University of *Ljubljana*
Faculty of *of Civil and Geodetic Engineering*

**PILOT PROJECT ON CLIMATE CHANGE:
BUILDING THE LINK BETWEEN FLOOD RISK MANAGEMENT PLANING AND CLIMATE CHANGE ASSESSEMENT IN THE SAVA RIVER BASIN**

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

PART 2: CLIMATE CHANGE IMPACT ON FLOOD DISCHARGE OF THE SAVA RIVER, HYDROLOGY REPORT

March 2014

ENVSEC Environment & Security

INTERNATIONAL SAVA RIVER BASIN COMMISSION

UNECE United Nations Economic Commission for Europe

This report has been produced in the framework of the project "Testing of the Guidance document developed under the Water Convention (UNECE) - Building the link between the flood risk management planning and climate change assessment in the Sava River Basin“, implemented in the framework of the Environment and Security Initiative (ENVSEC) by the International Sava Commission (ISRBC) and the United Nations Economic Commission for Europe (UNECE) with funding from Finland. The countries sharing the Sava River Basin, together with the ISRBC (www.savacommision.org), appreciate this successful cooperation and kind support.

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ABBREVIATIONS

BiH – Bosnia and Herzegovina

E-OBS – European observation - European daily high-resolution gridded data set

ICPDR – International Commission for the Protection of the Danube River

MOP – Ministry of the Environment and Spatial Planning of Slovenia (today Ministry of agriculture and environment Republic of Slovenia – MKO)

MOPP – The Ministry of Environment and Spatial Planning od Serbia (today Ministry of Energy, Development and Environmental Protection of Republic of Serbia - MERZ)

MPPO – Ministry of spatial planning and environment of Montenegro

MZOIP, Ministry of Environmental Protection, Physical Planning and Construction of Croatia

SHMZ H – Hidrološki godišnjak, Savezni hidrometeorološki zavod, Beograd.

SHMZ MII – Meteorološki godišnjak II (padavine), Savezni hidrometeorološki zavod, Beograd

WS – water station

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1 INTRODUCTION

In recent years the topic of climate change impact on the water regime of the Sava River basin has been presented in several studies. The studies focused mainly on temperature trends and mean yearly discharge values.

Climate trends in the Sava River Basin were analysed in the World Bank study (Meerbach et al., 2010)[1]. The study focused on the mean values based on observations and empirical analyses. In the study peak flood flows and draughts were not analysed. Notably, mean yearly temperatures show stronger trends in increase over shorter periods (trends of the last ten years) and are weaker in long-term.

In the study conducted by Jupp (2011)[2] the climate change impact was analysed based on the results which were calculated using a series of model simulations. Average seasonal precipitation data were calculated and presented. In the forecast the mean seasonal precipitation mainly decreases except in winter time. The results are not useful for flood prediction.

Each country in the basin produces its own country report on climate change which is submitted to the United Nations Framework Convention on Climate Change with scenarios A1B and C.

In Slovenia's Fourth and Fifth National Communication under the United Nations Framework Convention on Climate Change (MOP, 2006, 2010)[3] it is mentioned that weather extremes will be more frequent. Floods are not specifically referred to in those reports.

In the Second, Third, Fourth and Fifth National Communications of the Republic of Croatia under the United Nations Framework Convention on Climate Change (MZOIP 2006, 2010)[4], there is a short note on the Danube river flood in 2003. Furthermore the reports predicted more frequent flood events. Also the evident concern regarding the increase of erosion in the head water parts of watersheds is expressed in the report. However the specific measures which are to be adopted are not listed. The last report stresses the importance of decreasing precipitation and corresponding decrease of runoff.

In the Initial National Communication of Bosnia and Herzegovina under the United Nations Framework Convention on Climate Change, Banja Luka, October 2009 (BiH, 2009) [5] it is mentioned that the following conclusions were reached by assessing possible indications of impacts on hydrology and water resources and assessing needs in defining real influences and

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[1] Meerbach, D., Hancock, l. and Powell, A. (2010): Climate Trends in the Sava River Basin, World Bank.

[2] Jupp, T. E. (2011): Water and Climate Adaptation Plan for the Sava River Basin, University of Exeter, Exeter, Devon EX4 4QF, UK, World Bank.

[3] MOP (2006) and (2010): Slovenia's Fourth and Fifth National Communication under the United Nations Framework Convention on Climate Change.

[4] MZOIP (2006, 2010): Second, Third, Fourth and Fifth National Communication of the Republic of Croatia under the United Nations Framework Convention on Climate Change.

[5] BiH (2009): Initial National Communication of Bosnia and Herzegovina under the United Nations Framework Convention on Climate Change.

adequate responses as specific research has not yet been done in Bosnia and Herzegovina regarding the impact of climate change on hydrology and water resources. It also says that the changes that cannot be perceived on the basis of the average annual values but it is necessary to carry out sophisticated analysis and studies with the aim of the research phenomena that are becoming available: increases in the number of consecutive days without rain, changes in intensity and frequency of storms, floods and droughts will decrease in return period from 50 to 5 years.

The measures which will be adopted in relation to flood protection are mentioned in the section on physical planning and future development of urban areas.

The Ministry for spatial planning and environment published the report The initial national communication on climate change of Montenegro to The United Nations Framework Convention on Climate Change in 2010 (MPPO, 2010)[6]. Their general statement is that the lack of water and severe droughts are expected as the main issue for water management and more frequent floods are also expected.

Some chapters in the Initial National Communication of the Republic of Serbia under the United Nations Framework Convention on Climate Change (MOPP, 2010) deal with hydrology and climate change. The trends and changes of mean values of precipitation, evapotranspiration and discharges are well documented. It is clearly exposed "that the above projections show that climate change might cause more intense flood and drought episodes, greater both in scope and duration".

The International Commission for the Protection of the Danube River (ICPDR) (Wolfram et al., 2012)[7] study concerns the Middle Danube River Basin:

- High uncertainty in flood projections; no clear picture can be drawn about possible changes of flood conditions.
- Increase of flood hazard probability and magnitude as well as increase in vulnerability, especially in small catchments / head watersheds.
- Development of flood events depends largely on changes in precipitation patterns, extreme weather events and snow cover; flood peak may occur earlier because of rain/snow changes.
- No clear conclusion and contradicting findings about the behaviour of extreme flood events (100-year frequency) – they may increase or decrease.
- Mountain areas: possible increase in frequency and magnitude of flood events.
- Tisza: increase of flood frequency in winter is likely to occur.
- Torrential types of hydrological extremes such as flash floods will likely be more frequent and severe (e.g. in small catchments / head watersheds of the Tisza, Sava and Mureş); possible increase in floods in summer due to more extreme precipitation events (e.g. Mureş).

In the same study only Serbia is addressing floods while for other countries in the Sava River Basin no data are available.

[6] MPPO (2010): The initial national communication on climate change of Montenegro to The United Nations Framework, Convention on Climate Change.

[7] Wolfram et al., 2012, Danube Study, Climate Change Adaptation, Department of Geography, Chair for Physical Geography and Remote Sensing, Ludwig-Maximilians University Munich.

The topic of climate change impacts is broad. Various scenarios are being examined based mainly on increase of air temperature. The reports that we reviewed were mainly related to mean yearly or seasonal values, and not to extremes.

The formation of flood runoff is a complex non-linear process that cannot be easily obtained from precipitation data. For the transformation of extreme precipitation data, we developed a hydrological model and then incorporated the precipitation data calculated for different projections for the A1B scenario.

2 HYDROLOGICAL MODEL OF THE SAVA RIVER WATERSHED

The HBV model is a conceptual model for continuous calculation of runoff used to simulate hydrological forecasting. It was originally developed in the 1970's at SMHI, the Swedish Meteorological and Hydrological Institute. It was named after the Hydrological Bureau Water Balance section (the abbreviation of Hydrologiska Byrans Vattenbalansavdelning) (IHMS, 1999)[8].

2.1 WATERSHED AND SUB-BASINS

The Sava river watershed from its source to the discharge into the Danube extends over an area of around 95.000 km^2. To ensure the rigidity and robustness of the model the sub-basins were generated to be as large as possible while covering not more than one major tributary stream. As a result the watershed was divided into 13 sub-basins with areas ranging from 2.000 to 14.000 km^2 (Table 1, Figures 1–3). The sub-basins are linked together and the outflow from the upstream ones is routed through the downstream ones.

Table 1: List of sub-basins.

#	Sub-basin number	Sub-basin name	Stream	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

[8] IHMS. (1999): Integrated Hydrological Modelling System. Manual, Version 4.5., Norrköping, Sweden, Swedish Meteorological and Hydrological Institute.

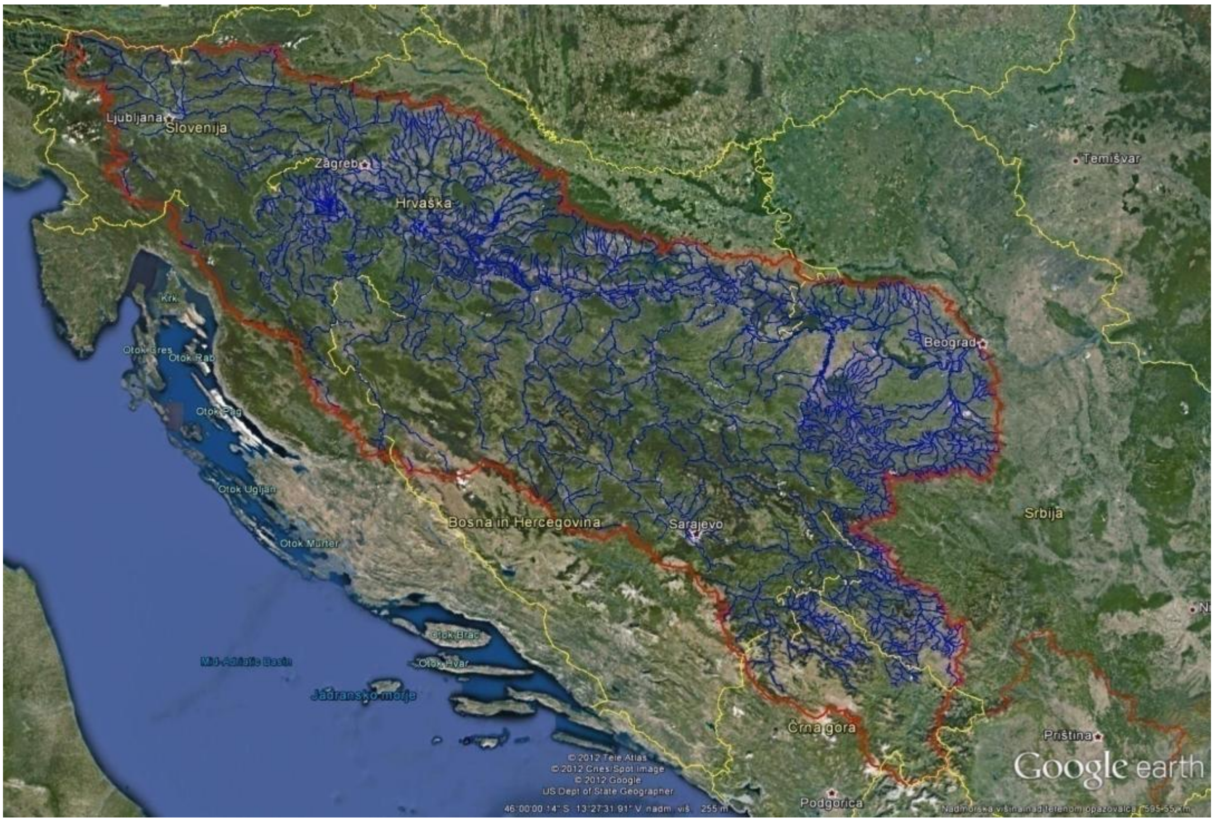


Figure 1: Modelled Sava river watershed – from its source to its confluence with the Danube – with all its major tributaries.

Figure 2: Modelled Sava river watershed – from its source to its confluence with the Danube – with all sub-basins.

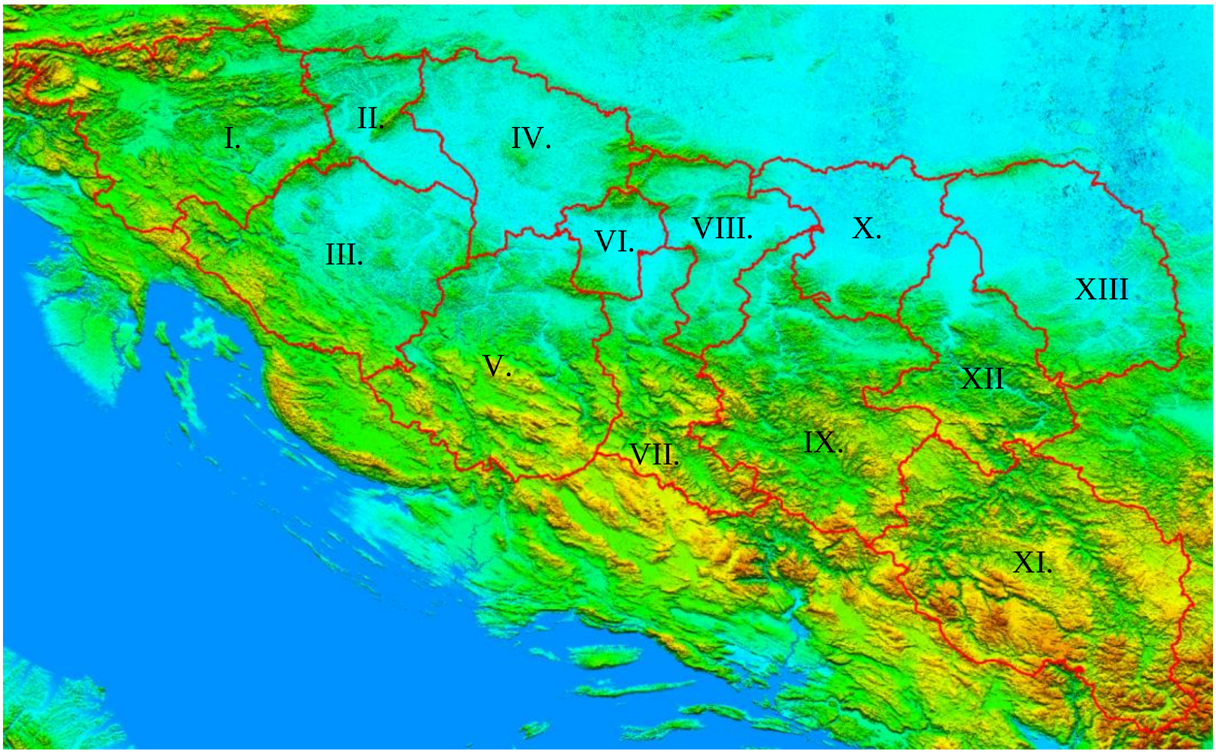
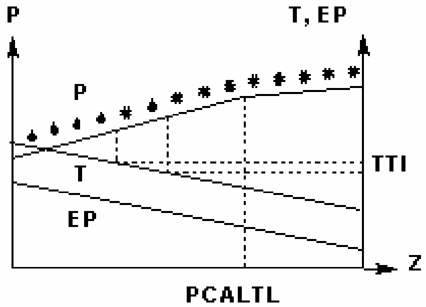


Figure 3: Modelled Sava river watershed – from its source to its confluence with the Danube – with orographic sub-basin and watershed borders.

2.1 GEOGRAPHICAL ZONES

All the sub-basins were divided into elevation (3 were chosen) and vegetation zones. The upper and South East part of the Sava river watershed is mountainous; as a result the sub-basins in that area have 3 elevation zones (Figure 4). The sub-basins in the plain area (North –West part of the watershed) where the altitudes generally do not exceed 200 m, have 2 elevation zones (Figure 4). Each elevation zone was then further divided into two areas according to land coverage (Figure 5) i.e. into the so called vegetation zones: forest and field (non-forest).

The division into elevation and vegetation zones (Table 2) is especially important for the snow calculating routine. The routine is best described with the schematic chart below:



Z = Elevation,
PCALTL = Threshold for altitude correction,
P = Precipitation,
T = Temperature,
EP = Potential evapotranspiration,
TTI = Threshold temperature interval

It is based on the simple degree-day relation. In this routine a threshold temperature (TT) which is usually close to 0°C is used to define the temperature above which snow melt occurs. The threshold temperature usually decides whether the precipitation falls as rain or as snow. Within the threshold temperature interval (TTI) the precipitation is assumed to be a mix of rain and snow (decreasing linearly from 100% snow at the lower end and to 0% at the upper end).

Snow melt and water refreezing is calculated according to:

Snow melt = CFMAX · (T-TT)
Refreezing melt water = CFR · CFMAX · (TT-T)

CFMAX = melting factor
CFR = freezing factor
TT = Threshold temperature

The snowpack is assumed to retain melt water as long as the amount does not exceed a certain fraction (given by the parameter WCH) of the snow. When the temperature decreases below TT the water refreezes according to the formula above.

Different melting and refreezing factors are used for forest and non-forest zones.

Table 2: List of sub-basins divided into geographical zones.

#	Sub-basin number	Sub-basin name	Elevation zone	Elevation zone area [km^2]	Mean elevation [ma.s.l.]
1	I.	Sava I	0-700	7265,35	434,96
2			700-1400	2463,27	960,62
3			1400-2100	344,71	1671,99
4	II.	Sava II	0-700	3455,74	213,77
5			700-1400	25,43	770,1
6	III.	Kolpa/Kupa	0-700	7731,19	282,45
7			700-1400	1770,26	850,9
8	IV.	Sava III	0-700	6664,45	161,53
9			700-1400	36,50	785,08
10	V.	Una	0-700	6164,43	390,9
11			700-1400	3743,30	982,88
12	VI.	Sava IV	0-700	1837,69	183,65
13			700-1400	42,29	796,92
14	VII.	Vrbas	0-700	2658,18	371,09
15			700-1400	2343,42	1009,15
16			1400-2100	293,41	1539,74
17	VIII.	Sava V	0-700	4356,07	207,97
18			700-1400	46,84	793,04
19	IX.	Bosna	0-700	5820,86	403,83
20			700-1400	3968,45	985
21			1400-2100	471,43	1593,37
22	X.	Sava VI	0-700	4435,67	349,63
23			700-1400	585,50	975,14
24	XI.	Drina I	0-700	1363,22	583,28
25			700-1400	9626,84	1068,95
26			1400-2100	2790,78	1624,26
27	XII.	Drina II	0-700	4435,67	349,63
28			700-1400	1536,48	968,15
29			1400-2100	6,51	1482,89
30	XIII.	Sava VII	0-700	8287,81	163,75
31			700-1400	135,91	853,12

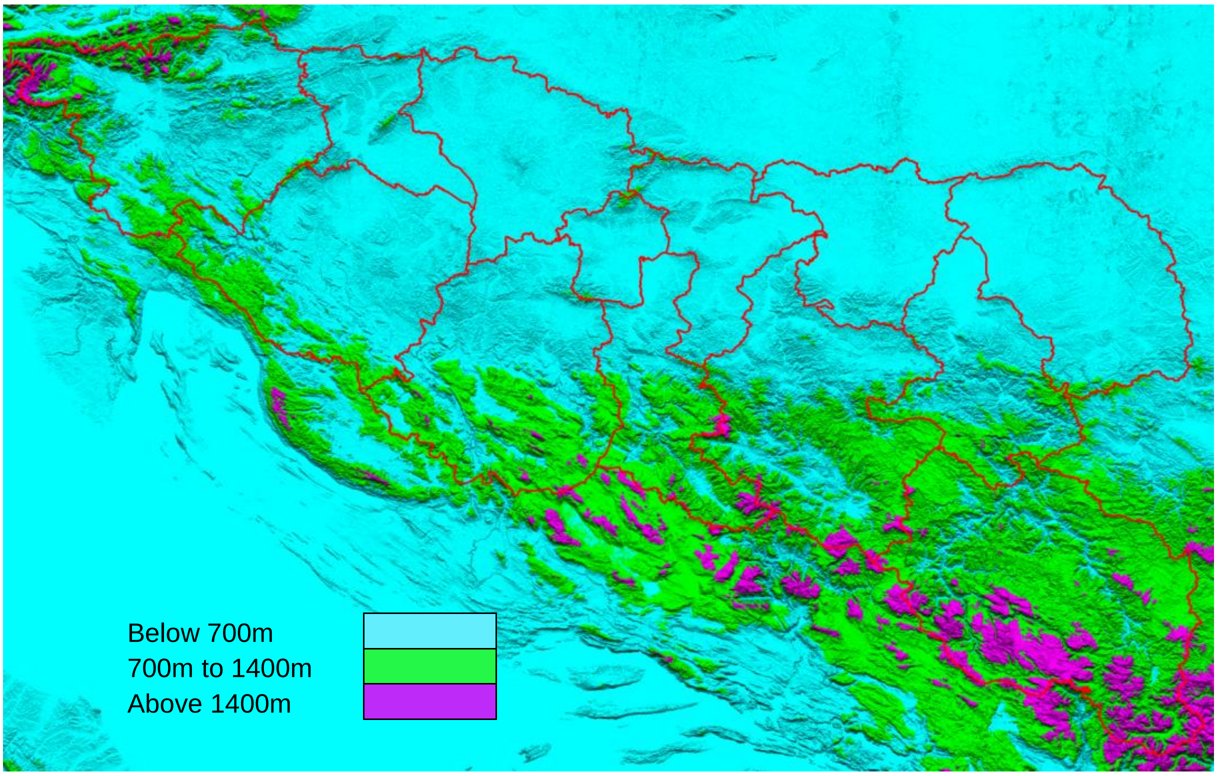


Figure 4: Modelled Sava river watershed – from its source to its confluence with the Danube – with all the sub-basins and geographical zones.

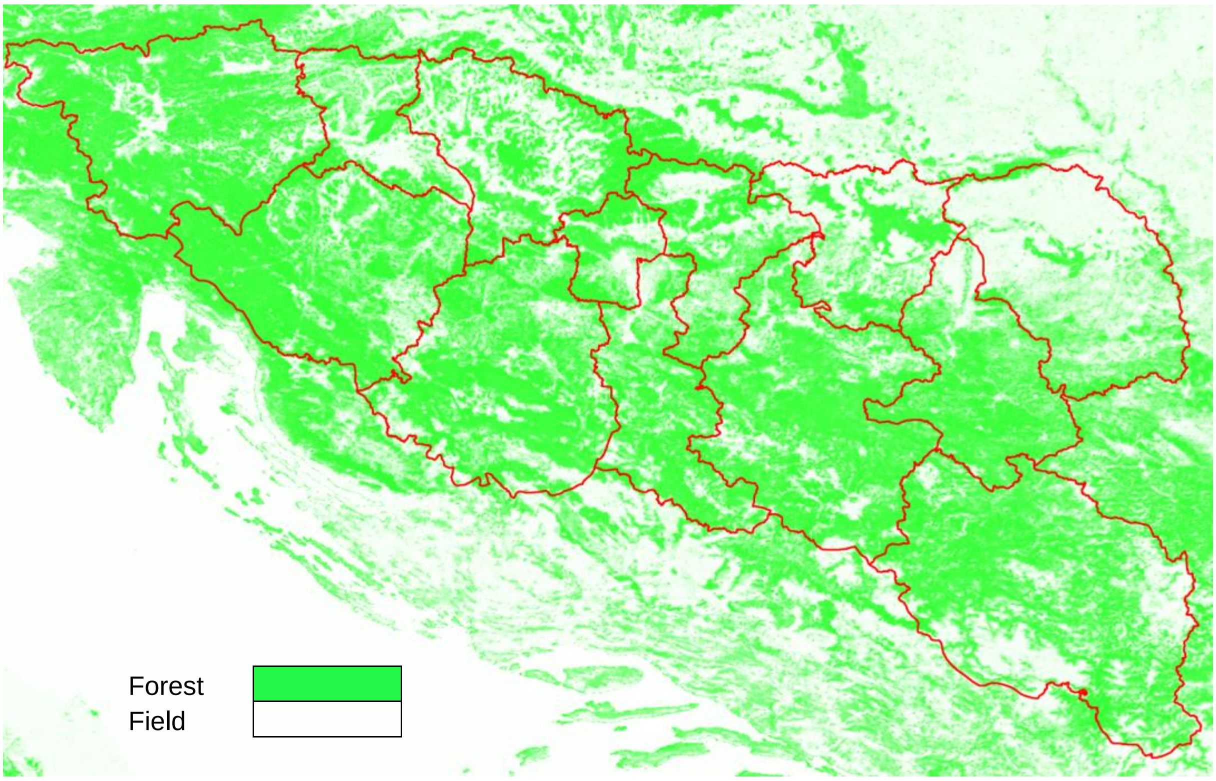


Figure 5: Modelled Sava river watershed – from its source to its confluence with the Danube – with all the sub-basins and the forest coverage.

2.2 INPUT DATA

The following input data are required to calibrate/run the model:

- precipitation (32 measurement stations were chosen (Table 3, Figure 6)),
- temperatures (8 measurement stations were chosen (Table 4, Figure 7)),
- discharge data (12 measurement stations were chosen (Table 5, Figure 8)),
- potential evapotranspiration (8 measurement stations were chosen (Table 4, Figure 7)).

The temperature and precipitation data were prepared as a set of data with a one-day time step. The time step of evapotranspiration data is usually greater than the one of the model. So a transformation to the model time step is required. This is done automatically by the model. In this case average monthly values (mm/day) are transformed to the one-day time step by linear interpolation and then modified by the ETF factor using the formula:

$$\textit{potential evapotranspiration} = E_{pot} \cdot (1+ETF \cdot (T-T_{norm}))$$

where E_{pot} is the standard value of potential evaporation, T is actual temperature and T_{norm} is normal temperature for the current day of the year.

To describe the areas of influence of points (which represent different stations) Thiessen polygons were used.

Precipitation data were obtained from Meteorological Yearbooks 1974 and 1978 (SHMZ M II, 1974, 1978)[9], discharge data from Hydrological Yearbooks 1974 and 1978 (SHMZ H, 1974, 1978), and temperature and potential evapotranspiration data from the database collected for the World Bank report (Meerbach, 2010).

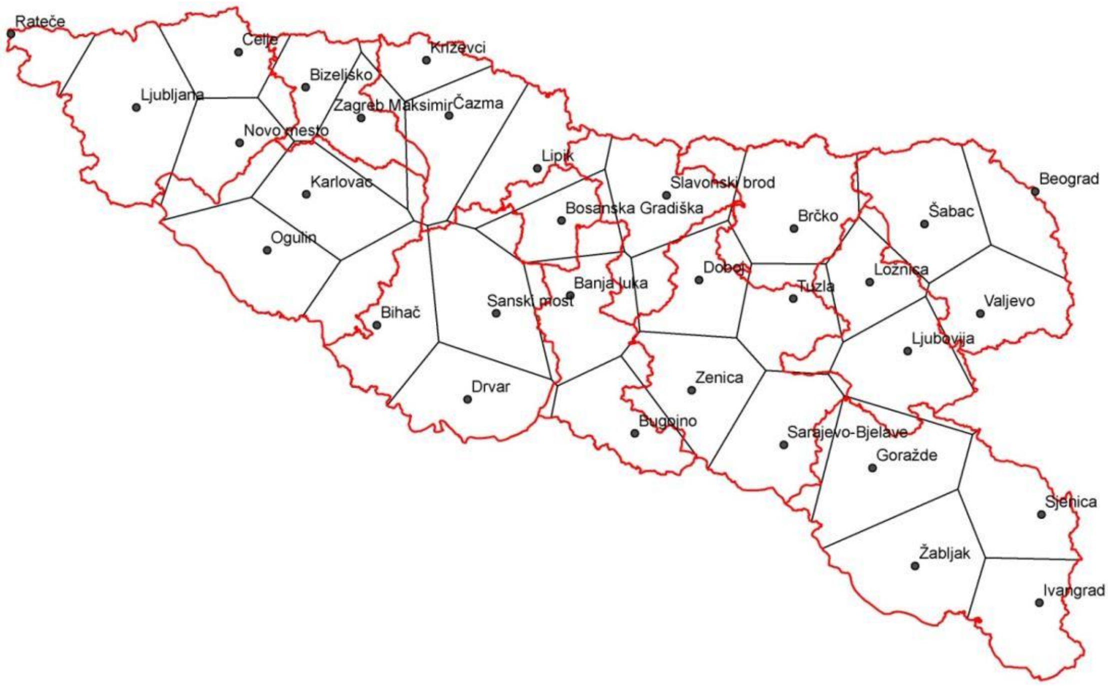


Figure 6: Sava river watershed with precipitation stations and Thiessen polygons.

[9] SHMZ H (1974): Hidrološki godišnjak, Savezni hidrometeorološki zavod, Beograd.
SHMZ H (1978): Hidrološki godišnjak, Savezni hidrometeorološki zavod, Beograd.
SHMZ MII (1974): Meteorološki godišnjak II, Savezni hidrometeorološki zavod, Beograd.
SHMZ MII (1978): Meteorološki godišnjak II, Savezni hidrometeorološki zavod, Beograd.

Table 3: List of precipitation stations.

#	Station name	Station number	m a.s.l.	Phi	Lambda
1	Rateče	18	864	46,3000	13,4300
2	Ljubljana	85	299	46,0400	14,3100
3	Celje	140	244	46,1500	15,1400
4	Bizeljsko	178	170	46,0100	15,6900
5	Novo mesto	286	220	45,4800	15,1100
6	Križevci	338	155	46,0333	16,5500
7	Ogulin	464	328	45,2667	15,2333
8	Karlovac	481	112	45,5000	15,5667
9	Zagreb – Maksimir	529	123	45,8167	16,0333
10	Čazma	574	144	45,7500	16,6333
11	Lipik	599	154	45,2500	17,1000
12	Slavonski Brod	641	88	45,1667	18,0000
13	Bosanska Gradiška	956	94	45,0900	17,1600
14	Bihač	982	246	44,8167	15,8833
15	Drvar	1008	485	44,3833	16,4000
16	Sanski most	1027	158	44,7667	16,7000
17	Banja Luka	1068	153	44,7833	17,2167
18	Bugojno	1091	562	44,0667	17,4667
19	Zenica	1126	344	44,2167	17,9000
20	Doboj	1144	146	44,7333	18,1000
21	Tuzla	1203	305	44,5500	18,7000
22	Brčko	1212	96	44,5300	18,5000
23	Sarajevo – Bjelave	1421	630	43,8667	18,4333
24	Goražde	1458	345	43,6667	18,9833
25	Ložnica	1732	121	44,5500	19,2333
26	Ljubovija	1744	17	44,1833	19,3833
27	Šabac	1772	80	44,7667	19,6833
28	Valjevo	1793	174	44,2833	19,9167
29	Beograd	1854	132	44,8000	20,4667
30	Sjenica	2053	1015	43,2667	20,0167
31	Žabljak	2484	1450	43,0900	19,0800
32	Ivangrad	2605	670	42,5000	19,5200

Table 4: List of temperature and potential evapotranspiration stations.

#	Station name	Station number	Mean elevation [m a. s. l.]
1	Ljubljana	85	299
2	Zagreb - Maksimir	529	123
3	Slavonski Brod	641	88
4	Bihać	982	246
5	Bugojno	1091	562
6	Goražde	1458	345
7	Ljubovija	1744	17
8	Beograd	1854	132

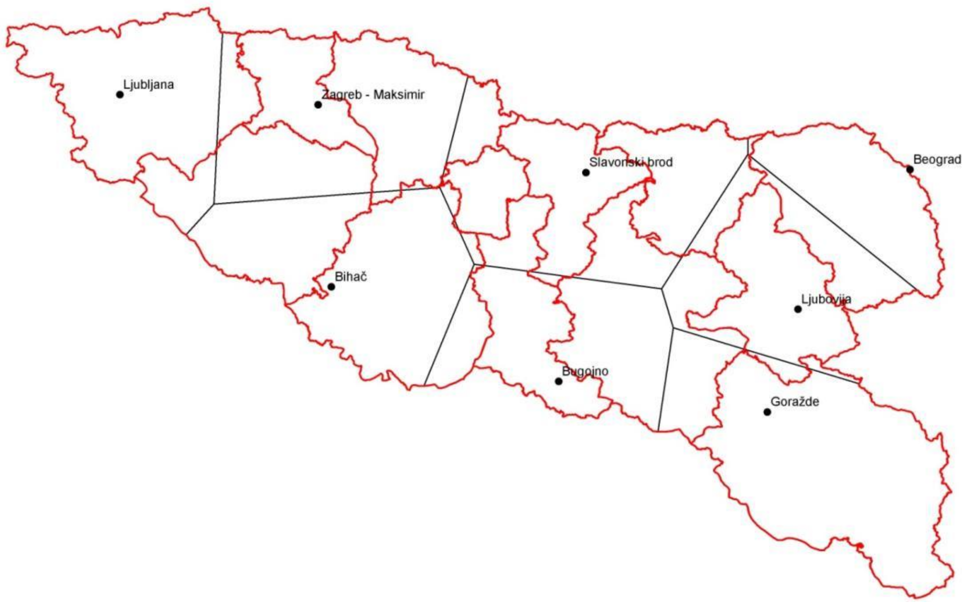


Figure 7: Sava river watershed with temperature and potential evapotranspiration stations and Thiessen polygons.

2.3 MODEL CALIBRATION AND VALIDATION

The number of parameters normally used in the model is in the order of 20–33. While in most cases 5 of them are set to standard values it is very important to calibrate approximately 15 of the parameters.

Three main criteria of fit are used while calibrating: visual inspection of the computed and observed hydrographs, Nash/Sutcliffe criterion R^2 and inspection of the accumulated error. The R^2 efficiency criterion was introduced by Nash and Sutcliffe (1970)[10] and is commonly used in hydrological modelling. R^2 has a value of 1.0 if the simulation and the observations agree completely and 0 if the model does not perform any better than the mean value of the runoff record. In practice values between 0.8 and 0.95 can be achieved if the quality of observed data is good. Negative values can be the result of poor model performance or poor data. In addition to the R^2 criterion there is another very important performance indicator: the accumulated error.

The calculation of basins is followed by the direction of the stream flow so for downstream basins the data computed from the upstream ones are required. As a result the calibration cannot be made in the order of the sub-basins desired by the user. It has to follow the natural stream and flow of the river.

The calibration is an interactive process. First one must carefully observe the hydrographs where the differences appeared. Then it is necessary to determine if there is a problem of volume or a problem of shape. After this one has to look at the conditions during the period of poor results (temperature, presence of snow, precipitation, and maximum discharge before, droughts) and change the relevant parameters. Finally the R^2 value is checked. Sometimes the result is better with the R^2 criterion a bit less strong because the peaks are better modelled.

[10] Nash, J. E. and J. V. Sutcliffe (1970): River flow forecasting through conceptual models part I -A discussion of principles, Journal of Hydrology, 10 (3), 282-290

For the calibration purposes we collected the data (input data: precipitation, temperature, evapotranspiration, discharge) for the period from June 1 to December 31, 1974. 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. In the east, head part of the watershed, maximum rainfall occurred on 25th September and in the west part on 27th September 1974 (SHMZ H, 1974 and SHMZ MII, 1974)[11].

The selected verification period was from 1st September, 1978 to 30th November, 1978 (SHMZ H, 1978 and SHMZ MII, 1978). The peak discharges are quit high and the data form the weather stations were available for modelling.

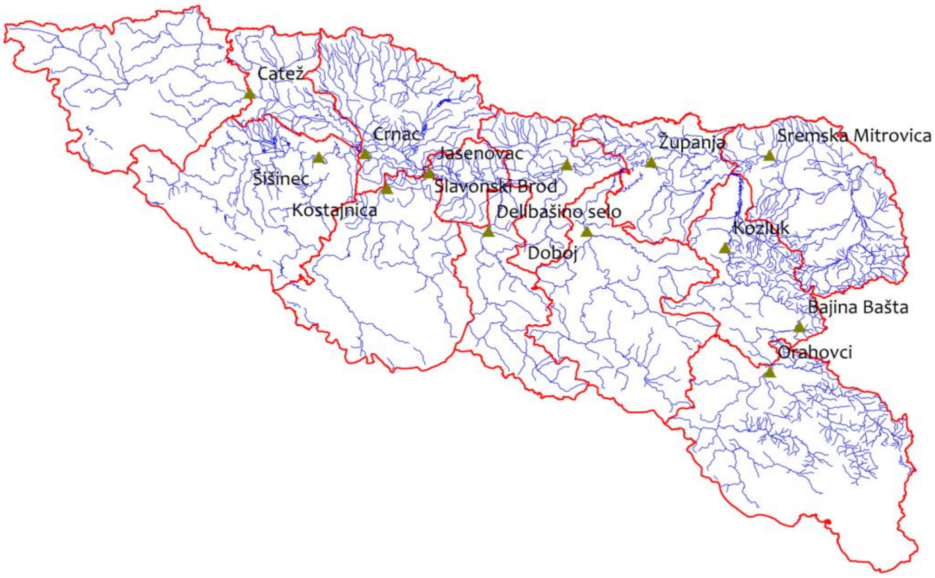


Figure 8: The Sava river basin with discharge stations (used for model calibration).

Table 5: Model calibration peak discharges in m^3/s (1974).

		Area	measured	calibrated	difference
Sub-basins	Water station	[km^2]	[m^3/s]	[m^3/s]	%
Sava I	Čatež	10.173	2294	2308	0,6
Kolpa	Šišinec	7.321	1250	1419	13,5
Sava II	Crnac	23.102	2147	2295	6,9
Una	Kostajnica	9.171	1370	1445	5,4
Sava III	Jasenovac	29.565	2580	2515	-2,5
Vrbas	Delibašino selo	5.469	691	762	10,3
Sava IV	Slavonski Brod	54.134	3460	3422	-1,1
Bosna	Doboj	9.618	1095	753	-31,3
Sava V	Županja	62.220	3930	4057	3,2
Drina I	Bajina Bašta	14.797	3359	2715	-19,2
Drina II	Kozluk	17.735	3041	2640	-13,2
Sava VI	Sremska Mitrovica	87.996	6275	6540	4,2
confluence with Danube				6653	

[11] SHMZ H (1974): Hidrološki godišnjak, Savezni hidrometeorološki zavod, Beograd.
SHMZ H (1978): Hidrološki godišnjak, Savezni hidrometeorološki zavod, Beograd.
SHMZ MII (1974): Meteorološki godišnjak II, Savezni hidrometeorološki zavod, Beograd.
SHMZ MII (1978): Meteorološki godišnjak II, Savezni hidrometeorološki zavod, Beograd.

Table 6: Model performance.

		Calibration		Verification		
Watershed No.	Watershed name	R2	Acc diff. [mm]	R2	Acc diff. [mm]	Station name
I.	Sava I	0,8183	-23,7937	-0,4213	20,8903	Čatež
III.	Kolpa/Kupa	0,9029	-19,8823	0,7461	-25,4299	Šišinec
IV.	Sava III	0,7689	-27,8047	0,4193	4,7807	Crnac
V.	Una	0,7921	18,8697	-3,2602	63,4986	Kostajnica
VI.	Sava IV	0,6361	-180,7203	0,6881	-24,1327	Jasenovac
VII.	Vrbas	0,3133	-10,3829	-1,5449	46,8637	Delibašino selo
VIII.	Sava V	0,8646	-46,2497	-0,4608	24,1783	Slavonski Brod
IX.	Bosna	0,2735	-91,3311	-2,9617	102,6221	Doboj
X.	Sava VI	0,8553	-14,7998	-2,0815	48,1689	Županja
XI.	Drina I	0,7999	-45,7861	-3,3535	4,6146	Bajina Bašta
XII.	Drina II	0,7830	-19,3865	-5,2540	22,571	Kozluk
	Sava VI+Drina	0,8561	10,1821	-3,1442	48,0747	Sremska Mitrovica
XIII.	Sava VII					confluence

The results of calibration and verification of the model are not impressive especially for sub-watersheds (Table 6). The sub-watersheds were modelled as homogenised areas except for the Drina River Basin. The main task of the calibration was flood peaks not water balance. In Figures 9 and 10 the comparison of the measured and modelled discharges for selected water stations are shown as a result of the hydrological model calibration procedure for the calibration period June 1–December 31, 1974.

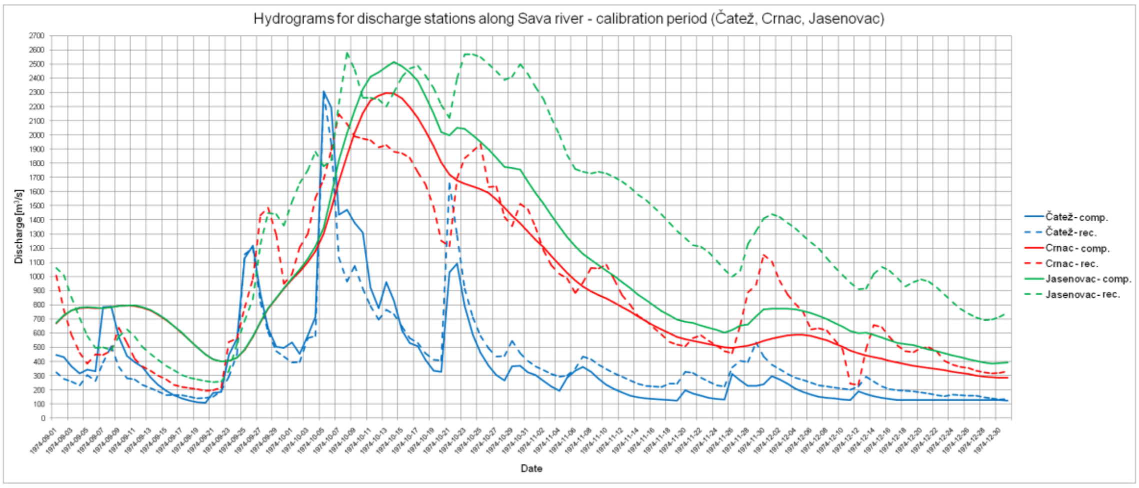


Figure 9: Measured and modelled discharges at the selected stations in the upper part of the Sava river basin (calibration period).

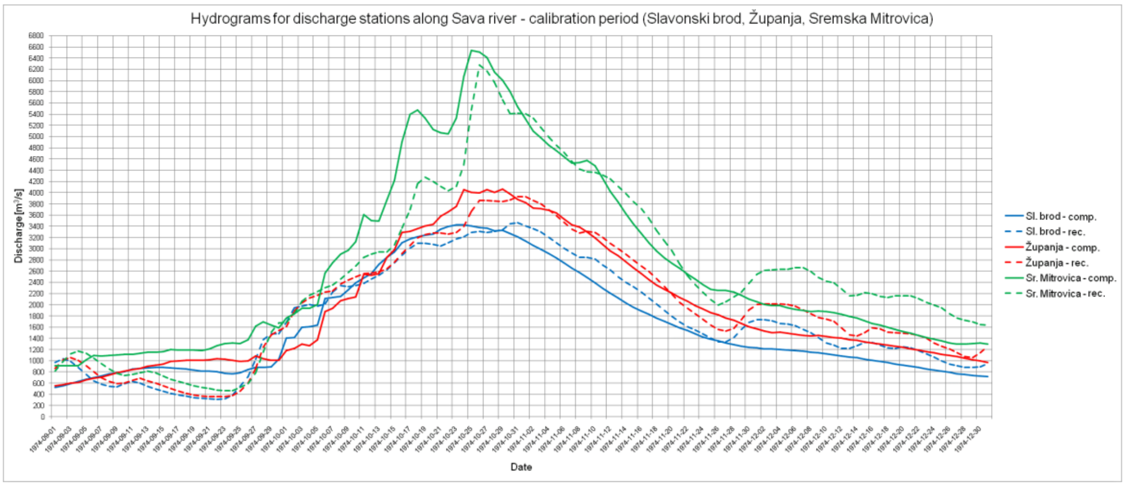


Figure 10: Measured and modelled discharges at the selected stations in the lower part of the Sava river basin (calibration period).

Figures 11 and 12 represent the measured discharges and hydrological model results for the verification period September 1–November 30, 1978.

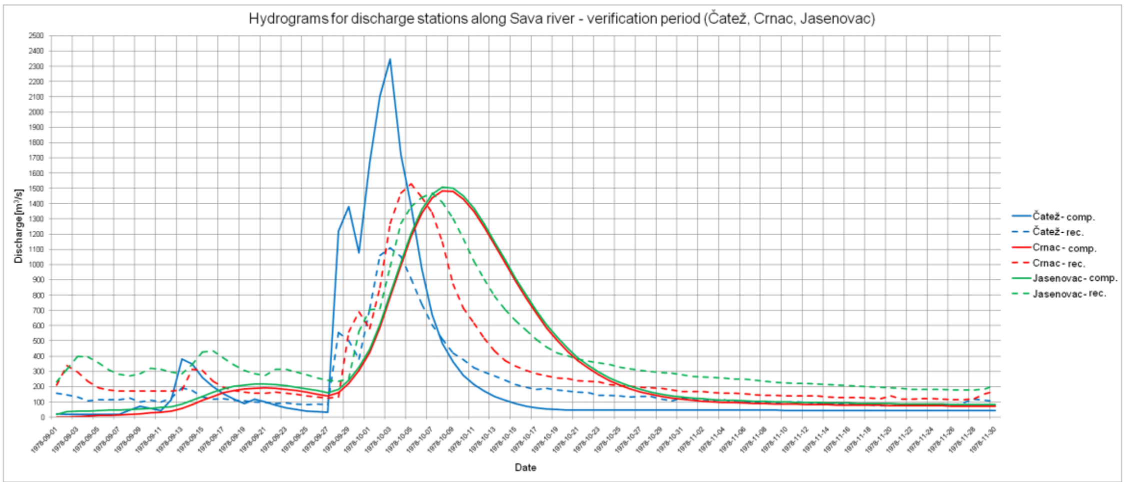


Figure 11: Measured and modelled discharges at the selected stations in the upper part of the Sava river basin (validation period).

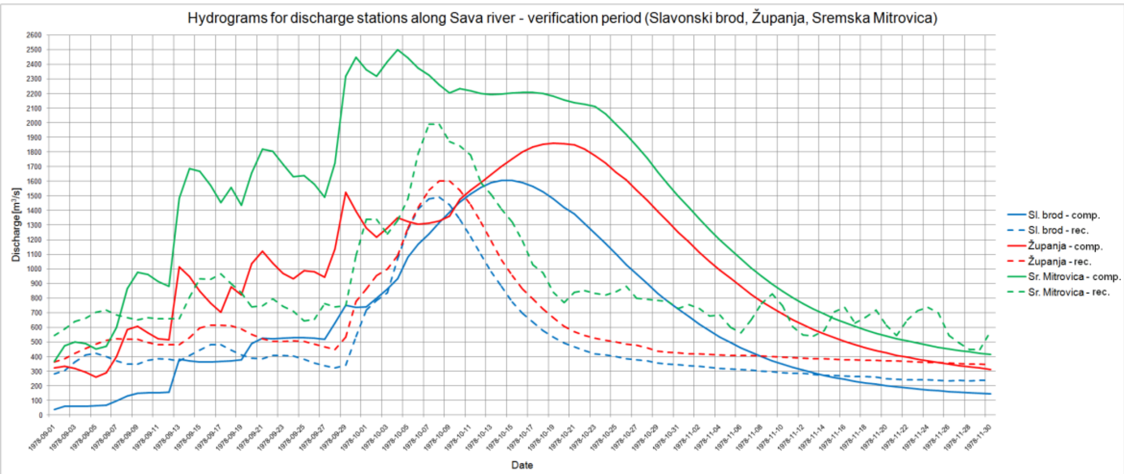


Figure 12: Measured and modelled discharges at the selected stations in the lower part of the Sava river basin (validation period).

3 DATA TRANSFORMATION FOR HYDROLOGICAL FORECASTS OF CLIMATE CHANGE IMPACTS

The precipitation and temperature data from the meteorological report (Rakovec and Ceglar, 2012)[12] are taken from the raster data set based on the position of rain gauge stations and used for the hydrological model. The observed data from the grid data base of European observation system (E-OBS) are extracted E-OBS (Haylock et al., 2008)[13] shown in Table 7. This 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 and the data collected between 1961 and 2010 were used in this study. An example of the data set is presented on the map (Figure 13).

Table 7: Daily maximum seasonal precipitation derived for weather station from E-OBS data for period 1971–2010 with 20-year return period in mm.

LONGITUDE	LATITUDE	Station	Max. prec. SHMZ 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
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

[12] Rakovec, J., Ceglar, A. (2012): Report on the development of climate projections for Sava river basin (part I of this report to the Sava Commission).

[13] Haylock et al., (2008): European daily high resolution gridded data set of surface temperature and precipitation for 1950-2006.

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

The precipitation data in the meteorological report are in raster format and we collected the data from the cell in which the precipitation station was positioned. Maximum daily precipitation values from E-OBS data are highest in summer and slightly lower (0.1 mm) in autumn.

The maximum daily values of the precipitation measured in 1974 are mainly slightly lower than the values of E-OBS. There is a high discrepancy between the E-OBS data and the measurements in the area of the Dinaric Mountains, especially in Montenegro (Figure 13). 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 8). A concern is that for the E-OBS data set the precipitation from Montenegro was not considered. The 1974 flood event was one of the highest floods measured before major flood protection construction works were put in place on the Posavina.

Summer daily precipitation is slightly higher than in autumn. However runoff in the autumn season is much higher due to higher evaporation so for further calculations and analysis we chose the autumn values (Table 8).

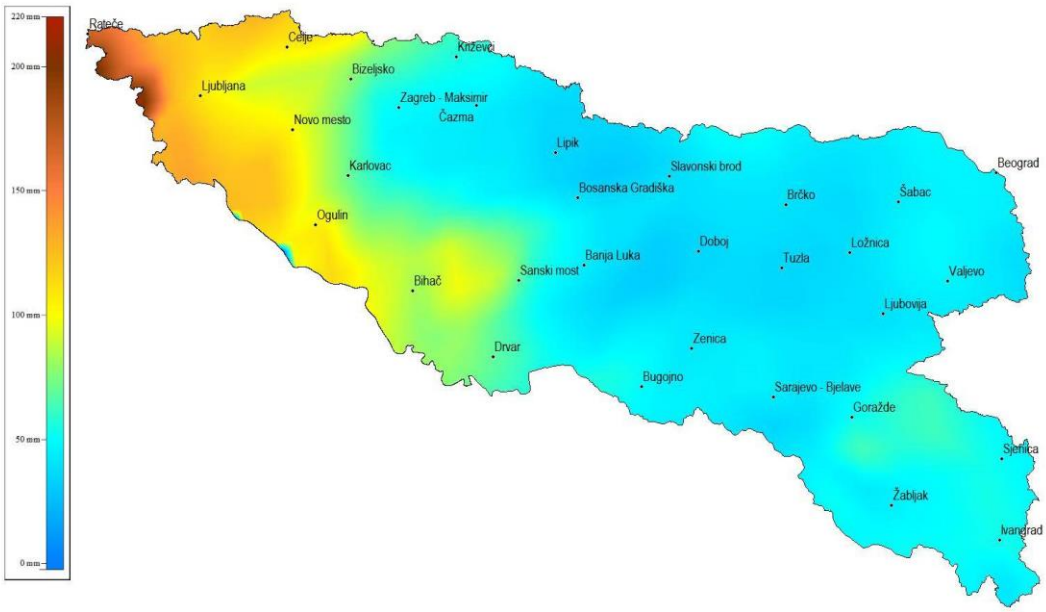


Figure 13: E-OBS data. Precipitation distribution for 100-year return period (Rakovec and Ceglar, 2012)[14].

[14] Rakovec, J., Ceglar, A. (2012): Report on the development of climate projections for Sava river basin (part I of report for the Sava Commission).

Table 8: Autumn rainfall values with 20- and 100-year return periods based on the E-OBS data with forecasts.

	EOBS_20	EOBS_100	20_11-40	**20_41-70**	20_ 71-2100	100_11-40	**100_41-70**	100_71-100
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

Forecast data for the periods of 2011–2040, 2041–2070 and 2071–2100 are presented in Table 8 and show interesting dynamics. Data for some stations increase with time, while with other stations first an increase and then a decrease can be observed. Average values for rainfall with a 20-year return period show a very small increase between periods 2041–2070 and 2071–2100 and even a slight decrease for the 100-year return period.

The probabilities in Table 9 are based on the Gumbel probability distribution and were calculated using the data on precipitation from the report by Meerbach (2010). The period of observation varied from 1908 or 1951 to 2009. The differences of values of precipitation with the 20-year return period calculated by the Gumbel distribution function and E-OBS varied. At some stations the values which were calculated using the Gumbel distribution were higher than those calculated by E-OBS, and vice versa. For the 100-year return period only the values from Slovenia are lower if calculated using the Gumbel distribution function than those calculated using the E-OBS data. All other stations have higher values. Finally the 100-year return period values for the forecast between 2041 and 2070 are lower than the values with the 100-year return period for all rainfall stations.

Table 9: Probability of maximum daily precipitation (mm) based on the report (Meerbach 2010) in the 1974 year (SZHM MII, 1974) and data from Table 8.

	return period			Max prec.	V1	V2	V3	V4
Station name	1.000	100	20	in 1974	EOBS_20	EOBS_100	20_41-70	100_41-70
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

Table 10: Temperature data and climate change forecast in ºC.

	EOBS temperature data for 1971-2010				Increase of temeperature		
Station	spring	summer	autumn	winter	2011_2040	2041_2070	2071_2100
Rateče	4,8	14,0	6,4	-3,2	0,9	**1,9**	3,0
Ljubljana	8,9	17,9	9,5	-0,3	0,9	**1,9**	2,9
Celje	8,4	17,2	9,1	-0,8	0,8	**1,8**	2,9
Bizeljsko	10,2	18,8	10,4	0,5	0,9	**1,8**	2,9
Novo mesto	9,2	17,9	9,8	0,0	0,9	**1,8**	2,9
Križevci	11,0	19,7	11,1	1,0	0,8	**1,8**	2,8
Ogulin	8,4	17,4	9,6	0,2	0,8	**1,7**	2,7
Karlovac	10,8	19,7	11,4	1,7	0,8	**1,7**	2,7
Zagreb - Maksimir	11,2	19,9	11,4	1,5	0,8	**1,8**	2,8
Čazma	11,5	20,3	11,7	1,7	0,8	**1,7**	2,8
Lipik	10,9	19,8	11,3	1,2	0,9	**1,7**	2,8
Slavonski brod	11,3	20,2	11,5	1,2	0,9	**1,8**	2,8
Bosanska Gradiška	11,1	20,0	11,6	1,5	0,8	**1,7**	2,7
Bihač	8,5	17,5	9,5	0,0	0,8	**1,6**	2,7
Drvar	7,1	16,3	8,7	-0,6	0,9	**1,8**	3,0
Sanski most	10,1	19,2	11,0	1,4	0,7	**1,6**	2,5
Banja Luka	10,7	19,8	11,5	1,7	0,7	**1,6**	2,5
Bugojno	7,2	16,3	8,9	-0,5	0,8	**1,8**	3,0
Zenica	8,8	17,6	9,8	0,1	0,8	**1,8**	2,9
Doboj	11,0	19,8	11,4	1,3	0,8	**1,6**	2,6
Tuzla	10,1	18,8	10,4	0,4	0,8	**1,7**	2,8
Brčko	11,4	20,1	11,3	1,2	0,8	**1,7**	2,8
Sarajevo - Bjelave	8,1	16,9	9,2	-0,5	0,9	**1,9**	3,2
Goražde	8,2	17,0	9,4	-0,6	0,9	**1,9**	3,2
Ložnica	10,6	19,4	10,8	0,7	0,8	**1,7**	2,8
Ljubovija	9,1	17,9	9,8	-0,3	0,9	**1,8**	3,0
Šabac	11,5	20,3	11,4	1,1	0,9	**1,8**	2,9
Valjevo	10,2	19,1	10,6	0,4	0,8	**1,8**	2,9
Beograd	11,8	20,8	12,1	1,5	0,9	**1,9**	3,1
Sjenica	5,5	14,2	6,7	-3,5	0,9	**2,0**	3,3
Žabljak	4,8	13,8	6,7	-3,0	0,9	**2,1**	3,4
Ivangrad	5,7	14,7	7,3	-2,7	0,9	**2,0**	3,2
average	9,3	18,2	10,0	0,1	0,8	**1,8**	2,9
stand. dev.	2,1	2,0	1,6	1,5	0,1	0,1	0,2

Temperature data are given in Table 10. Temperature data vary significantly inside the Sava River watershed. However the forecast variation is rather small. For further calculations we chose an increase of 0,8ºC in autumn in the period 2011–2040, 1,8ºC for autumn in the period 2041–2070 and 2,9ºC in the period 2071–2100, i.e. for the watershed as a whole.

4 RESULTS OF CLIMATE CHANGE MODELLING

The hydrological model presented in Chapter 2 was used for modelling of the impact of climate change forecasts on the Sava River discharges at selected stations (Table 11). For modelling the impact of climate change the same input data as those for the calibrated model for the 1974 flood were used. We only changed the rainfall data for the day with maximum precipitation and increasing temperature (Table 10). Instead of using the measured maximum daily precipitation, we used the predicted maximum daily precipitation from Table 8. All other input data are still the same. First we calculated peak discharges for the E-OBS (1971–2010) data with 20- and 100-year return periods. The calibrated and measured discharges with the E-OBS data modelling are presented in Table 11.

Table 11: Result of modelling recent climate flood peaks (in m^3/s).

Sub-basins	WS	measured	calibrated	EOBS_ret20	EOBS_ret100
Sava I	Čatež	2294	2308	2308	2780
Kolpa	Šišinec	1250	1419	1473	1522
Sava II	Crnac	2147	2295	2350	2510
Una	Kostajnica	1370	1445	1382	1407
Sava III	Jasenovac	2580	2515	2561	2718
Vrbas	Delibašino selo	691	762	620	707
Sava IV	Slavonski Brod	3460	3422	3411	3573
Bosna	Doboj	1095	753	742	767
Sava V	Županja	3930	4057	4068	4227
Drina I	Bajina Bašta	3359	2715	2336	2474
Drina II	Kozluk	3041	2640	2276	2407
Sava V	Sremska Mitrovica	6275	6540	6328	6603
confluence with Danube			6653	6432	6715

Peak calibrated discharges in the central part of the watershed down to Sava III are lower than those calculated by 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 by 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 the calculated ones.

We calculated the impact of climate change in the same way as in the model calibration taking into account the change of the maximum daily values of precipitation with the data from Table 8 and the increase in temperature using the data from Table 10. The results of modelling for the E-OBS data for the 20-year return period and for forecasts in periods 2011–2040, 2041–2070 and 2071–2100 are presented in Table 12 and on Figure 14 and for E-OBS data with the 100-year return period the results are shown in Table 13 and on Figure 15.

The forecasted flood peaks produced by precipitation with the 20-year return period in the period 2071–2100 will increase on average from 14 % up to 36 % in the upper part of the basin and on some tributaries (Table 12). The calculated base flow drops a little due to higher temperatures (Figure 14). 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 forecasted discharges will increase in time due to climate change. However the predicted discharges on the Drina River WS and the downstream Sremska Mitrovica WS on the Sava River for the period 2071–2100 are lower than those for the period 2041–2070.

The discrepancies in the peak discharges on the Drina River basin could be the result of fewer predictions used for the 2071–2100 periods of precipitation forecasts. Also some results of climate change modelling (Rakovec and Ceglar, 2012)[15] which were used for periods 2011–2040 and 2041–2070 were not available for the 2071–2100 forecasts.

Table 12: Result of modelling climate change flood peaks using the E-OBS data for the 20-year return period (in m^3/s and %).

Sub-basins	**WS**	**E-OBS** m^3/s	**11-40** m^3/s	**41-70** m^3/s	**71-2100** m^3/s	**11-40 /E-OBS %**	**41-70 /E-OBS %**	**71-2100 /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

The forecasted flood peaks produced by precipitation with 100-year return period are in Table 13. The data are presented with peak discharge values and percentage of increase relative to the calculation using the E-OBS data.

The percentages of increase of flood discharges produced by precipitation with 100-years return period (Table 13) indicate a higher increase than the discharge values produced by precipitation with the 20-years return period, as presented in Table 12. The average increase i.e. for the period until 2100 is 14% and 23% for the 20- and 100-year return period of precipitation, respectively.

[15] Rakovec, J., Ceglar, A. (2012): Report on the development of climate projections for Sava river basin (part I of report for the Sava Commission).

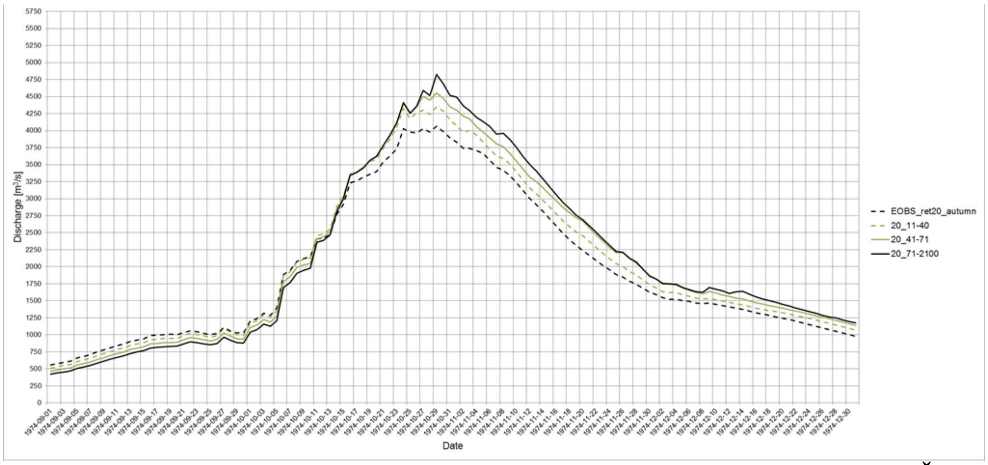


Figure 14: Discharges calculated using the E-OBS data for 20-year return periods for WS Županja, Sava V.

Table 13: Results of modelling climate change flood peaks using the E-OBS data of the 100-year return period (in m^3/s and %).

Sub-basins	**WS**	**E-OBS** m^3/s	**11-40** m^3/s	**41-70** m^3/s	**71-2100** m^3/s	**11-40 /E-OBS** %	**41-70 /E-OBS** %	**71-2100 /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 upper part of the watershed at WS Čatež 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 to the end of 2100 (Table 8). Similar is the dynamics of flood discharges produced by precipitation with 100-year return period forecast for the Vrbas River tributary i.e. an increase by 20% followed by a lower increase of 17%. The flood discharge of the Bosna River tributary 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 forecasts is more significant. The flood discharge of the Drina River will increase up to 27% and then drop to 12% which is similar to the increase in the first period of the forecasts. The forecasted discharges increase along the Sava River indicating a drop from WS

Čatež (49%) to 17 % on WS Crnac and to 14% on WS Jasenovac, discharges than increased at WS Slavonski Brod for 16%. The percentage of discharge increases downstream down to WS Županja up to 25%. Downstream of the Drina River mouth the percentage of The Sava River flood discharges increases, for the period 2041–2070, up to 15% on the WS Sremska Mitrovica and then drops to 12% for the period of 2071–2100.

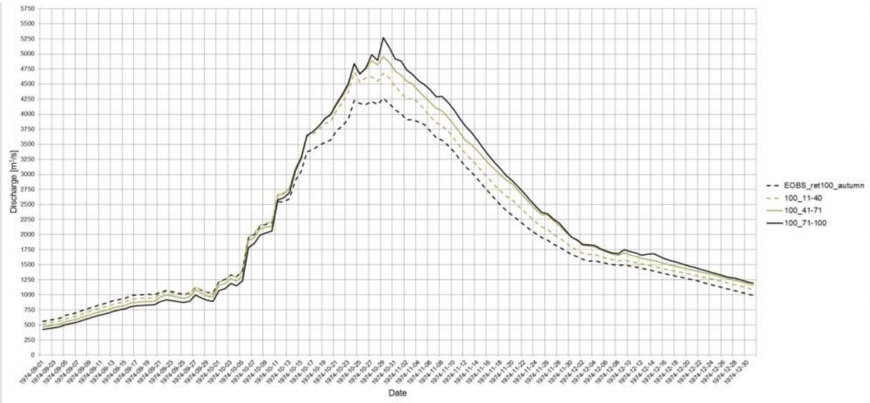


Figure 15: Discharges calculated using the E-OBS data for the 100-year return period for WS Županja, Sava V.

Accuracy of calculations meteorological forecasts of rainfall is estimated at 30 % with 90 % of confident level. We also designed a model of the Sava River with HBV-Light model and its calculation is made by the same procedure. The analysis showed discrepancies between the models that are less than 10 % (Božek, 2013)[16]. Thus, we assume a final overall uncertainty of calculated discharges roughly as ± 40% of the presented in Tables 12 and 13.

The results from Tables 12 and 13 were recalculated for WS from the Annex 1 of Contract. We assume that calculated values valid not only for the river mouth but also the percentage of increase could be used for the watershed as a whole. Results are presented in Table 14 and Table 15. Lowest part of the Sava River Basin downstream of the confluence with the Drina River has arid climate with low precipitation rate. The Increase of the precipitation due to climate change is quite low so the impact of increase of temperature decrease discharges significantly. The values of predicted discharges with the EOBS 20 years return period data (Table 14) are even slightly lower than today's values and the EOBS 100 years return period values are slightly higher that today's values (Table 15).

[16] Božek, K. 2013. Impact of floods on natural protected areas of Lonjsko polje, Croatia, and Obedska Bara, Serbia. Master thesis, Flood Risk Management master study, Erasmus mundus, IHE UNESCO, TU Dresden, TU Barcelona, University of Ljubljana.

Table 14: Climate Change impacts on increase of flood peaks cause by E-OBS precipitation with 20-year return period up to the year 2100, for WS in the Sava River Basin in %.

Country	Stream	Station	% of inc.		Country	Stream	Station	% of inc.
Slovenia	Sava	Radovljica	33		BiH-FBiH	Unac	Rmanj Manastir	24
Slovenia	Sava	Šentjakob	33		BiH-RS	Sana	Donji Ribnik	24
Slovenia	Sava	Litija	33		BiH-RS	Sana	Prijedor	24
Slovenia	Sava	Čatež	33		BiH-FBiH	Sana	Ključ	24
Croatia	Sava	Jesenice	33		BiH-FBiH	Sana	Sanski Most	24
Croatia	Sava	Podsused	20		BiH-FBiH	Vrbas	Daljan	11
Croatia	Sava	Zagreb	20		BiH-FBiH	Vrbas	Kozluk Jajce	11
Croatia	Sava	Rugvica	10		BiH-RS	Vrbas	Banja Luka	11
Croatia	Sava	Crnac	9		BiH-RS	Vrbas	Delibašino Selo	11
Croatia	Sava	Jasenovac	7		BiH-RS	Vrbanja	Vrbanja	11
Croatia	Sava	Stara Gradiška	10		Croatia	Pleternica	Orljava	8
BiH-RS	Sava	Gradiška	10		BiH-FBiH	Bosna	Maglaj	36
Croatia	Sava	Mačkovac	10		BiH-FBiH	Bosna	Reljevo	36
Croatia	Sava	Davor	10		BiH-FBiH	Bosna	Raspotočje	36
BiH-RS	Sava	Srbac	11		BiH-FBiH	Bosna	Zavidovići	36
Croatia	Sava	Slavonski Kobaš	11		BiH-RS	Bosna	Doboj	36
Croatia	Sava	Slavonski Brod	11		BiH-FBiH	Željeznica	Ilidža	36
Croatia	Sava	Slavonski Šamac	19		BiH-FBiH	Miljacka	Sarajevo	36
Croatia	Sava	Županja	19		BiH-FBiH	Lašva	Merdani	36
Serbia	Sava	Jamena	19		BiH-FBiH	Krivaja	Olovo	36
Serbia	Sava	Sremska Mitrovica	8		BiH-FBiH	Krivaja	Zavidovići	36
Serbia	Sava	Šabac	8		BiH-FBiH	Tinja	Srebrenik	20
Serbia	Sava	Beljin	8		Serbia	Bosut	Batrovci	-2
Serbia	Sava	Beograd	8		BiH-RS	Drina	Foča-nizv	5
Slovenia	Sora	Suha	33		BiH-FBiH	Drina	Goražde	5
Slovenia	Ljubljanica	Moste	33		Serbia	Drina	Bajina Bašta	5
Slovenia	Savinja	Nazarje	33		Serbia	Drina	Mihaljevići	7
Slovenia	Savinja	Veliko Širje	33		Serbia	Drina	Radalj	7
Slovenia	Krka	Podbočje	33		Serbia	Jadar	Lešnica	7
Slovenia	Kolpa/Kupa	Metlika	33		Serbia	Lim	Brodarevo	5
Croatia	Kupa/Kolpa	Brodarci	8		Serbia	Lim	Prijepolje	5
Croatia	Kupa/Kolpa	Karlovac S	8		Serbia	Lim	Priboj	5
Croatia	Kupa/Kolpa	Jamnička Kiselica	8		Serbia	Vapa	Čedovo	5
Slovenia	Sotla	Rakovec	8		Serbia	Kolubara	Valjevo	-2
Croatia	Sutla	Zelenjak	8		Serbia	Kolubara	Slovac	-2
Croatia	Krapina	Kupljenovo	8		Serbia	Kolubara	Draževac	-2
BiH-FBiH	Una	Martin Brod	24		Serbia	Kolubara	Obrenovac	-2
BiH-FBiH	Una	Kralje Bihać	24		Serbia	Tamnava	Ćemanov most	-2
BiH-FBiH	Una	Otoka	24					
Croatia	Una	Kostajnica	24					
Croatia	Una	Dubica	24					
BiH-RS	Una	Novi Grad-uzv.	24					
BiH-RS	Una	Novi Grad-niz.	24					

Table 15: Climate Change impacts on increase of flood peaks cause by E-OBS precipitation with 100-year return period up to the year 2100, for WS in the Sava River Basin in %.

Country	Stream	Station	% of inc.	Country	Stream	Station	% of inc.
Slovenia	Sava	Radovljica	49	BiH-FBiH	Unac	Rmanj Manastir	56
Slovenia	Sava	Šentjakob	49	BiH-RS	Sana	Donji Ribnik	56
Slovenia	Sava	Litija	49	BiH-RS	Sana	Prijedor	56
Slovenia	Sava	Čatež	49	BiH-FBiH	Sana	Ključ	56
Croatia	Sava	Jesenice	49	BiH-FBiH	Sana	Sanski Most	56
Croatia	Sava	Podsused	40	BiH-FBiH	Vrbas	Daljan	17
Croatia	Sava	Zagreb	40	BiH-FBiH	Vrbas	Kozluk Jajce	17
Croatia	Sava	Rugvica	25	BiH-RS	Vrbas	Banja Luka	17
Croatia	Sava	Crnac		BiH-RS	Vrbas	Delibašino Selo	17
Croatia	Sava	Jasenovac	16	BiH-RS	Vrbanja	Vrbanja	17
Croatia	Sava	Stara Gradiška	16	Croatia	Pleternica	Orljava	13
BiH-RS	Sava	Gradiška	16	BiH-FBiH	Bosna	Maglaj	44
Croatia	Sava	Mačkovac	16	BiH-FBiH	Bosna	Reljevo	44
Croatia	Sava	Davor	16	BiH-FBiH	Bosna	Raspotočje	44
BiH-RS	Sava	Srbac	16	BiH-FBiH	Bosna	Zavidovići	44
Croatia	Sava	Slavonski Kobaš	16	BiH-RS	Bosna	Doboj	44
Croatia	Sava	Slavonski Brod	16	BiH-FBiH	Željeznica	Ilidža	44
Croatia	Sava	Slavonski Šamac	25	BiH-FBiH	Miljacka	Sarajevo	44
Croatia	Sava	Županja	25	BiH-FBiH	Lašva	Merdani	44
Serbia	Sava	Jamena	25	BiH-FBiH	Krivaja	Olovo	44
Serbia	Sava	Sremska Mitrovica	13	BiH-FBiH	Krivaja	Zavidovići	44
Serbia	Sava	Šabac	13	BiH-FBiH	Tinja	Srebrenik	25
Serbia	Sava	Beljin	13	Serbia	Bosut	Batrovci	3
Serbia	Sava	Beograd	13	BiH-RS	Drina	Foča-nizv	10
Slovenia	Sora	Suha	49	BiH-FBiH	Drina	Goražde	10
Slovenia	Ljubljanica	Moste	49	Serbia	Drina	Bajina Bašta	10
Slovenia	Savinja	Nazarje	49	Serbia	Drina	Mihaljevići	12
Slovenia	Savinja	Veliko Širje	49	Serbia	Drina	Radalj	12
Slovenia	Krka	Podbočje	49	Serbia	Jadar	Lešnica	12
Slovenia	Kolpa/Kupa	Metlika	49	Serbia	Lim	Brodarevo	10
Croatia	Kupa/Kolpa	Brodarci	13	Serbia	Lim	Prijepolje	10
Croatia	Kupa/Kolpa	Karlovac S	13	Serbia	Lim	Priboj	10
Croatia	Kupa/Kolpa	Jamnička Kiselica	13	Serbia	Vapa	Čedovo	10
Slovenia	Sotla	Rakovec	13	Serbia	Kolubara	Valjevo	3
Croatia	Sutla	Zelenjak	13	Serbia	Kolubara	Slovac	3
Croatia	Krapina	Kupljenovo	13	Serbia	Kolubara	Draževac	3
BiH-FBiH	Una	Martin Brod	56	Serbia	Kolubara	Obrenovac	3
BiH-FBiH	Una	Kralje Bihać	56	Serbia	Tamnava	Ćemanov most	3
BiH-FBiH	Una	Otoka	56				
Croatia	Una	Kostajnica	56				
Croatia	Una	Dubica	56				
BiH-RS	Una	Novi Grad-uzv.	56				
BiH-RS	Una	Novi Grad-niz.	56				

5 CLIMATE CHANGE IMPACT ON PROBABILITY OF FLOOD PEAKS

The probability analysis was derived from the probability analysis represented in the report by Prohaska (2009)[17]. The probability analysis in the report was derived from the 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 data about 90, 99 and 99.9 percentage of probability were used as the basic relations for water stations. Probability of discharge values calculated from the E-OBS data with the 20- and 100-year return periods were estimated based on probability from report Prohaska (2009) and presented in Tables 16–20 (bold). It was assumed that predicted discharges, calculated by model and predicted maximum E-OBS precipitation with certain return period, have the same probability as discharges calculated.by today E-OBS precipitation with same return period.The new probability curves of maximum discharges for each period of forecast are determined by Gumbel probabilty curves fit to two forecasted discharges. In this way the discharges for different probabilities were estimated, according to data in the report (Prohaska, 2009). The results are presented in the Tables 16–20 and on the Figures 16–20.

Table 16: Probability of peak discharges on WS Čatež (m³/s).

	E-OBS_20		E-OBS_100		
probabilty %	**74**	**90**	**96,95**	**99**	**99,9**
Period/exceeded prob. %	**26**	**10**	**3,05**	**1**	**0,1**
today	2308	2524	2780	3026	3400
2011_2040	2552	2892	3297	3685	4258
2041_2070	2859	3276	3770	4245	4946
2071_2100	3073	3558	4134	4687	5504

The current 100-year return period discharges on the WS Čatež (Table 16) will increase for almost 22% in the first period (2011–2040) and for 55% until the year 2100. It means that the 100-year return period flood discharge will increase by 2100 for 1661 m³/s (Figure 16), while the water level will increase for 226 cm.

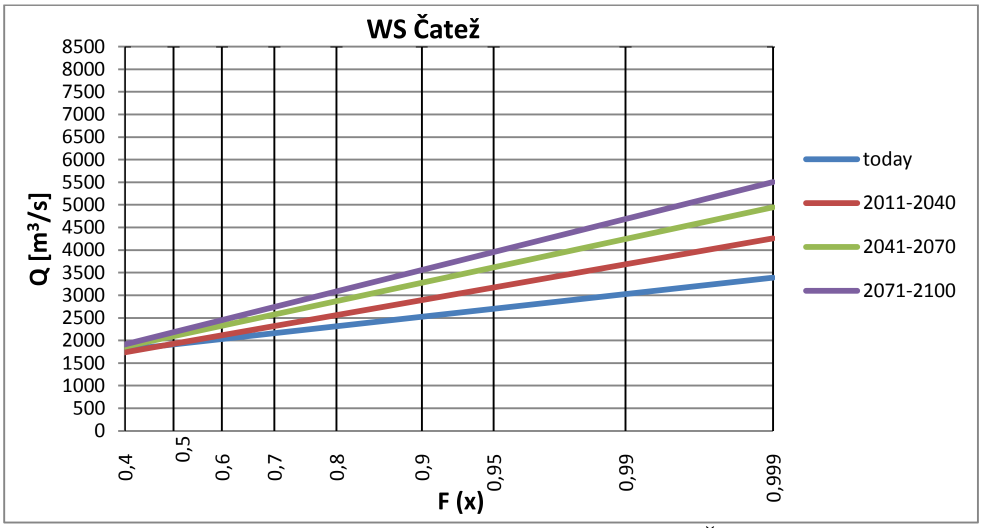


Figure 16: Probability of peak discharges on WS Čatež (m³/s).

[17] Prohaska, S. (2009) Hydrology Report for The Sava River Basin Analysis – Draft Final Report.

Table 17: Probability of peak discharges on WS Crnac (m^3/s).

		E-OBS_20		E-OBS_100	
probabilty %	**90**	**96,9**	**99**	**99,56**	**99,9**
Period/exceeded prob. %	**10**	**3,1**	**1**	**0,44**	**0,1**
today	2240	2350	2456	2510	2613
2011_2040	2317	2428	2570	2670	2770
2041_2070	2409	2520	2690	2817	2920
2071_2100	2460	2571	2780	2929	3030

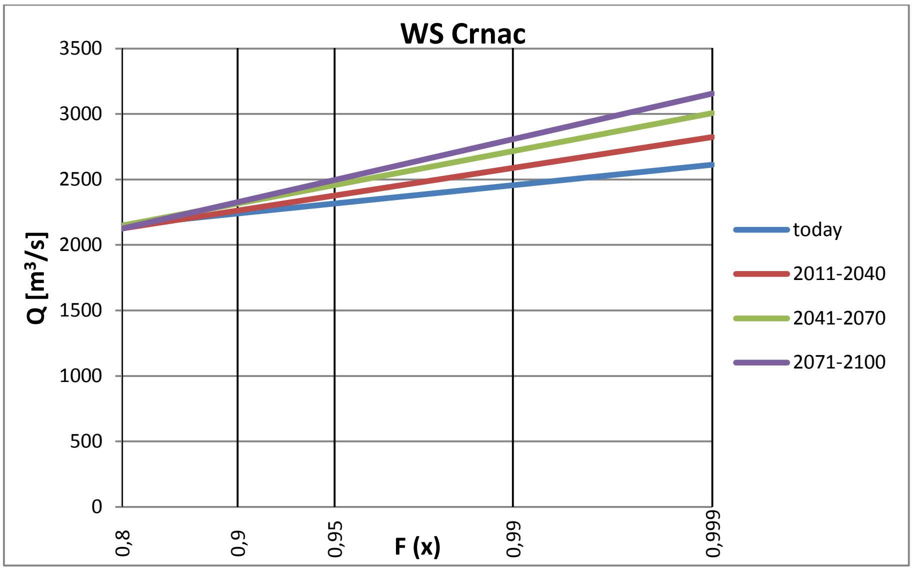


Figure 17: Probability of peak discharges on WS Crnac (m^3/s).

The 100-year return period discharges on the WS Crnac (Table 17) will in comparison with current discharges increase for 5 % in the first period 2011–2040 and for 13% the year 2100. The 100-year return period discharge will be by then higher for 324m^3/s (Figure 17). The huge inundation area of the Central Posavina is causing the decrease not only of flood discharges from the upstream part but also a significant decrease in the percentage of discharge increase due to climate change.

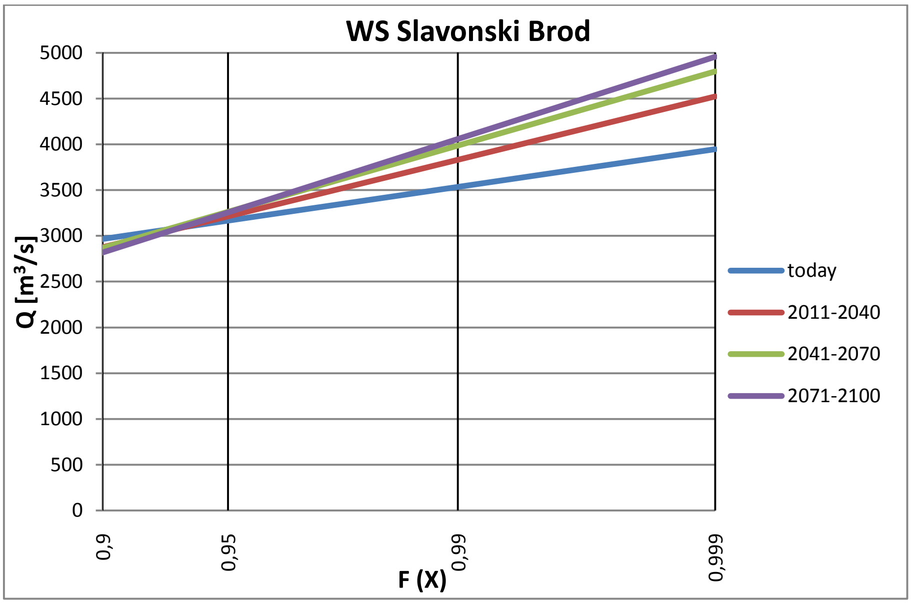


Figure 18: Probability of peak discharges on WS Slavonski Brod (m^3/s).

Table 18: Probability of peak discharges on WS Slavonski Brod (m^3/s).

		E-OBS_20		E-OBS_100	
probabilty %	**90**	**98,38**	**99**	**99,16**	**99,9**
Period/exceeded prob. %	**10**	**1,62**	**1**	**0,84**	**0,1**
today	2966	3411	3535	3573	4041
2011_2040	2876	3623	3831	3895	4522
2041_2070	2868	3742	3987	4062	4796
2071_2100	2819	3788	4058	4142	4956

The current 100-year return period discharges on WS the Slavonski Brod (Table 18) will first increase for 8% in the 2011–2040 period and then for 15% in the 2071–2100 period. The increase is similar to the one on the upstream WS Crnac. The discharge with 100-year return period will be by the year 2100 higher for $523 m^3/s$ (Figure 18).

Table 19: Probability of peak discharges on WS Županja (m^3/s)

		E-OBS_20		E-OBS_100	
probabilty %	**90%**	**96,15%**	**99%**	**99,06%**	**99,9%**
Period/exceeded prob. %	**10**	**3,85**	**1**	**0,94**	**0,1**
today	3585	4068	4215	4227	4759
2011_2040	3275	4346	4671	4699	5682
2041_2070	3331	4554	4925	4957	6079
2071_2100	3479	4826	5235	5270	6507

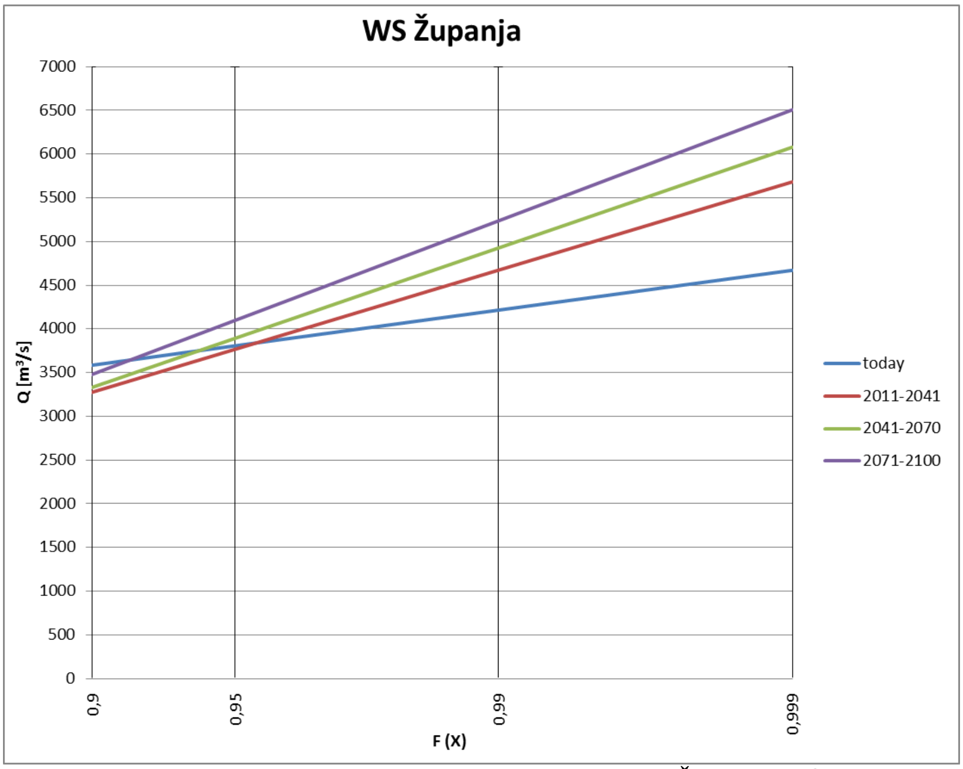


Figure 19: Probability of peak discharges on WS Županja (m^3/s)

The current 100-year return period discharges on the WS Županja (Table 19) will increase from 11% in the first period (2011–2040) to 24% in the last period (2071–2100). The increase is higher than on the upstream WS Slavonski Brod. Also the 100-year return period discharge will be higher for 1020 m^3/s by 2100 (Figure 19).

Table 20: Probability of peak discharges on WS Sremska Mitrovica (m³/s).

			E-OBS_20	E-OBS_100	
probabilty %	**90**	**99**	**99,63**	**99,84**	**99,9**
Period/exceeded prob. %	**10**	**1**	**0,37**	**0,16**	**0,1**
today	5140	6000	6328	6603	6760
2011_2040	4573	6083	6659	7143	7176
2041_2070	3764	6007	6862	7580	7630
2071_2100	4459	6193	6854	7409	7448

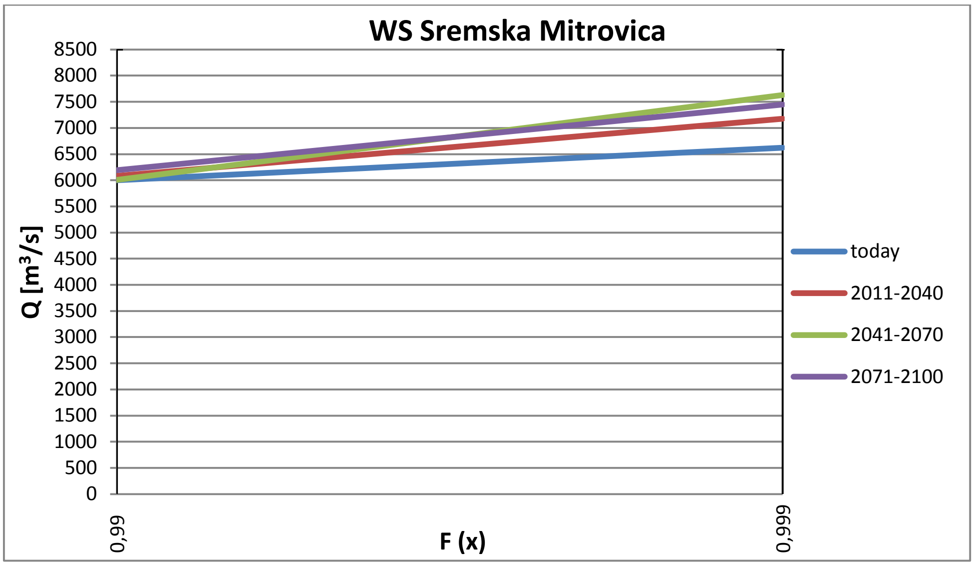


Figure 20: Probability of peak discharges on WS Sremska Mitrovica (m³/s).

The 100-year return period discharges on the WS Sremska Mitrovica (Table 20) will increase from 1% in the first period (2011–2040) to 3% in the last period (2071–2100). The increase is rather lower than the one on the upstream WS Županja. The 100-year return period discharge will increase for 193m³/s and the water level will increase for 10 cm by the year 2100. The increase of 1000-year return period discharges are quit higher, up to 10%.

The discharges estimated as a result of the climate change impact are high, but still much lower than the Probability Maximum Flood of 7081 m³/s, calculated at the upper Sava for the Nuclear Power Plant Krško (Brilly et al., 2009)[18] and the discharge registered in the year 1896 on the lower part of the Sava River.

The process of reforestation has decreased the mean discharges on the experimental river basin in Slovenia by 35% (Šraj and Brilly, 2012)[19]. Also, the process will decrease flood discharges and mitigate the impact of climate change on floods in the Sava River Basin. The process of reforestation should be researched in more detail for the Sava River Basin at the whole.

[18] Brilly M.,et al., (2009): »Preparation of new revision of PMF study and conceptual design package for flood protection of NPP Krško«, report, NPP Krško

[19] Šraj M., Brilly M., (2012): Vpliv gozda na vodno bilanco. I. Kongres o vodah Slovenije 2012, Ljubljana, Slovenija, 22. marec 2012.

6 ANALYSIS OF FLOOD WATER LEVEL

The data on flood discharge of a 100-year return period are transformed by the discharge curve on the corresponding water level. The flood water level rise for different forecast periods and it is calculated and presented in Tables 22–26 and on Figures 21–25 for particular water stations (WS). The altitudes “0” of stage gage of water stations are in Table 21, SHMZ H (1978).

Table 21: Altitude “0” of stage gages

Water station	“0”
Čatež	137,28
Crnac	89,99
Slavonski Brod	81,80
Županja	76,33
Sremska Mitrovica	72,22

Table 22: Water level increase for flood with a 100-year return period at the WS Čatež

PERIOD	Q **[m³/s]**	h **[cm]**	Δh **[cm]**
today	3026	744	
2011_2040	3685	832	88
2041_2070	4245	908	164
2071_2100	4687	970	226

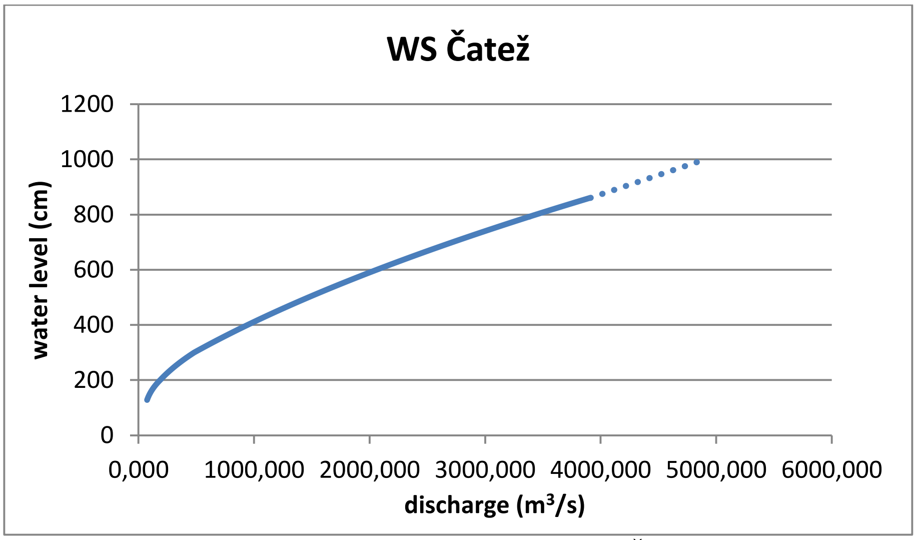


Figure 21: Rating curve at the WS Čatež

Today at the event with 100-year return period the water level on WS Čatež is 7,44 m (Figure 21). But in 90 years the event which will by then also have the 100-year return period will cause the 2,26 m higher water level which means that it will reach the height of 9,70 m (Table 22).

Value of increased water levels should be considered with certain reservations, table 22. Rating curve for WS Čatež were determined based on linear interpolation without taking into account the morphological and hydraulic characteristics in the section of gauging station. Probability of discharges for today's period is taken into account based on data from the period 1926-1965, (Prohaska 2009). Today's value flows with 100 years return period for gauging station Catež are significantly higher. Due to the uniform treatment of data throughout the Sava River Basin are for all stations considered data for the same period.

Table 23: Water level increase for flood with a 100-year return period at the WS Crnac.

PERIOD	Q [m³/s]	h [cm]	Δh [cm]
today	2456	802	
11_40	2570	829	27
41_70	2690	860	58
71_100	2780	884	82

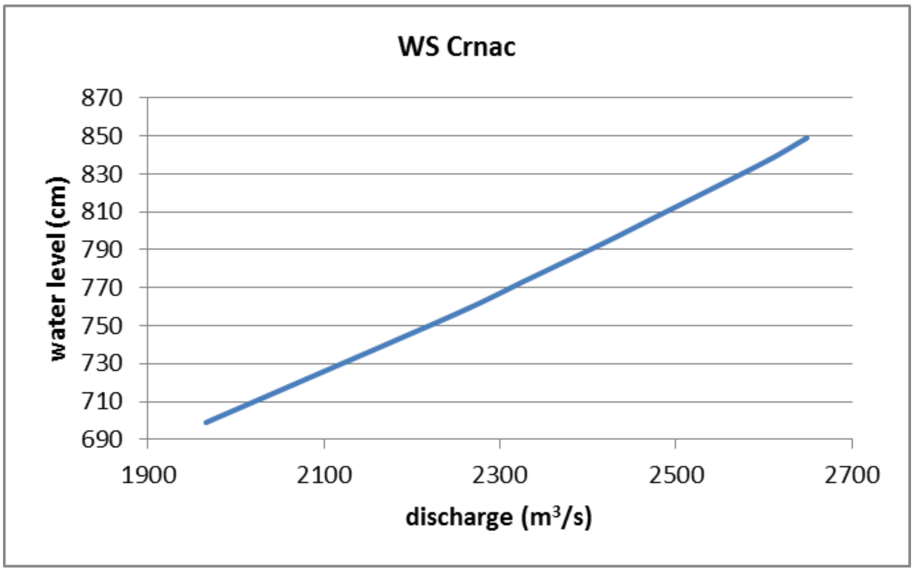


Figure 22: Rating curve at the WS Crnac

On WS Crnac the rise of 100-year return period water level (Figure 22) by year 2100 will also appear but for less than half of the rise on WS Čatež. It will rise from todays 8,02 m to 8,84 m (Table 23).

Table 24: Water level increase for flood with a 100-year return period flood at the WS Slavonski Brod.

PERIOD	Q [m³/s]	h [cm]	Δh [cm]
today	3535	943	
2011_2040	3825	1008	65
2041_2070	3975	1040	97
2071_2100	4050	1056	113

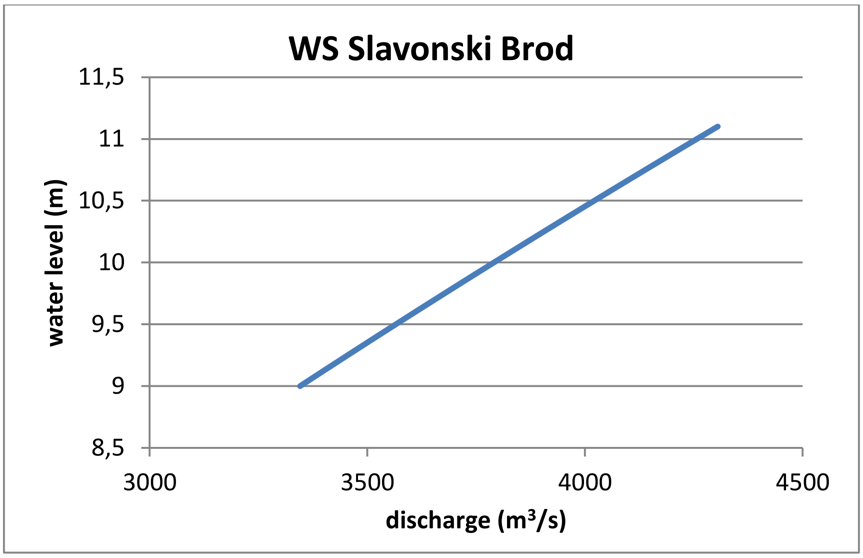


Figure 23: Rating curve at the WS Slavonski Brod

The expected increase of water level on WS Slavonski Brod (Figure 23) is again higher than on WS Crnac, its predicted value is 1,13 m. It means that the water level will rise from 9,43 m as it is today to 10,56 m (Table 24).

Table 25: Water level increase for flood with a 100-year return period at the WS Županja.

PERIOD	Q [m³/s]	h [cm]	Δh [cm]
today	4215	1045	
2011_2040	4687	1129	84
2041_2070	4945	1173	128
2071_2100	5268	1226	181

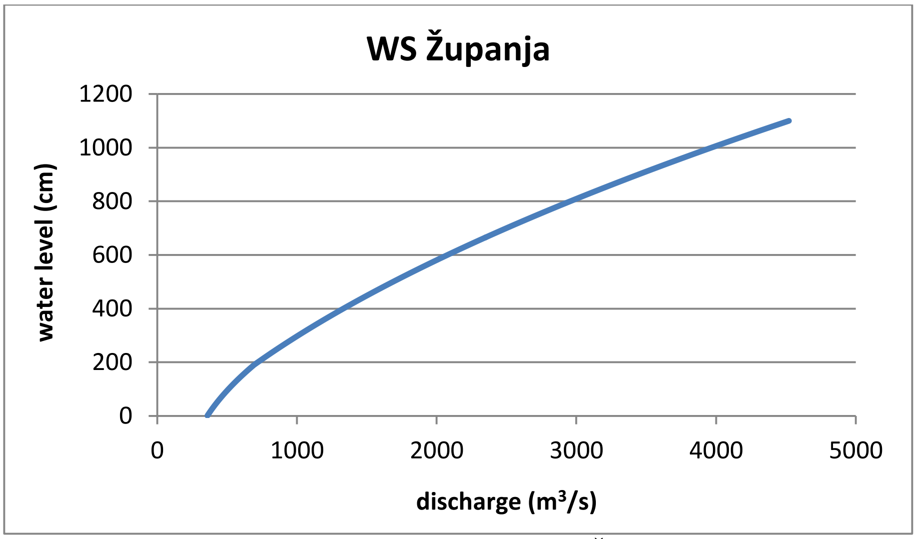


Figure 24: Rating curve of WS Županja

For WS Županja quite higher water level is calculated again2100 (Figure 24), it will increase for 1,81 m, from todays 10,45 m up to 12,26 m (Table 25).

Table 26: Water level increase for flood with a 100-year return at the WS Sremska Mitrovica

PERIOD	Q **[m³/s]**	h **[cm]**	Δh **[cm]**
today	6000	8019	
11_40	6083	8024	5
41_70	6007	8020	1
71_100	6193	8029	10

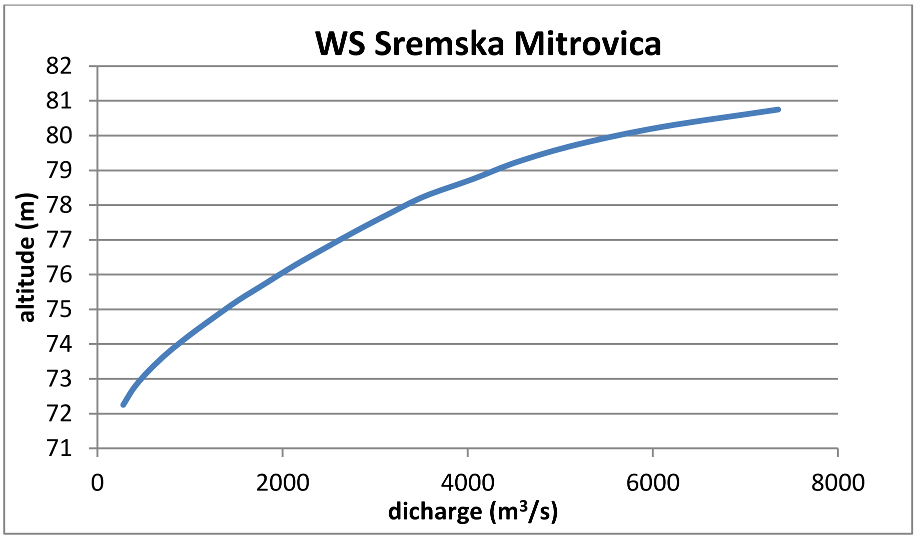


Figure 25: Rating curve of WS Sremska Mitrovica

The rise of water level on WS Sremska Mitrovica is the lowest of all observed (Figure 25) and is equal to 10 cm. So the level of water will rise from 80,19 m to 80,29 m (Table 26).

On all water stations, the gradual increase of water levels of the 100-year return period floods over time is expected. The only exception is WS 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 (Table 22), is expected in the upper part of the basin at WS Čatež.
Downstream the Sava River, the water level rise is strongly reduced to 0.82 m at WS Crnac (Table 23). Downstream of WS Crnac, the water level gradually increases up to 1.81 m at WS Županja (Table 25). Then, downstream of WS Županja, the increase of water level strongly drops to 0.10 m at WS Sremska Mitrovica (Table 26).
The modelling was derived from a model calibrated for the 1974 flood event, i.e. before any major construction on the »Central Posavina« system was developed. The impact of the flood protection system »Central Posavina« and the impact of hydropower plant Mratinje on the Drina River could not be implemented in the model. Notably, the hydrological model presented semi-natural conditions, without taking into consideration the structures developed after 1974.

7 CONCLUSIONS

The reports on climate change impacts in the Sava River Basin deal mainly with the average values of hydrological variables. All reports suggest that in the future flood events will increase. So far there was no quantification of this expectation (Jupp, 2011, Meerbach, et al. 2010, MOP, 2006, MZOIP, 2006, MPPO, 2010 and MOPP, 2010).

The E-OBS data set is useful for hydrological climate change forecasts of flood peak discharges in the Sava River Basin. The assembly of data is not accurate enough on some parts of the basin 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 water station Sremska Mitrovica up to 55 % at water station Čatež.

There were 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 the water station Sremska Mitrovica.

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