, special structures and objects, protected areas – i.e. nature, and cultural heritage.

As expected, the most vulnerable zones are those flood prone areas that overlap with big settlements with high population density and economic activities. Some parts between Zagreb and Slavonski Brod, as well as some eastern parts of the Basin are vulnerable due to protected natural habitats. Almost 50% of flood prone areas is classified as having moderate vulnerability and the remainder is equally distributed between high and low vulnerability.

Areas with high vulnerability are mainly those around Zagreb, Belgrade and areas at the confluence with the Drina River into the Sava River. Sensitivity analysis was performed only within the 100 year return flood zone, but not beyond. Historical events like the 1896 in the Drina River and the Probable Maximum Flood event with extremely high water downstream on the Sava River need special treatment. The question on how will vulnerability change in the future and what will be the change in population density is also important.

There is also the process of reforestation already mentioned above, which has a strong impact on the water balance and decrease in discharge. In Slovenia, the area covered by forest is increasing by almost 1% each year, however in Bosnia and Herzegovina, the reverse is taking place.

A number of packages of short-term, medium-term and long-term mitigation measures for flood protection on the SRB and to combat climate change have been elaborated. These are as follows:

1. Phase A: Short-term measures over the next three years with cost of Euro 50 million, including:

- Development of flood warning system based on institutional strengthening;
- Determination and survey of permanent geodetic monitoring points (river bed cross sections); surveys to be repeated ideally every 2 years;
- Hydrologic modelling for predicting flood flows;
- Hydraulic modelling for calculating water levels;
- Maintenance and reconstruction of existing flood protection structures and its mechanical equipment (gates and pumping stations).

2. Phase B: Medium-term measures over the next 15 years with cost of Euro 1 billion, including:

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

3. Phase C: Long-term measures over the next 50 years with a cost of Euro 2 billion, including:

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

5 Conclusions

- In general all literature on floods in the SRB indicates that future flood events will increase, but there has been no real quantification of this expectation. Recent work by Brilly et al (2012) has tried to redress this inadequacy.
- The E-OBS data set is useful for hydrological climate change forecasts of flood peak discharges in the SRB. However this data set is not accurate enough for some parts of SRB and additional improvements of the E-OBS data are required.
- Climate change will increase the peak discharges mainly in the head part of the Sava River Basin watershed. The peak discharges will increase at the end of the 21st century for the 100-year return period i.e. from 3 % at Sremska Mitrovica up to 55 % at Čatež.
- There are some discrepancies in the Drina River basin, i.e. the discharges in the forecast for period 2071–2100 were lower than those for period 2041–2070. This also resulted in the lower discharge downstream of the confluence with the Sava River. Similar discrepancies but not as strong are presented on the tributaries Una River, Vrbas River and Bosna River.
- The probability functions were derived for water stations along the main stream of the Sava River with an estimation of high flows up to the flows with the return period of 1000 years. The climate change forecast was derived for the periods 2011–2040, 2041–2070 and 2071–2100.
- The impact of climate change on the water level forecasts with 100-year return period floods is quite high in the head part of the watershed, i.e. more than 2 m. Downstream it initially strongly decreases then it gradually increases up to 1.81 m and finally it drops to 0.10 m at Sremska Mitrovica.

- The Central Posavina region is an extremely important flood retention basin which needs to be protected from further development (building of flood protection structures, levees etc.).
- There is clear evidence that reforestation has decreased the mean discharges in Slovenia by up to 35 % and consequently such actions will decrease flood discharges and mitigate the impact of climate change on floods in the SRB. Further research on reforesting should be undertaken on other areas of the SRB.
- As part of a mitigation and climate change adaptation, a number of packages of short-term, medium-term and long-term measures for flood protection on the SRB have been elaborated. These measures have been predicted to cost more than Euros 3 billion over the next 50 years and include integrated water management, spatial planning and sustainable development activities in order to assure the production of synergistic effects and the optimum use of funds.

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