D.T2.4.1. REPORT FROM PILOT ACTION - Report from testing the dynamic model to assess cumulative effect of N(S)WRM

Slovenia / FGG UL	Version 7
Pilot catchment Kamniška Bistrica	November 2019

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Content

List of Figures

List of Tables

1. Application of the hydrological model

1.1. Description of the catchment

Kamniška Bistrica River catchment is located in the northern part of Slovenia and represents almost 3% of its overall area. It was chosen as a pilot catchment because of its diverse character, ranging from wooded subalpine hills to lowland plains, which are highly urbanized. The main problem within the catchment are relatively frequent floods. As for water quality, Kamniška Bistrica River has moderate to very good ecological status. Although a large part of the settlements is connected to a sewage system and central WWTP, water in lower parts of the catchment is occasionally polluted, especially in summer months when the main channel is almost dry and the water temperature rises. Other sources of water pollution are sewage overflows during flood events.

In its middle and lower part, Kamniška Bistrica river is highly regulated due to its hydropower potential and as protection against floods. This part of the catchment is covered with a dense network of artificial channels that used to supply water for the operation of water and sawmills. Today, they are mainly used for supplying small hydropower plants.

Characteristic	Unit	Value
Character of the catchment		Upper part: highland; wooded, sparsely populated Middle and lower part: low-land; highly urbanized
Catchment size:	km^2	539
Max/Min surface elevation	m a.s.l.	2558/261
Average flow low/avg/high*	m^3/s	2.2/7.9/67.2
Extreme flow low/high*	m^3/s	0.9/282
Annual precipitation low/avg/high*	mm	998/1383/1851
Annual air temperature min/avg/max*	°C	9/11/13
Agriculture area	%	34.5
Urban area	%	8.2
Forest area	%	54.1
Open spaces with little or no vegetation	%	2.8
Open Water area	%	0.4
Flooded area (1/100 years)	km^2	39.2
Artificial drainage area	km^2	12.7
Ecological status	Water body	Moderate (4/5) to very good (1/5)
Major problems to achieve good ecological status		Hydromorphological alteration

Table 1: Characteristics of the catchment.
*Note: *Hydrological yearbook of Slovenia 2018*

There are five main water bodies within the catchment: Kamniška Bistrica, Pšata, Radomlja, Rača and Nevljica of lengths 38, 36, 23, 13 and 19 km, respectively.

Flooding is often, especially in late autumn. Based on previous flooding events we can define five areas of significant impact of floods: Stahovica-Kamnik, Komenda-Moste-Suhadole, Domžale, Nožice and Ihan- farms.

Upper course of Kamniška Bistrica has near-natural morphological alteration which changes downstream from slightly modified to severely modified on few points before Nevljica inflow. Nevljica has near-natural to slightly modified morphological alteration, similar Rača with moderately modified morphological alteration before confluence with Radomlja River. On the other hand, Radomlja and Pšata have mostly moderately to severely modified morphological alteration. Middle and lower course of Kamniška Bistrica has slightly to severely modified morphological alteration.

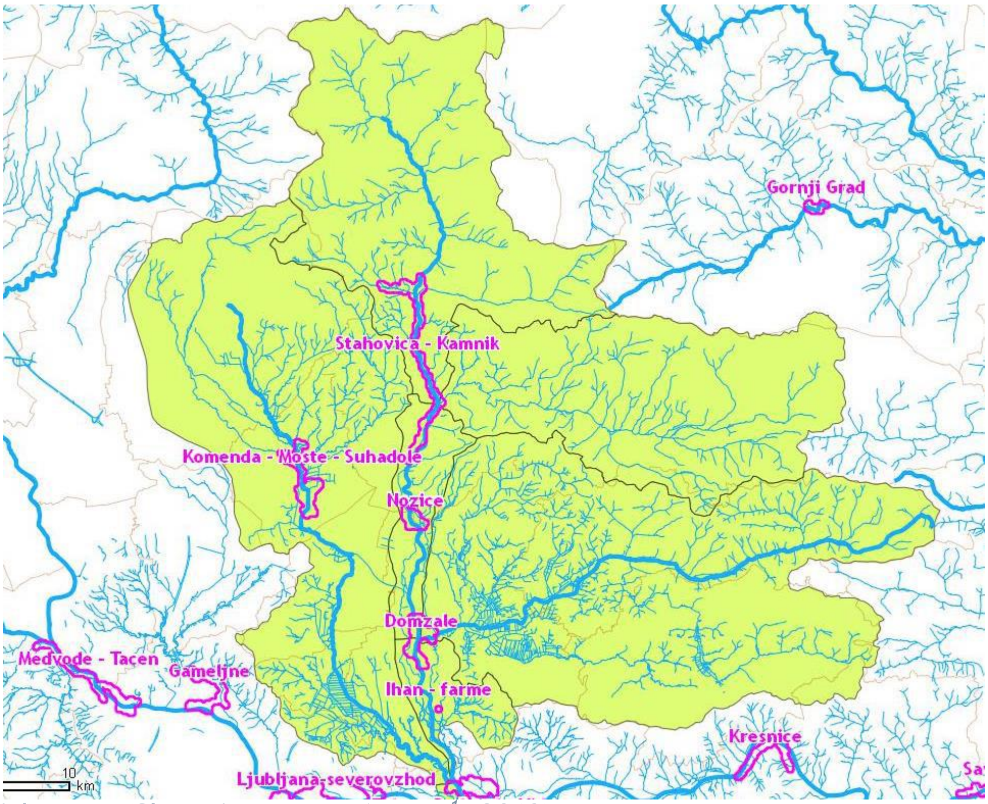


Figure 1: Risk areas (Slovenian Water Agency[1], 2018).

All rivers in Kamniška Bistirca basin have moderate ecological status, except upper course of Kamniška Bistrica has a very good ecological status3. Chemical status of Kamniška Bistrica and Nevljica is very good while Pšata, Radolmlja and Rača have a good chemical status. The main problem to achieve a good ecological status lies in hydro morphological alteration.

1.2. Watershed delineation

Area of the Kamniška Bistrica catchment has been delineated using GIS software Global Mapper. Main input for that task was a digital elevation model (DEM, courtesy of Ministry of the environment and spatial planning, 2014) with a resolution of 1m, which is freely available for the entire Slovenia.

[1]http://www.mko.gov.si/fileadmin/mko.gov.si/pageuploads/podrocja/voda/opvp/09_Kamniska_Bistrica_OPVP.jpg

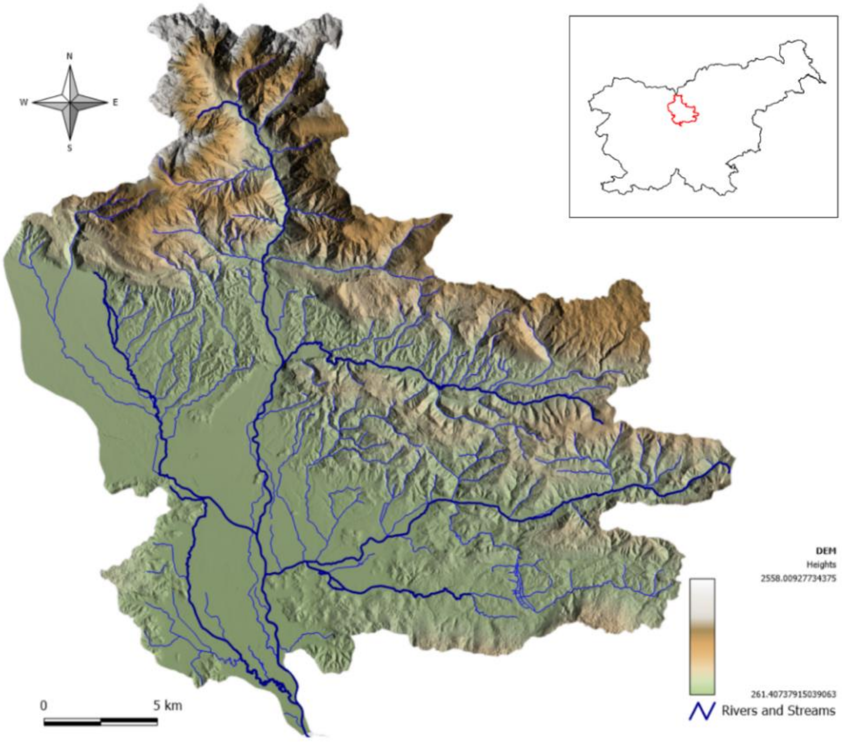


Figure 2: Kamniška Bistrica catchment including all rivers and streams with known names

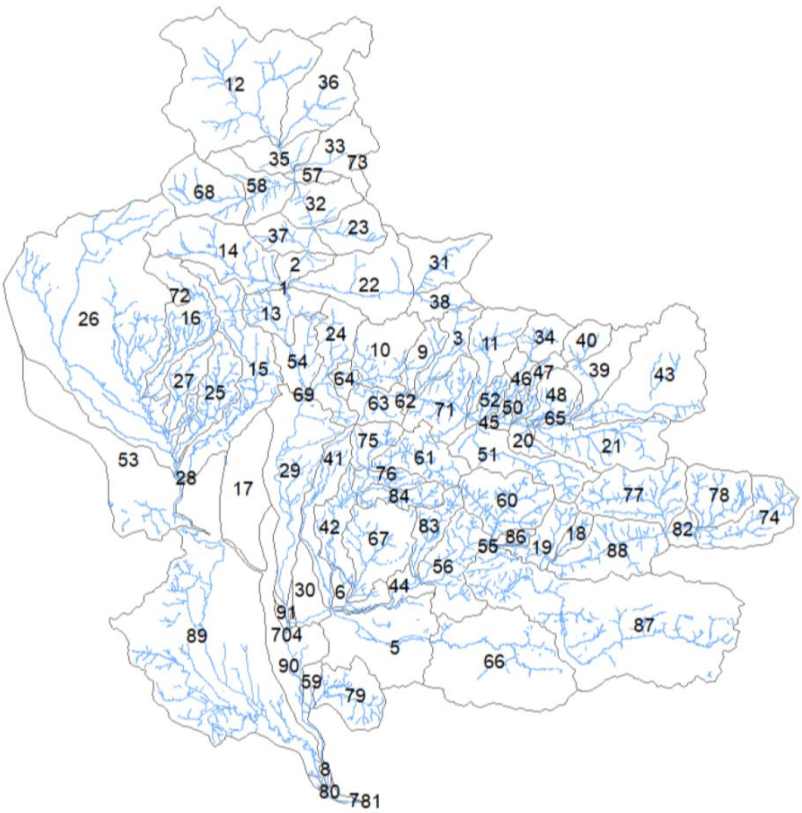


Figure 3: SPUs of Kamniška Bistrica river basin (Slovenian Water Agency[2], 2018)

[2] https://gisportal.gov.si/portal/apps/webappviewer/index.html?id=11785b60acdf4f599157f33aac8556a6

Along the delineation process, river network has also been defined. For the purpose of later analyses, it has been segregated to three different scales – main rivers, main and middle rivers and all rivers with known names.

We are using hydraulics approach on hydrological modelling (rain on grid as described in further chapters) where subcatchment watershed division is not needed. As detailed subcatchments based on DEM have not been defined, we are using SPU's from Slovenian Water Agency (2018) for the purpose of spatial planning and other regarding tasks.

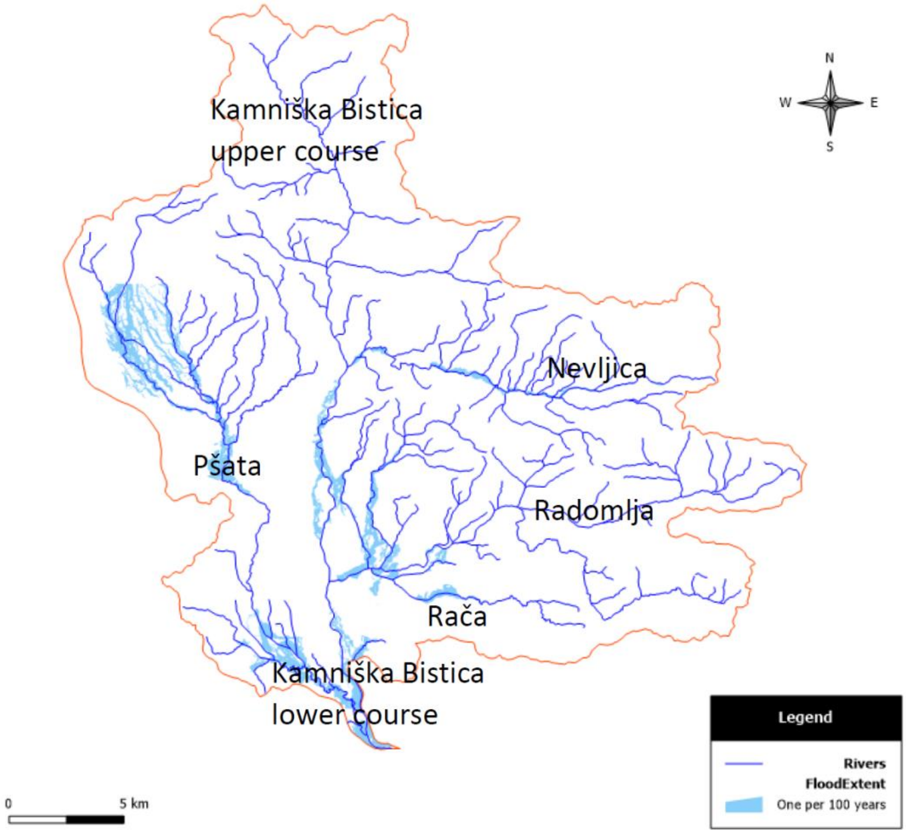


Figure 4: Main water bodies and flooding extent of one per 100 years flooding

1.3. Land cover, soils and HRU delineation

All needed data has been obtained from existing, publicly available global datasets:

- Land use map was created from European CORINE land cover 2012[3] (25h/100m resolution)
- Hydrologic soil group map was created upon cross-referencing data from European Soil Data Centre[4] and Slovenian pedological map M 1:25 000 (courtesy of Biotechnical Faculty of Ljubljana, 2010)

One of inputs for our hydrological-hydraulics model is Curve number (CN) map for the whole catchment. It has been made using topological overlapping of hydrologic soil group, land use and hydrological conditions at the time of precipitation event. As a result, we got three different CN maps on the catchment, depending on the type of hydrological conditions (good, average, bad), which can be seen on next Figures.

[3] https://land.copernicus.eu/pan-european/corine-land-cover

[4] https://esdac.jrc.ec.europa.eu/

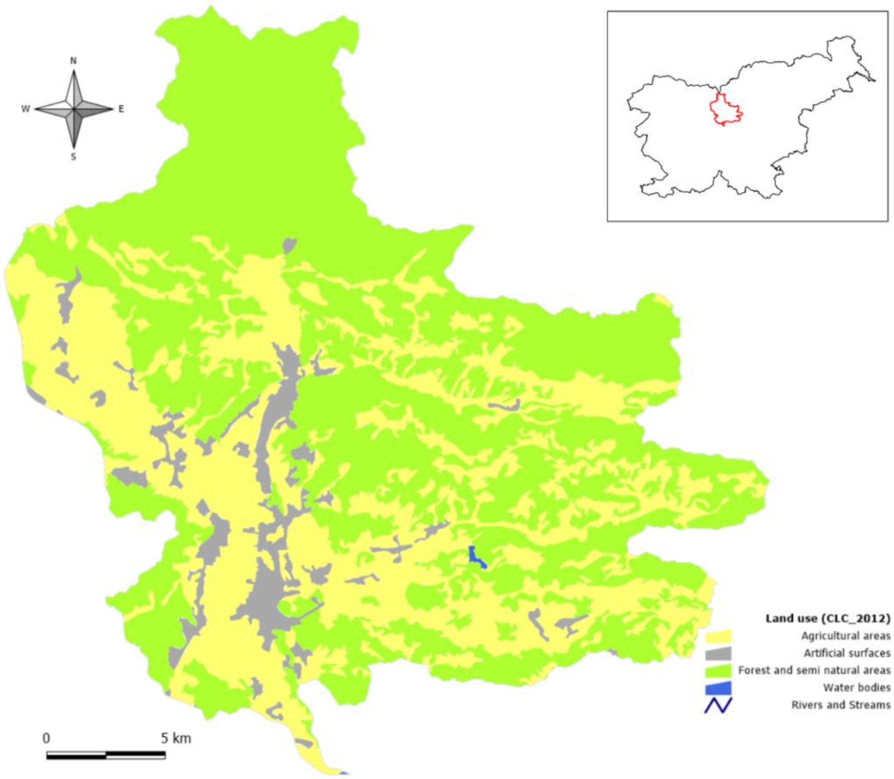


Figure 5: Land use (CORINE land cover 2012)

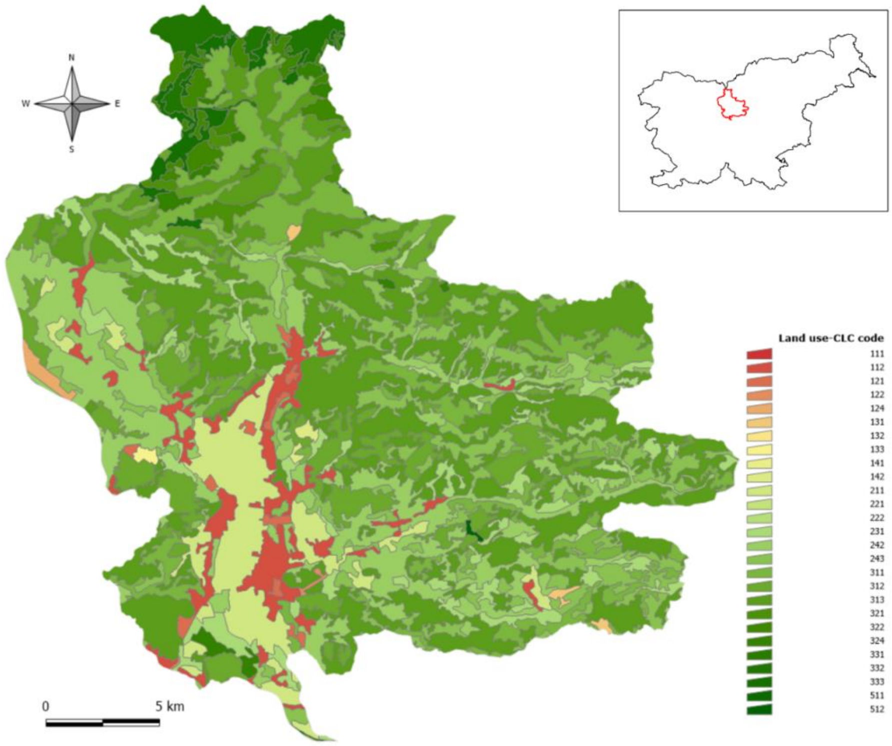


Figure 6: Land use - CLC code (CORINE land cover 2012)

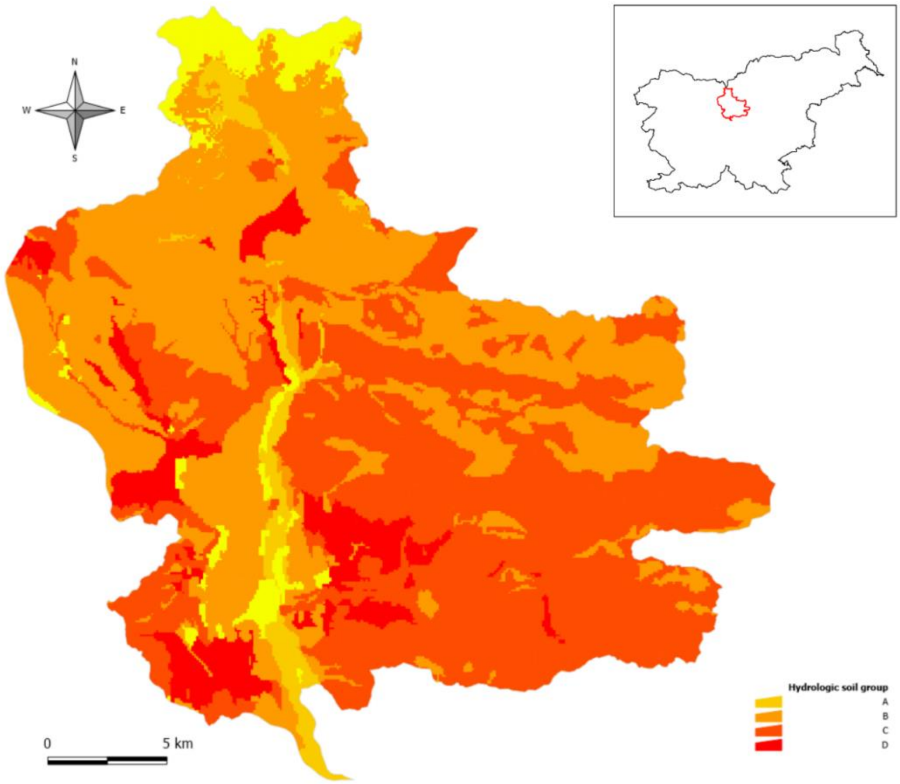


Figure 7: Hydrologic soil group (Biotechnical Faculty of Ljubljana, 2010)

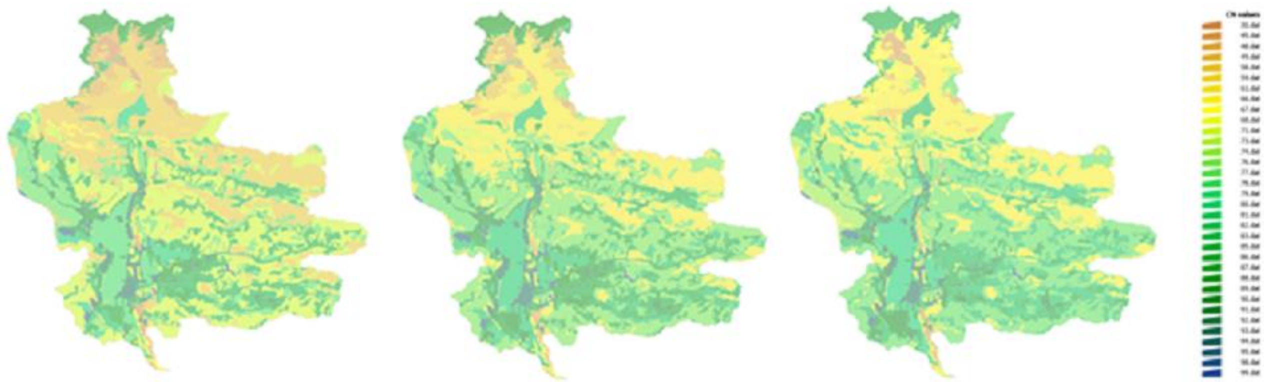


Figure 8: Curve number classification (from left to right: good, average and bad conditions)

1.4. Weather data and model parametrization

Slovenian environmental agency is performing continuous monitoring of spatial precipitation. We have defined all available weather-precipitation stations with measurable impact on our catchment (impact based on Thiessen polygons) and obtained detailed precipitation measurements for all of them. To be able to model precipitation events effectively, we obtained half-hourly precipitation measurements.

Time period of measurements can greatly differ amongst them though, so special care was undertaken with their analysis and preparation. Another problem are inconsistencies of measured data and inconsistencies in weather stations naming, sometimes noticeable time periods without any measured data, etc.

In the last years, four major precipitation/flooding events have occurred on the Kamniška Bistrica catchment. The worst event, based on maximum measured discharge at Vir river gauge, happened in year 2010, others followed in years 2007, 2012 and 2014.

The most reliable data were available for the 2012 and 2010 event therefore they have been chosen for calibration and validation purposes, respectively. Other events were used solely for rough validation purpose. For each event, measured precipitation data has been prepared in forms of ASCII files which were suitable for later model inputs.

Riverflow2D allows us to choose among different hydrological methods. We have chosen the SCS Curve Number method (USDA SCS, 1972) which was developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS). It is a method of estimating rainfall excess from rainfall, hydrologic soil group, land use, treatment and hydrologic condition.for single storm event (Hjemfelt, 1991) which has been tested on many practical Slovenian cases and has in general proved to be a reliable and appropriate method.

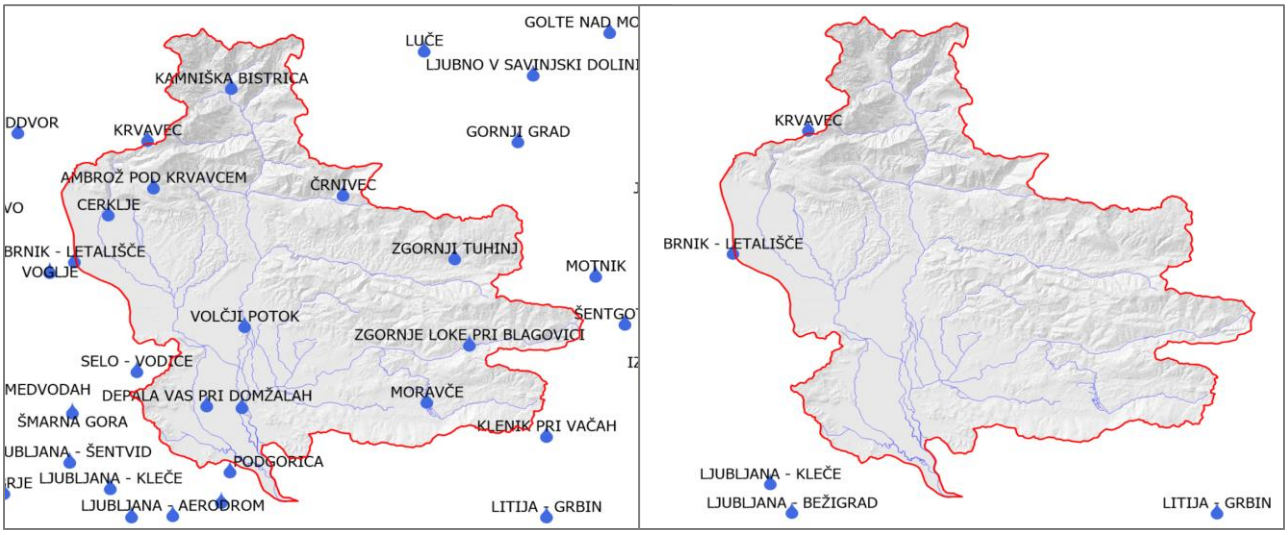


Figure 9: Precipitation stations: all precipitation stations (left), stations with sufficient data to be used for the 2010 and 2014 event (right)
Note: Hrastnik station is not visible due to zoom levels. Litija-Grbin station is not used in 2007 event, other stations used are the same as for 2012 and 2010 event.

Hydrological model runs simultaneously with hydraulic model using a "rain on grid" method, where mesh size is the same. The Riverflo2D's hydrological model inputs are:
- mesh (based on topography - Lidar) with applied Manning roughness values
- applied CN values
- applied total precipitation (based on Thiessen polygons)

More detailed description of elements related to hydraulics is in chapter *2.3 Description of the model structure*.

To determine influence of each individual precipitation station on the amount of total precipitation inside of the model area, the Thiessen polygons method (Shaw, 1994) has been used. With this method the modelled area is divided to polygons representing individual precipitation stations. Polygons are separated with strait lines with equal distance between two neighbouring weather stations, where polygon areas represent so called "weight factors". These factors are then multiplied with precipitations on belonging precipitation stations, and sum of all multiplications represent the total amount of rainfall on modelled area.

Based on created Thiessen polygons the biggest impact (based on covered area) on total precipitation for all calibration and validation events has Krvavec precipitation station, as seen on next Figure.

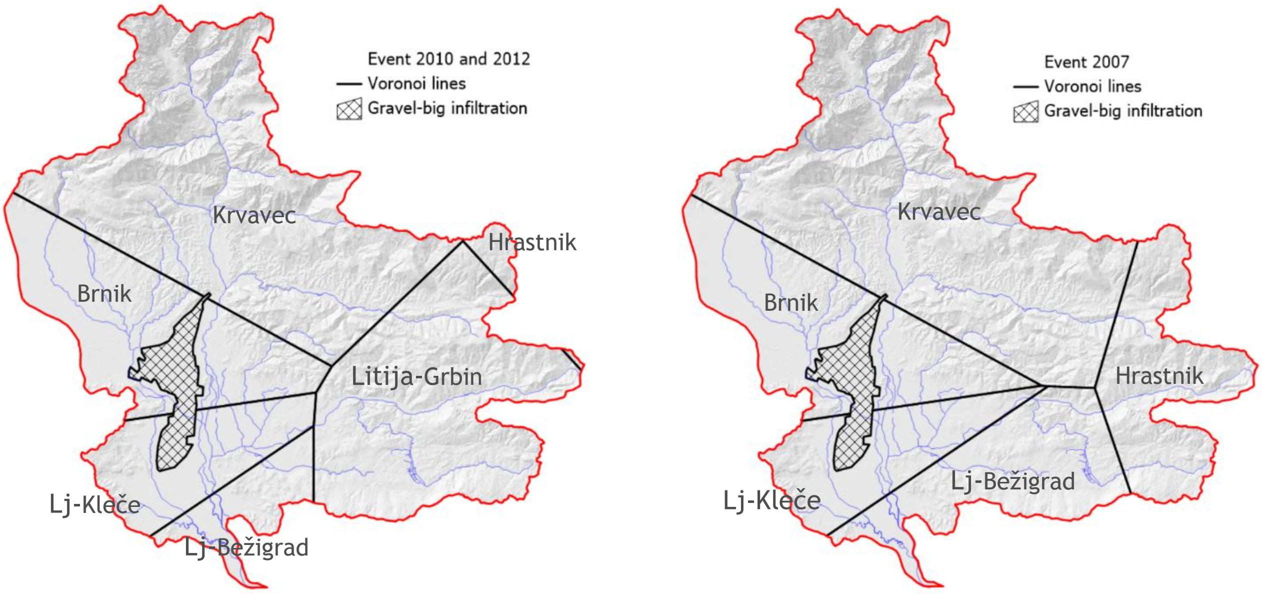


Figure 10: Precipitation stations for events 2010, 2012 (left) and 2007 (right) assigned to HH calibration and validation model, based on Thiessen polygons (Shaw, 1994). Precipitation haven't been assigned to hatched area due to natural severe infiltration

Graphical representations of measured precipitation data (half-hourly histograms from precipitation stations) used for calibration and validation purposes are shown on next Figures.

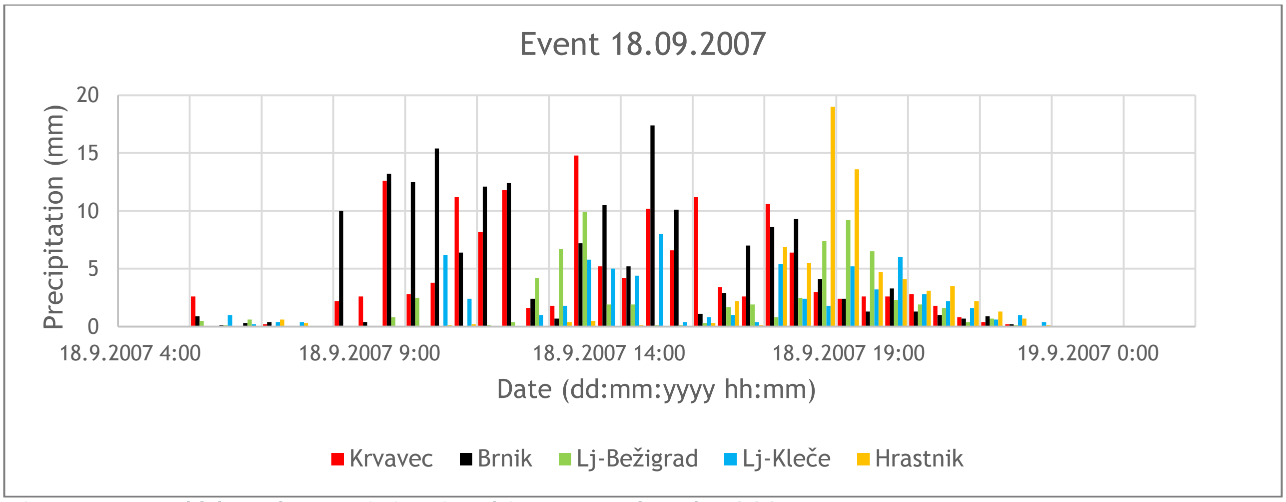


Figure 11: Half-hourly precipitation histogram for the 2007 event

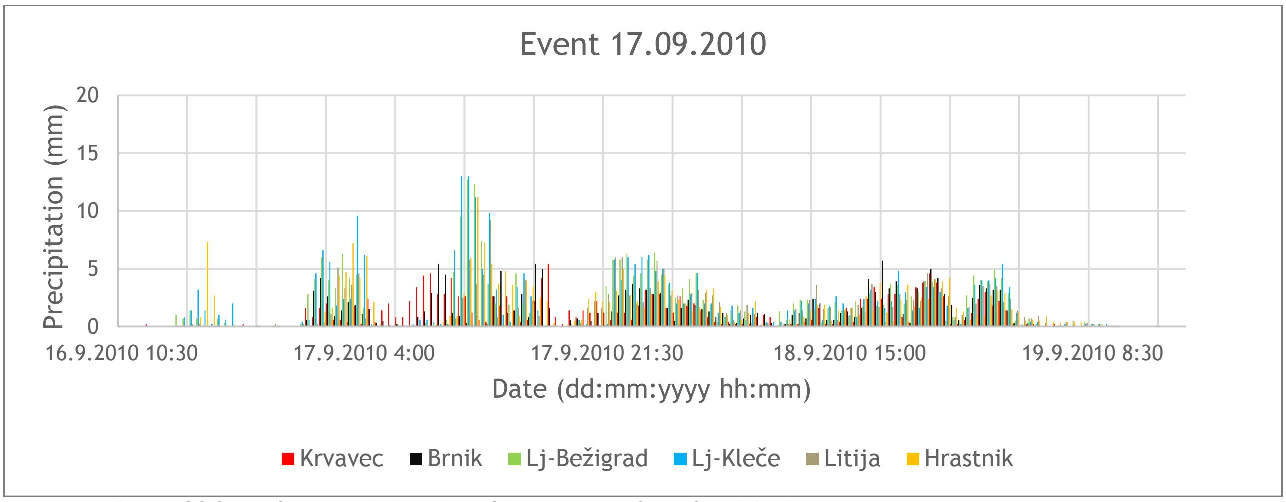


Figure 12: Half-hourly precipitation histogram for the 2010 event

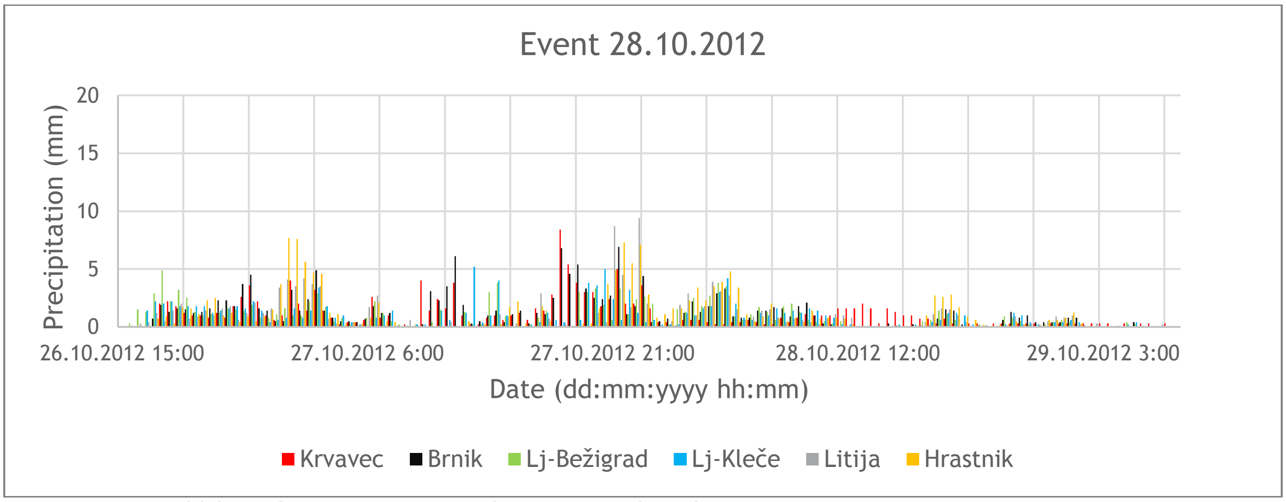


Figure 13: Half-hourly precipitation histogram for the 28.10.2012 event

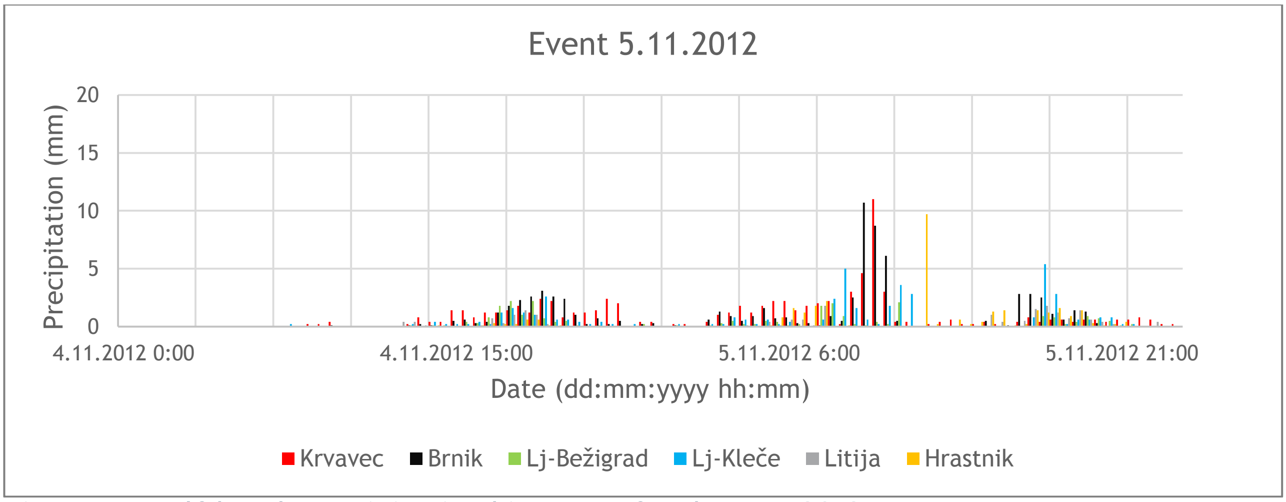


Figure 14: Half-hourly precipitation histogram for the 5.11.2012 event

1.5. Model calibration and validation

Hydrological model calibration was done together with hydraulic model calibration as both models are connected and run simultaneously. Detailed description is in chapter 2.6 Model calibration and validation.

2. Application of the hydraulic model

RiverFlow2D is a combined hydrologic and hydraulic, mobile bed and pollutant transport finite-volume model for rivers, estuaries and floodplains. It can route floods in rivers and simulate inundation over floodplains and complex terrain at high resolution. The use of adaptive (unstructured) triangular-cell meshes enables the flow field to be resolved around key features in any riverine environments.

Its user interface is based upon Surface-Water Modeling Solution (SMS) developed by Aquaveo. This GIS-integrated software system provides interactive functions to generate and refine the flexible mesh used by RiverFlow2D.

Computation engine uses an accurate, and stable finite-volume solution method, and can integrate hydraulic structures such as culverts, weirs, bridges, gates and internal rating tables. The hydrologic capabilities include spatially distributed rainfall, evaporation and infiltration. Time step is automatically defined by calculation engine itself and can vary during a simulation (Hydronia ltd., 2019).

2.1. Description of the river network

There are five main water bodies within the catchment: Kamniška Bistrica, Pšata, Radomlja, Rača and Nevljica of lengths 38, 36, 23, 13 and 19 km, respectively. A large part (South-West, North and South-East) of the catchment is hilly with noticeable terrain slopes where detailed river bed adjustment wasn't performed due to lack of field measurements.

Rivers, which river beds heights have been altered and where computational mesh has been refined, were chosen based on test runs on unaltered mesh (raw DEM), where flooding was (roughly) estimated. As a result, lower parts of all main water bodies, which turned out to potentially have the biggest impact on flooding, have been modeled in detail in total length of 86 km, and are shown on the next Figure.

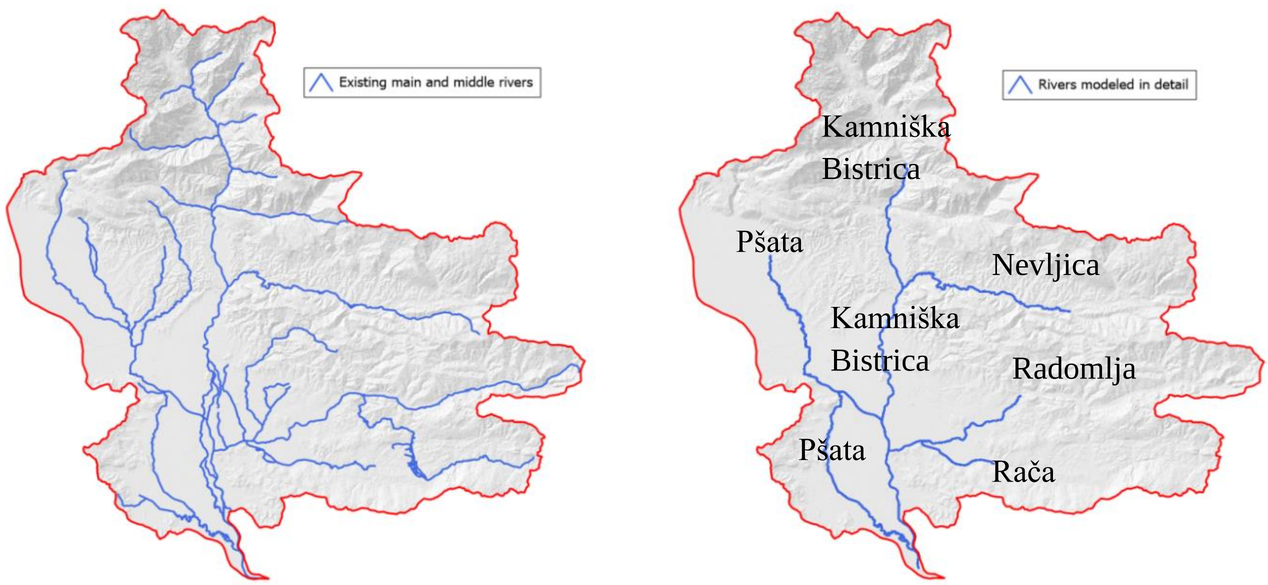


Figure 15: Comparison of river network: existing main and middle rivers (left), river reaches which topology was altered and modelled in detail within the HH model (right)

2.2. Geometric data (DEM, cross-sections)

Our combined HH model has been built over a digital elevation model (DEM, courtesy of Ministry of the environment and spatial planning, 2014) with a resolution of 1m, which is freely available for the entire Slovenia.

As DEM had been made based on LIDAR (Flycom ltd., 2013-2014) it does not represent stream ground elevations below the water surface correctly hence for river reaches, which have been modeled in detail, we had to alter in-stream DEM. DEM alteration for such long river reaches is a tedious and time demanding process. Existing surveying in-stream measurements (measured cross sections) served us for that task, and where those measurements weren't sufficient, we performed additional field surveying.

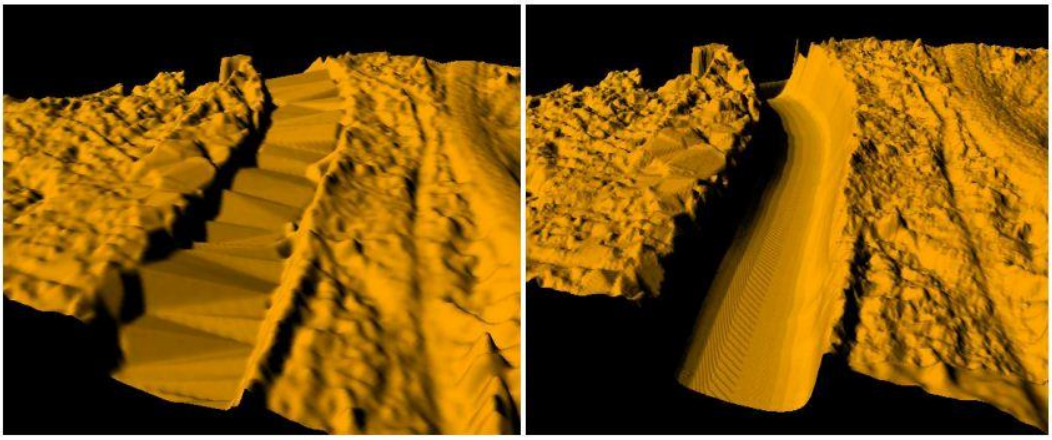


Figure 16: Comparison between raw DEM (left) and modified in-stream DEM (right)

In the process, we had to first detect in-stream water surface perimeter, then linearly interpolate ground elevations between measured cross sections and lastly merge the newly created surface with the existing one and clean/fill eventual artefacts at their intersections.

2.3. Description of the model structure

The aim was to build a light, fast and reliable combined hydraulic-hydrological model with acceptable accuracy.

At first, we used six (6) independent models to cover all catchment, but later on decided to model the whole catchment in only one model. Using multiple model setup can lead to difficulties with setting boundary conditions (BC's) due to the high number of proposed measures, their complexity and topography of the catchment itself. Transferals of high number of BC's between the models (upstream - downstream BC) and numerical limitations (number of cells, run times etc) can become difficult too.

Model size [km^2]	Max. mesh element size [m^2]	Min. mesh element size [m^2]	Avg. mesh element size [m^2]	DBC*	UBC** [mm]
539	300	1	198	Normal depth	Total precipitation

*Table 2: Main characteristics of HH model (*Downstream boundary condition, **Upstream boundary condition)*

The main advantage of one model over multiple models is more accurate flow transition. Our catchment's topography is very diverse, spreaded with roads and streams which direct surface flooding and make it difficult to define good downstream boundary conditions in case of several models. One model is also much easier to develop and to perform multiple calculations on.

Model uses unstructured triangular mesh which is refined in the most important computational areas such as in-bank channels etc. Each mesh element has assigned Manning values, CN number and total precipitation, all corresponding to underlying zones defined in GIS environment and imported as shape layers.

Longitudinal objects such as streets, levees, railroads, etc. were modeled as weirs, their elevations were taken directly from raw DEM, as comparisons between surveying and raw DEM elevations showed very good elevation matching. All the important inline structures such as weirs and bridges have also been implemented in the model. During the model calibration we have not only calibrated the standard parameters (Mannings values, CN, etc) but also optimized numerical cell size and other model parametrization.

The final model consists of 2.6 million cells, has targeted mesh refinement and uses one upstream and downstream boundary condition.

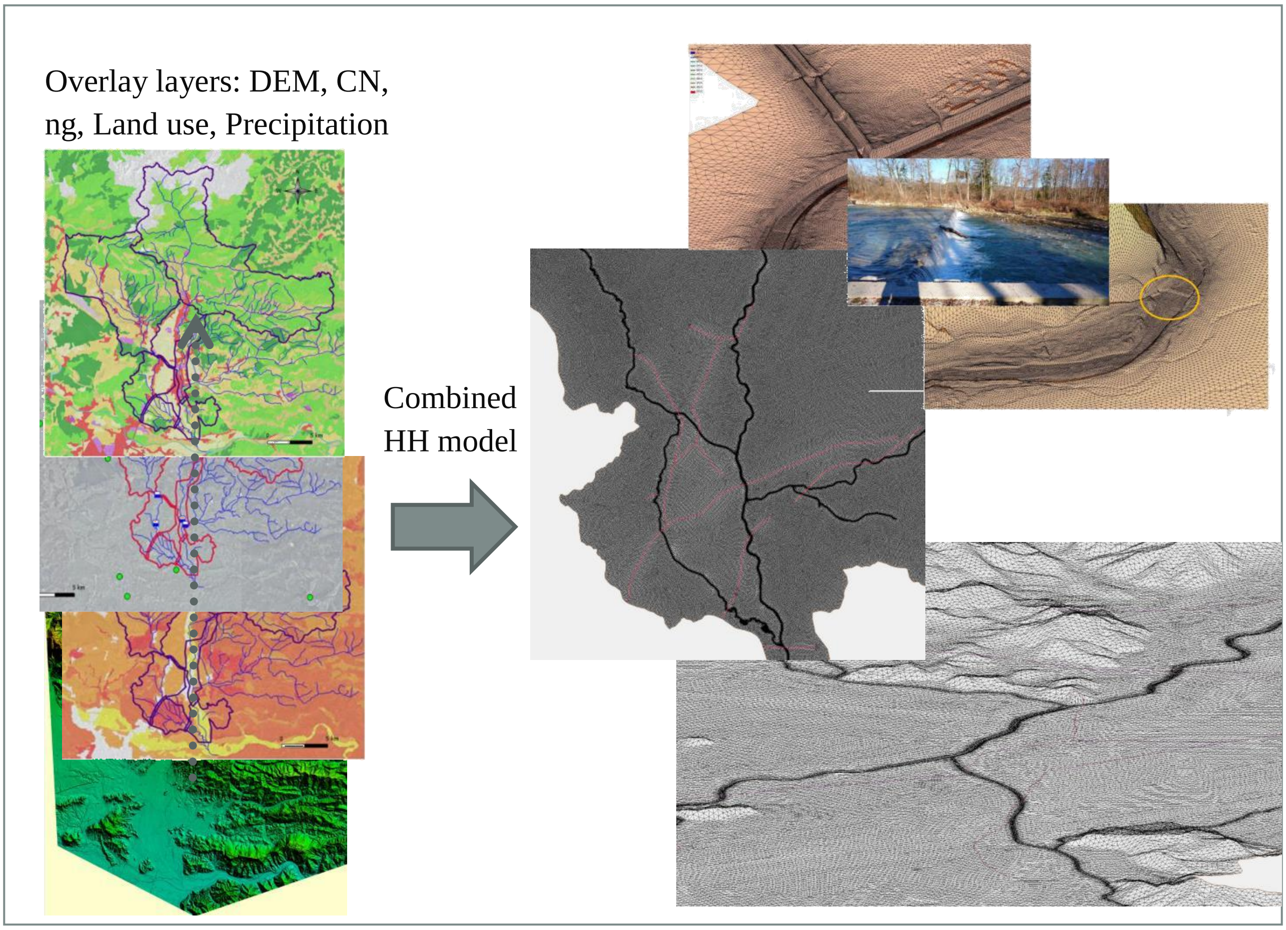


Figure 17: Model creation workflow

2.4. Boundary conditions

Downstream boundary condition (DBC) is normal depth, upstream boundary condition (UBC) is total precipitation applied directly to model mesh. DBC is located in such a location where it's impact on flooding condition upstream is non-existent.

2.5. Hydrologic and hydraulic data

Precipitation data (half hourly, hourly, 5 minutes interval - dependent on location) used for calculations was obtained from Slovenian Environment Agency's[5] web application and transformed in ASCII files suitable for further use.

2.6. Model calibration and validation

According to official data, there are currently ten (10) gauging stations (GS) located over the whole catchment. Gauging stations Pšata and Kamniška Bistrica are located at the most upper course hence unsuitable for calibration and validation purposes. Gauging station Bišče is relatively new and has not been active at the time of maximum flooding events.

During the calibration and validation process several conclusions have been made:

- lack of measurements at several gauging stations (GS) during extreme events
- stage of uncertainty at others
- not all events suitable for calibration/validation due to notable spatial precipitation variation at the time of events
- main calibration event is 2010

The model was calibrated and validated to measured discharges at gauging stations written in the next table.

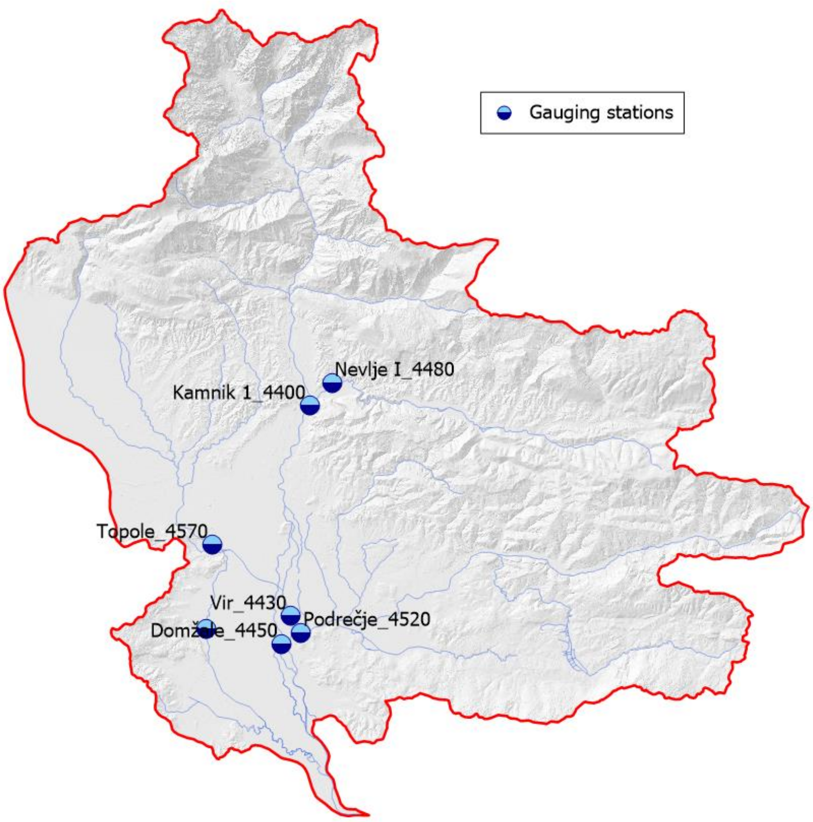


Figure 18: Gauging stations used for calibration/validation purposes

5 http://www.arso.gov.si/vreme/napovedi%20in%20podatki/padavine_odeja.html

GS	GS code	River	year of event and max. measured discharge (m^3/s)			
			2007	2010	2012	2014
Vir	4430	Kamniška Bistrica	204	232	195	/
Kamnik 1	4400	Kamniška Bistrica	157	135	177	132
Domžale	4450	Mlinščica kanal	/	/	/	/
Nevlje 1	4480	Nevljica	/	65	65	59
Topole	4570	Pšata	/	56	42	45
Loka	4575	Pšata	/	/	7	14
Podrečje	4520	Rača	/	90	55	76

Table 3: All gauging stations used for calibration and validation purposes, main precipitation/flooding events and maximal measured discharges at those events

Calibrated roughness coefficient ng is 0.035-0.045 $m/s^{-1/3}$ for river channels, 0.06 $m/s^{-1/3}$ for agricultural and other green surfaces on lowlands and hilly areas, 0.1 for forested areas on lowlands and hilly areas. For overbank areas, roughness was defined based on Corine Land Cover 2012. Roughness coefficients on hilly areas tend to be of same scale as the ones on lowlands due to a model specific numerical computational scheme.

The model is showing good matching between observed and modeled flow for the calibration 17.9.2010 event. At Nevlje I, modeled flow is 2 m^3/s smaller than observed flow and at Kamnik I modeled flow is 9 m^3/s smaller. Percentage wise, modeled flow is 4% and 6% smaller at Nevlje I and Kamnik I respectively, which is a good match regarding all uncertainties in underlaying data (precipitation,geometry etc) for a catchment of this size. Graphical representation of the computed and observed calibration data is shown on next Figures.

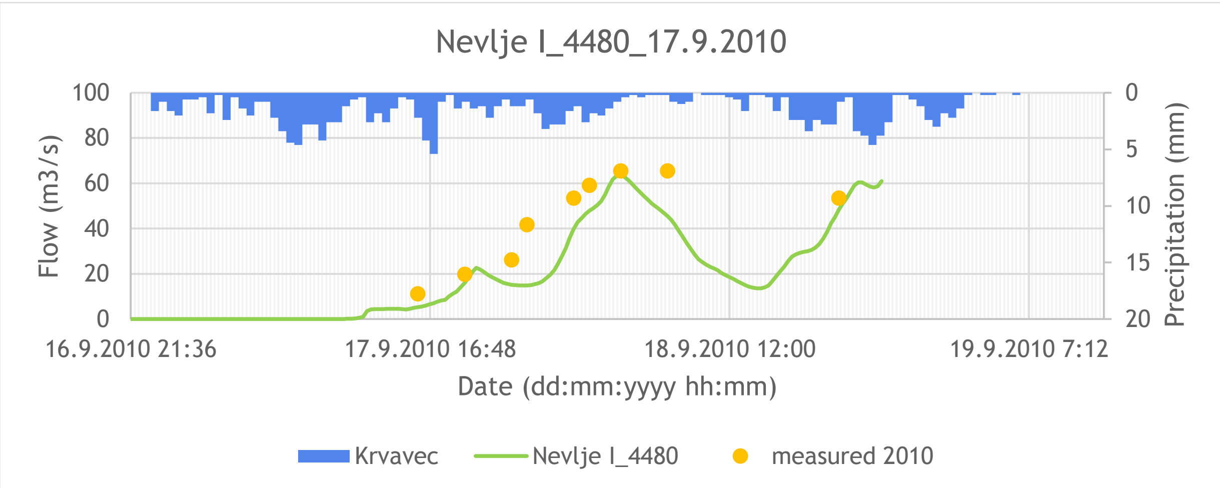


Figure 19: Comparison between measured and computed values at Nevlje I GS for the 17.9.2010 event

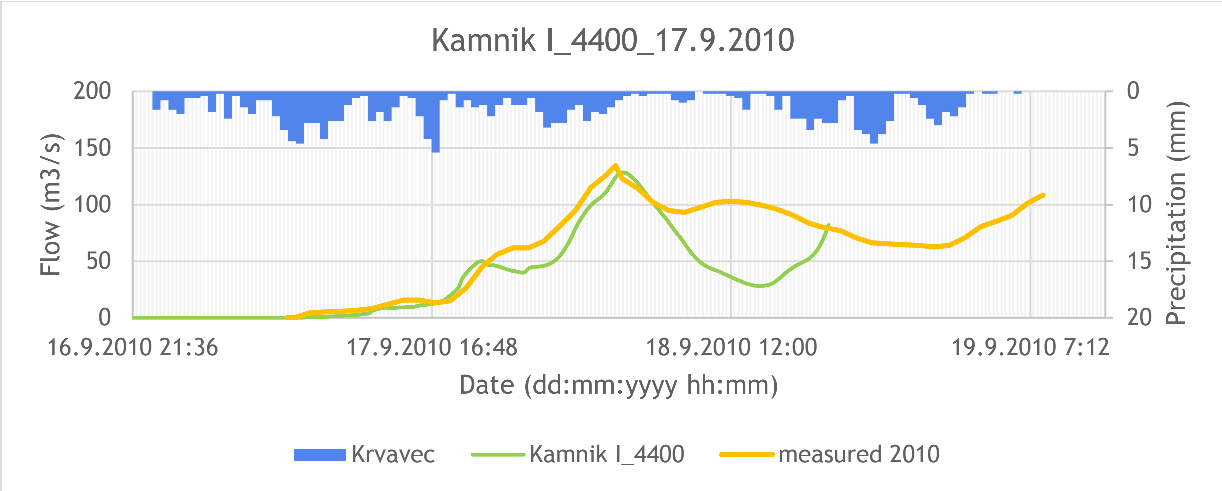


Figure 20: Comparison between measured and computed values at Nevlje I GS for the 17.9.2010 event

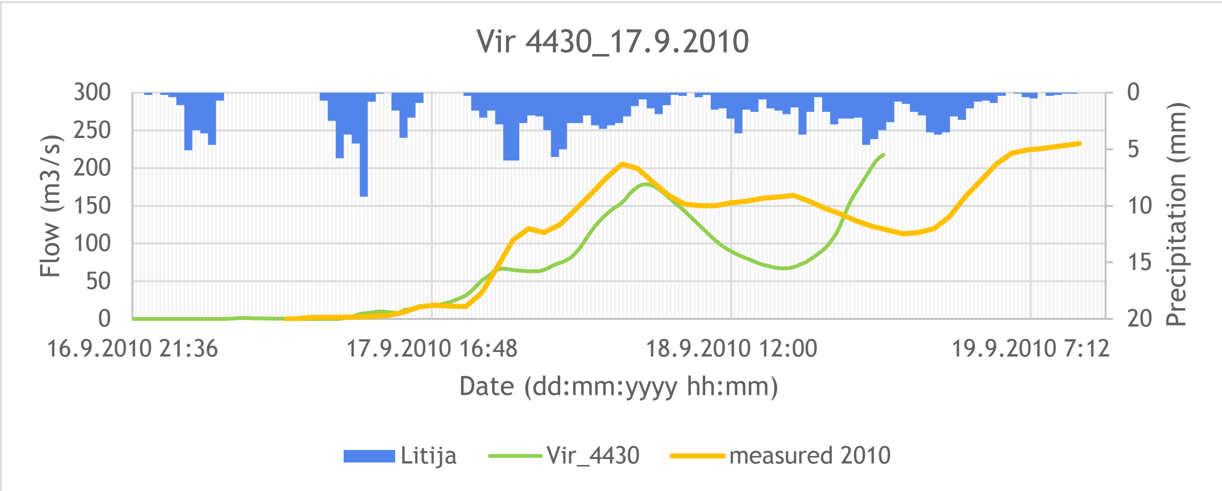


Figure 21: Comparison between measured and computed values at Nevlje I GS for the 17.9.2010 event

Initial results for the 2007 event, which were used for validation purposes, show significantly over estimated maximal discharge at both stations, Kamnik I and Vir. Close inspection of the precipitation data reveals, that at the time of the event, ground was very dry due to long period without rain. At initial run, CN values were taken for intermediate conditions which cause higher excess rain compared to actual dry conditions. Therefore, we have decided to lower CN values to the lowest theoretical value for dry conditions according to reference literature (Neitsch in sod., 2009), where next Equation is proposed.

$$CN_{min} = CN - \frac{20\cdot(100-CN)}{(100-CN+exp[2{,}533-0{,}0636\cdot(100-CN)])} \qquad \textit{Equation 1}$$

As we can see from the next Figures, by using theoretical minimum CN values we were able to simulate flooding event much better regarding the measurements. From Initial runs with unaltered CN's where calculated peak discharges where more than two (2) times bigger than measured ones, the differences between calculated and measured peak discharges when using altered CN were closer to +-10%.

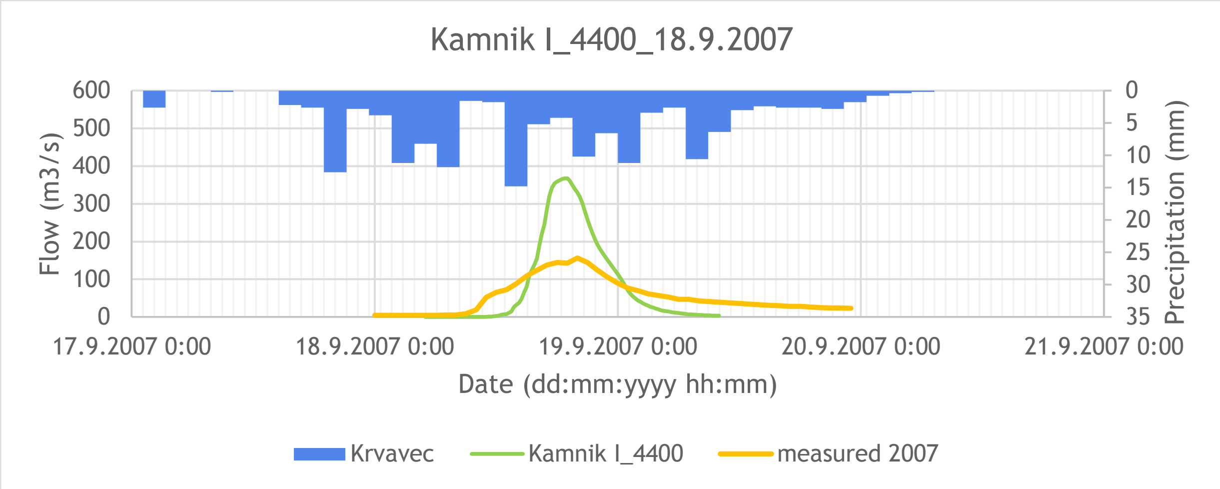


Figure 22: Comparison between measured and computed values at Kamnik I GS for the 18.9.2007 event (unaltered CN values)

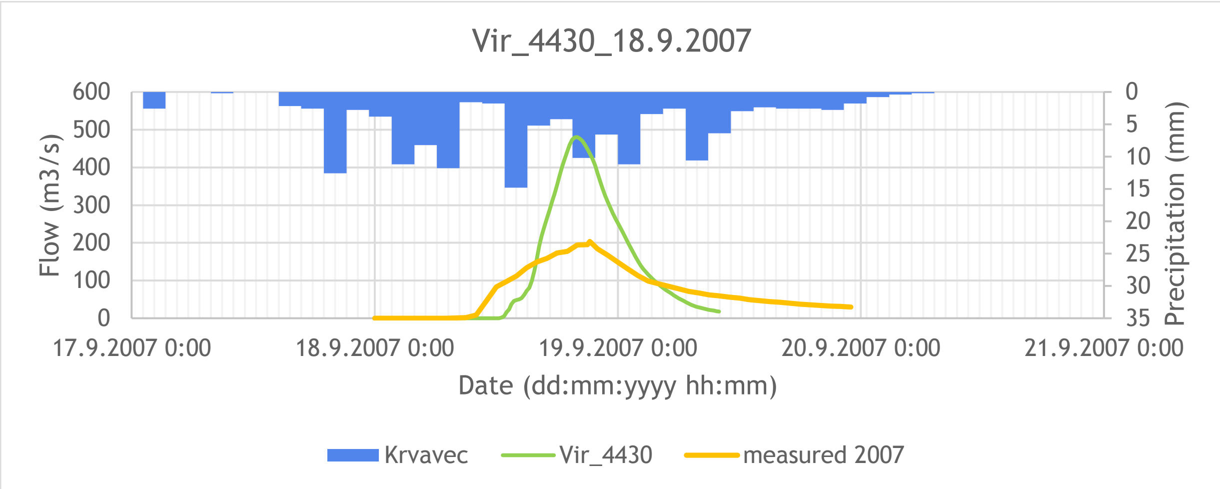


Figure 23: Comparison between measured and computed values at Virl GS for the 18.9.2007 event (unaltered CN values)

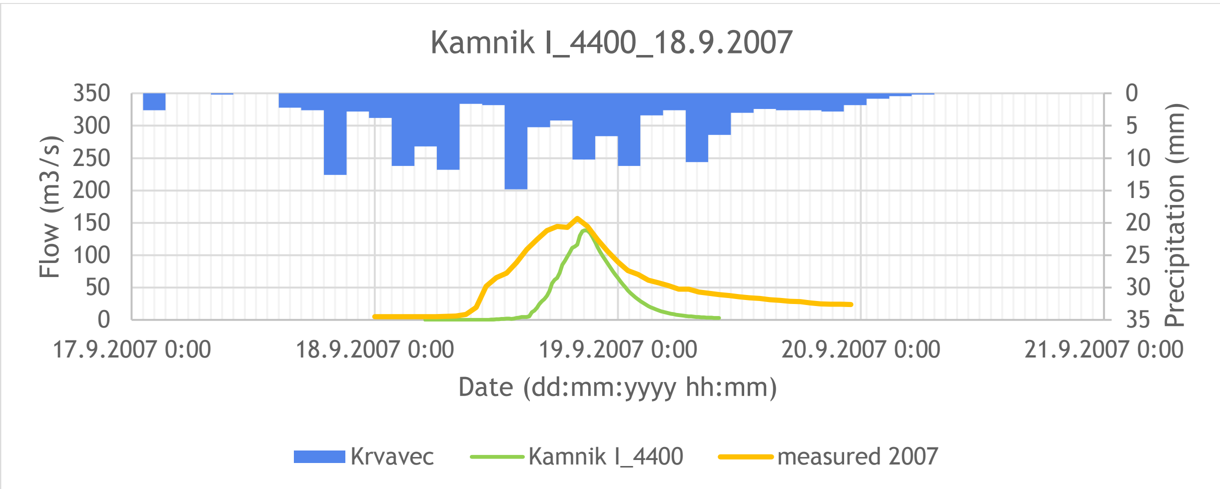


Figure 24: Comparison between measured and computed values at Kamnik I GS for the 18.9.2007 event (altered CN values to the theoretical lowest for dry conditions)

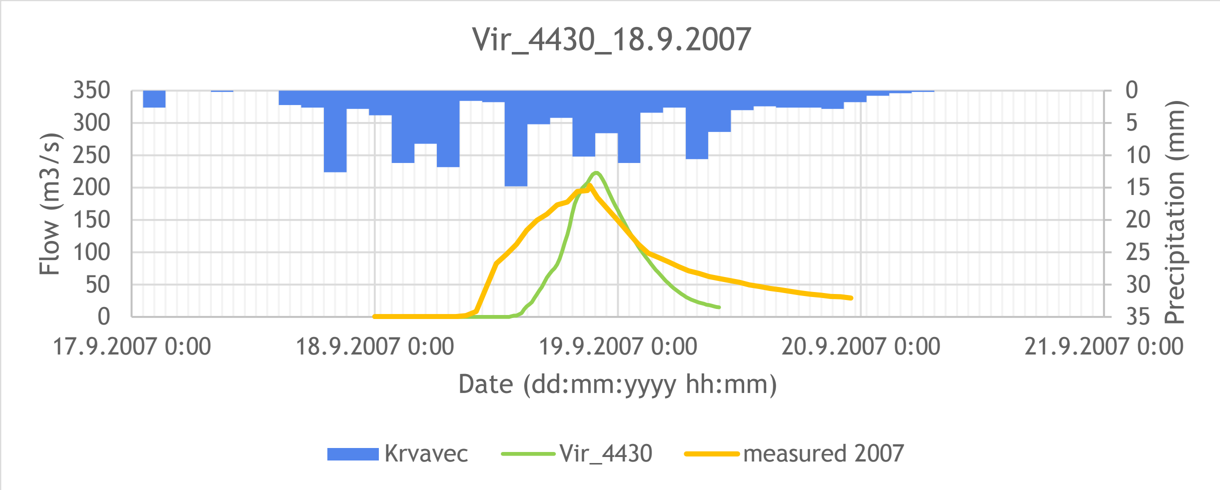


Figure 25: Comparison between measured and computed values at Virl GS for the 18.9.2007 event (altered CN values the theoretical lowest for dry conditions)

Manning's ng values were calibrated through a series of test runs of the 2010 event. Calibrated values are shown in the next Figure. These values will be used for further calculations regarding evaluation of S(W)RM's.

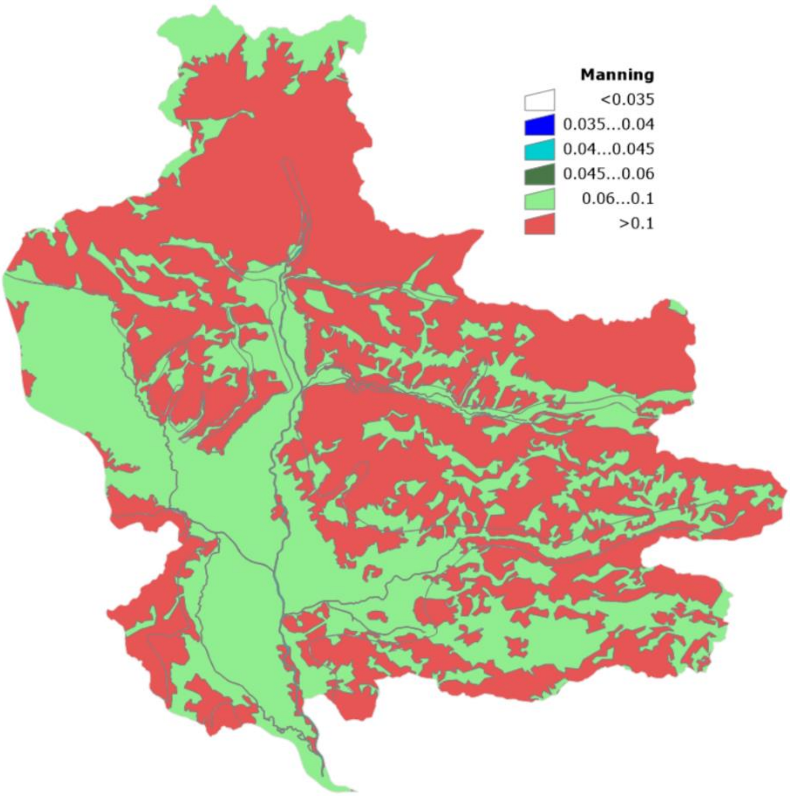


Figure 26: Calibrated values of Manning's roughness coefficient

2.7. Conclusions of validation and calibration

Entire Kamniška Bistrica catchment has been modeled in one combined hydrological-hydraulic model. As seen from the results, calibration of the catchment this size is a tedious work, especially when spatial distribution of rainfall differs greatly and available precipitation data could/should be better. Despite having quite a lot of gauging station measurements, they are not to be completely trusted as there appear to be longer period of missing data, as well as QH (discharge/height) curves tend to overestimate/underestimate discharges as they are usually extrapolated from (un)sufficient data.

However, results of calibration had proven suitable hydrological-hydraulic response of the catchment and good match with observed discharges for the observed events and field situations observed by the locals. The model as such is considered appropriate for further evaluation of S(W)RM effects on flooding. In next stages, flooding of 1/100 year precipitation will be calculated and evaluated for both existing and intended condition with S(W)RM's. Later on, optimal S(W)RM's will be defined and analyzed in detail.

3. Hydrological data for NSWRM evaluating purposes

The next stage after calibration of the Kamniška Bistrica hydrologic-hydraulic model is evaluating impact of the NSWRM's on the pilot catchment. In the next chapters the procedure of evaluation will be presented and discussed. The Kamniška Bistrica hydrological – hydraulic model has been calibrated to 2010 flooding event and validated for the 2007 event. Evaluation of NSWMR's was decided to be done on precipitation data with 100 years return period, hence additional statistical and areal analysis had to be done.

At first, we had acquired all available daily precipitation data from weather stations at or near the modelled area (ARSO, 2019). Data had been checked and maximal yearly precipitation for each and every precipitation station had been defined. Acquired daily data from ARSO is measured from 7am from the first day to 7am the next day, and can underestimate maximal 24-hour precipitation by a large margin, so we analysed daily and connected 2 daily events. Connected 2-daily event means summed two consecutive days into one event, which can represent connected 24-hour event, shorter non-connected events or long event with duration above 24 hours. Based on maximal yearly daily and 2 daily precipitation data defined in previous step, Q100 year statistical precipitation had been calculated using different statistical methods and is shown in the next Table.

				2 daily		daily	
Precipitation station	In working order (years)			LPIII (mm)	Gumbel (mm)	LPIII (mm)	Gumbel (mm)
	from	to	Num				
Ambrož pod Krvavcem	1961	2018	58	208	216	173	173
Brnik-letališče	1963	2014	52	217	211	171	168
Cerklje+Cerklje letališče	1961	1989	39	155	177	99	112
Depala vas pri Domžalah+Domžale	1961	1993	47	204	204	152	156
Kamniška Bistrica	1961	2018	58	280	302	221	228
Krvavec	1961	2018	58	197	197	153	152
Moravče	1961	2014	54	176	177	123	128
Volčji potok	1961	1989	29	139	176	105	137
Zgornje Loke pri Blagovici	1961	2018	58	186	188	146	148
Zgornji Tuhinj	1961	2013	53	197	194	164	155
Črnivec	1961	2018	57	225	230	165	167

Table 4: List of precipitation stations used for statistical calculations and computed statistical precipitation values for 2 daily and daily event from Log Pearson III and Gumbel distribution method

To determine influence of each individual precipitation station on the amount of total precipitation inside of the model area, the Thiessen polygons method (Shaw, 1994) has been used in a same way as during the calibration process. With this method the modelled area is divided to polygons representing individual precipitation stations. Polygons are separated with strait lines with equal distance between two neighbouring weather stations, where polygon areas represent so called “weight factors”. These factors are then multiplied with precipitations on belonging precipitation stations, and sum of all multiplications represent the total amount of rainfall on modelled area.
Thiessen polygons assigned to areas and graphical spatial presentation (Kriging interpolation method) of computed statistical values for 100-year precipitation event with daily and 2 daily duration, can be seen on the next Figures.

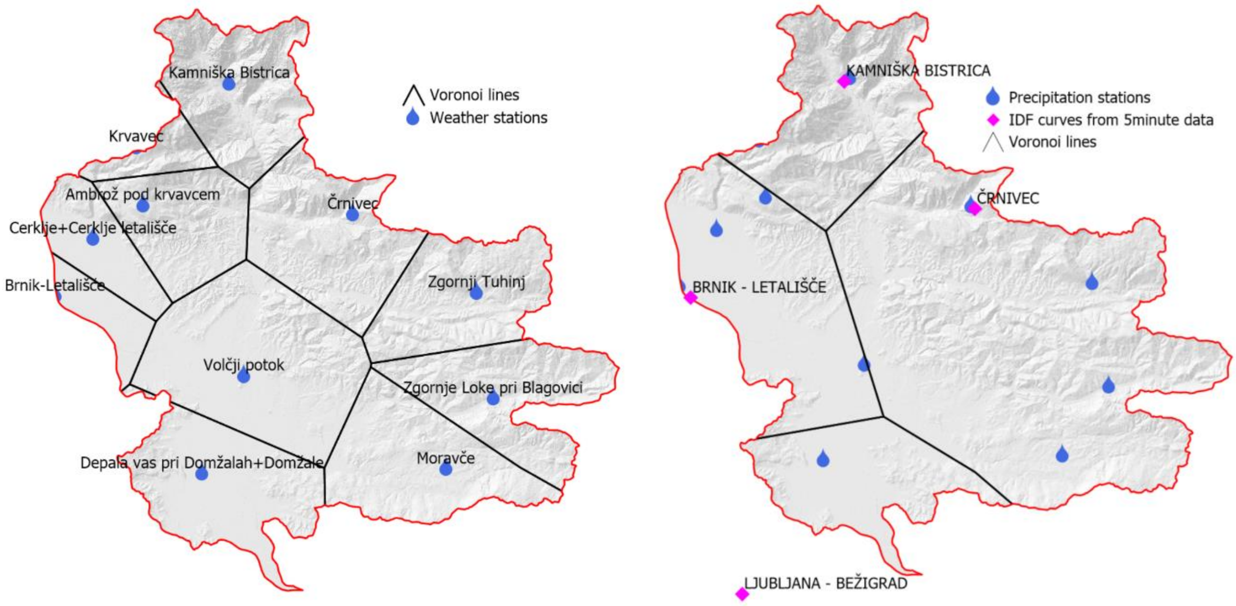


Figure 27: Precipitation stations for 100-year return period assigned to Thiessen polygons (left) and precipitation stations where IDF curves based on 5minute data – Gumbel, already exist (right, courtesy of ARSO, 2019)

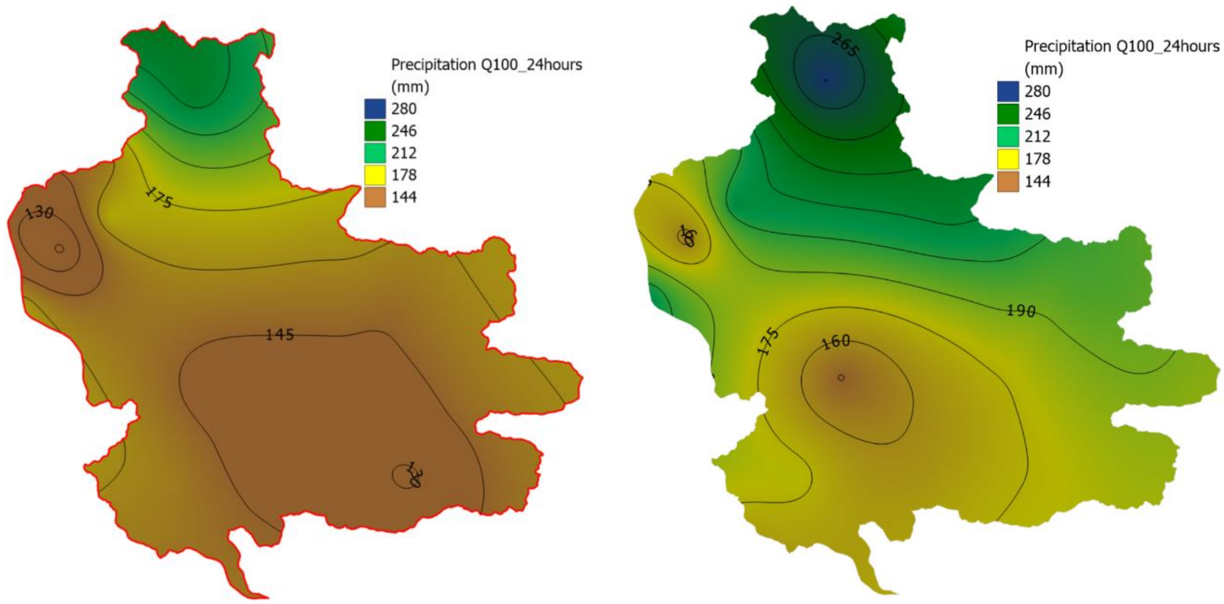


Figure 28: Graphical spatial representation for statistical daily precipitation values using Kriging interpolation (left) and 2 daily precipitation (right). Isohyets show 15cm equidistance.

daily statistical precipitation - Gumbel distribution method												
Return period (years)	Brnik-letališče			Ljubljana Bežigrad			Kamniška Bistrica			Črnivec		
	from data **5min**	from data **daily**	factor	from data **5min**	from data **daily**	factor	from data **5min**	from data **daily**	factor	from data **5min**	from data **daily**	factor
	1970-1993, 2004	1970-1993, 2004		1948-2008	1948-2008		1977-2008			1977-1991		
100	134	131	1.02	145	/	/	253	254	1.00	186	149	1.25

Table 5: Comparison of daily statistical precipitation for 100-year return period calculated from daily and 5 minutes (courtesy of ARSO, 2018) data.

Comparison from previous table shows, that 100-year statistical precipitation calculated from daily and 5minutes data differs up to 25%, which is direct effect of measurements grouping into time frames. On the other hand, difference between daily and 2daily data lies between 20% and up to 60% (2-daily statistical values are higher).

So, for modelling purposes to prevent precipitation under or overestimation, we used Gumbel statistical precipitation values gotten from daily data increased by 10 percent which is an average factor for statistical values calculated from daily and 5minutes data for all four weather stations analysed above.

Due to lack of measured precipitation data for shorter events it was only possible to statistically calculate daily precipitation values, those with shorter duration (e.g. 1, 5 10-hours) were therefore defined based on ratio from existing IDF (intensity-duration-frequency) curves available for certain stations around modelled area where measurements have been made based on 5 minutes interval (courtesy ARSO, 2018). Initially those curves are available unaltered, meaning created directly from measured data. For efficient hydrological-hydraulic calculation the ones with zigzag data had to be altered in order to get smooth and logical transition between calculated flooding waves for different duration of precipitation. Naturally, IDF curves follow logarithmic shapes, therefore alteration of existing curves was applied by fitting them to a logarithmic curve (or multi log curves with breaks at natural transitions on a log-log scale).

Altered and unaltered IDF curves for the Kamniška Bistrica precipitation station are shown on the next Figures.

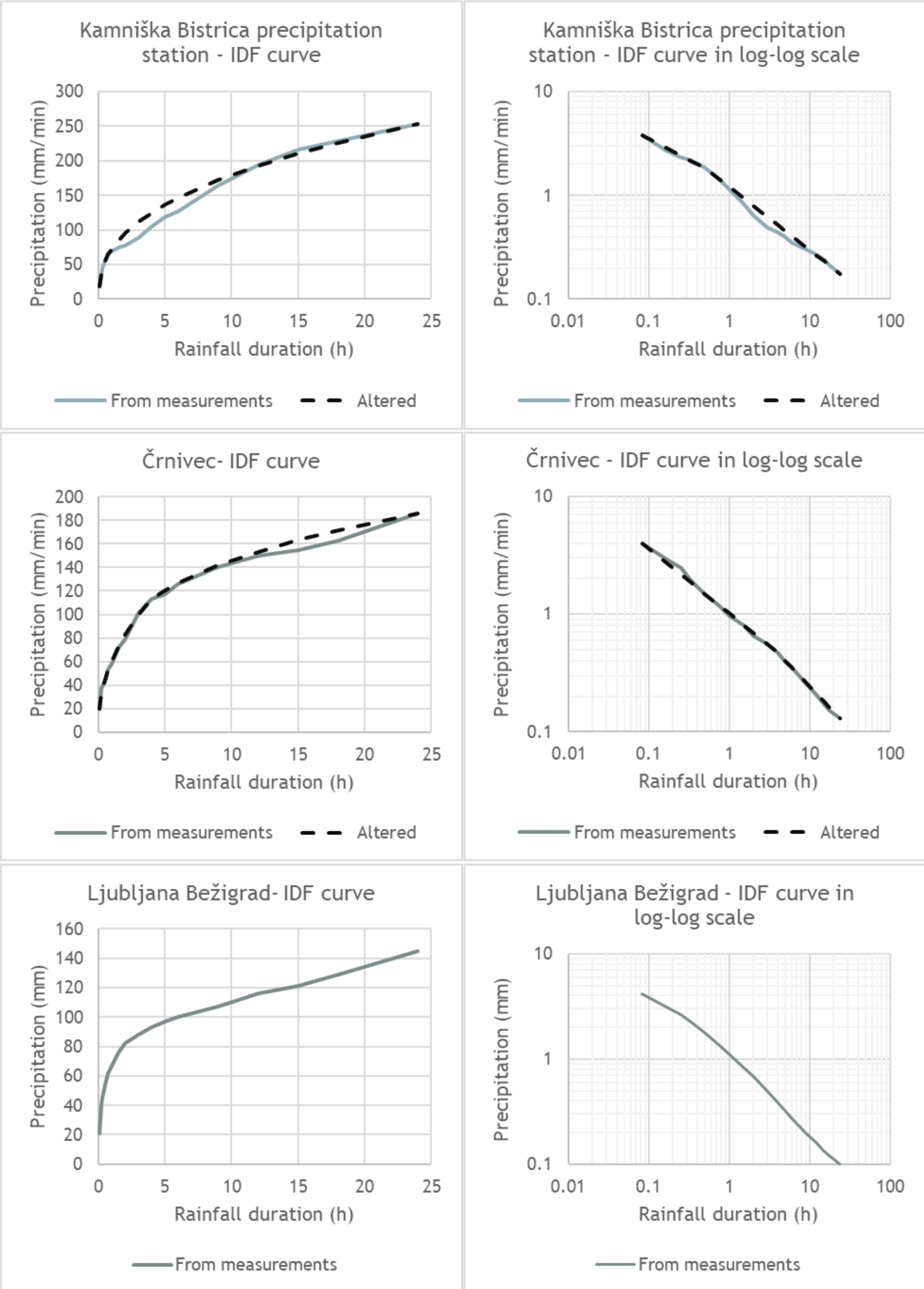


Figure 29: IDF curve of the precipitation stations with 5 minutes measurement interval

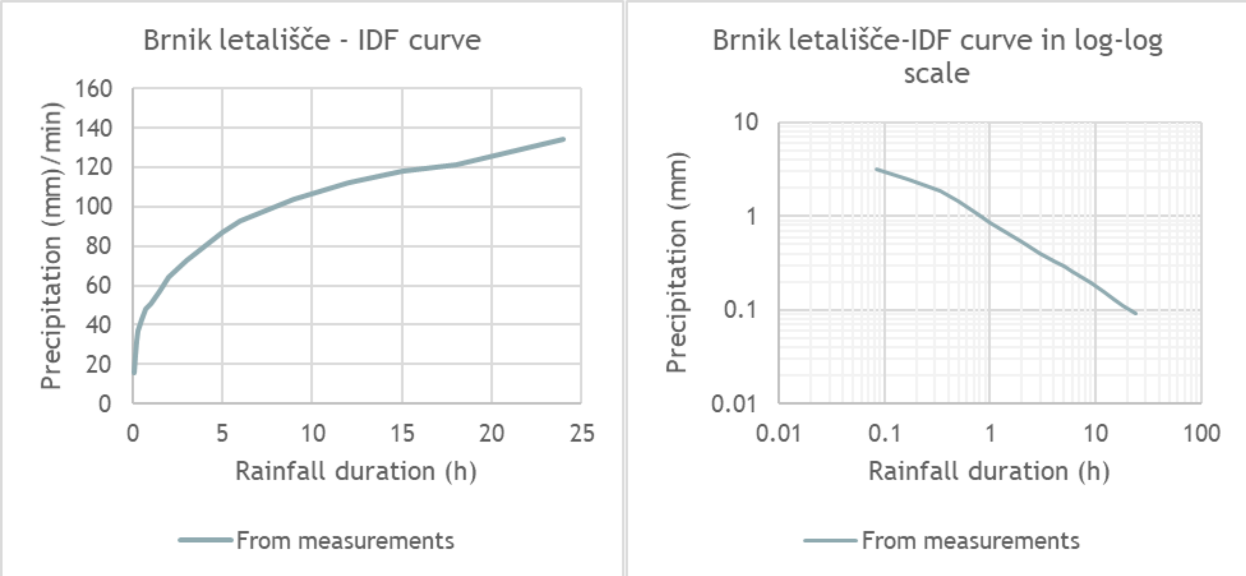


Figure 30: IDF curve of the precipitation stations with 5 minutes measurement interval

Precipitation station	Assigned IDF station regarding precipitation factors Q100	Precipitation factors Q100		Q100 24h (Daily*1.1) (mm)	Q100 15h (mm)	Q100 6h (mm)
		Daily/ 15h	Daily/ 6h			
Ambrož pod Krvavcem	Brnik-letališče	0.87	0.66	190	166	126
Brnik-letališče	Brnik-letališče	0.87	0.66	185	161	122
Cerklje+Cerklje letališče	Brnik-letališče	0.87	0.66	123	107	81
Depala vas pri Domžalah+Domžale	Ljubljana Bežigrad	0.83	0.69	172	142	118
Kamniška Bistrica	Kamniška Bistrica	0.83	0.58	251	208	145
Krvavec	Kamniška Bistrica	0.83	0.58	167	139	97
Moravče	Črnivec	0.88	0.68	141	124	96
Volčji potok	Brnik-letališče	0.87	0.66	151	131	99
Zgornje Loke pri Blagovici	Črnivec	0.88	0.68	163	143	111
Zgornji Tuhinj	Črnivec	0.88	0.68	171	150	116
Črnivec	Črnivec	0.88	0.68	184	162	125

Table 6: Precipitation used for NSWRM evaluation using hydraulic model. Values for Q100 15h and 6h are calculated from Q100 24h multiplied by precipitation factors Q100.

4. Hydraulic calculations

Hydraulic calculations were done by using the same model which had been calibrated beforehand. Based on local precipitation and hydraulics experiences It was decided, that for modeling purposes of NSWRM efficiency, three precipitation scenarios will be analyzed. These include 6 hours, 15 hours and daily (24 hours) precipitation with 100-year return period. Precipitation data used for calculation can be seen in Table 3. When deciding which theoretical precipitation time distribution to use, we examined three most commonly used ones, naming Linear, equal and Huff. Due to lack of comparison data we decided to use equal time distribution as it is the most common of the three.

At first, each precipitation scenario was run on existing model, that is without NSWRM. Afterwards, NSWRM were grouped and runs were performed on models altered with grouped NSWRM's. Finally, a model with all NSWRM's was run and results off all runs were examined.

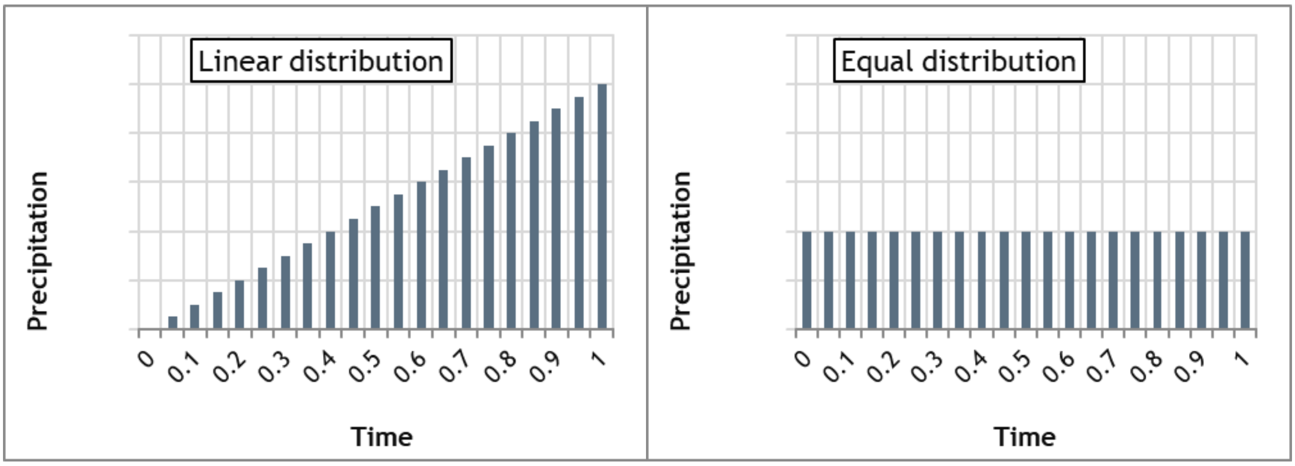


Figure 31: Example of linear and equal precipitation distribution

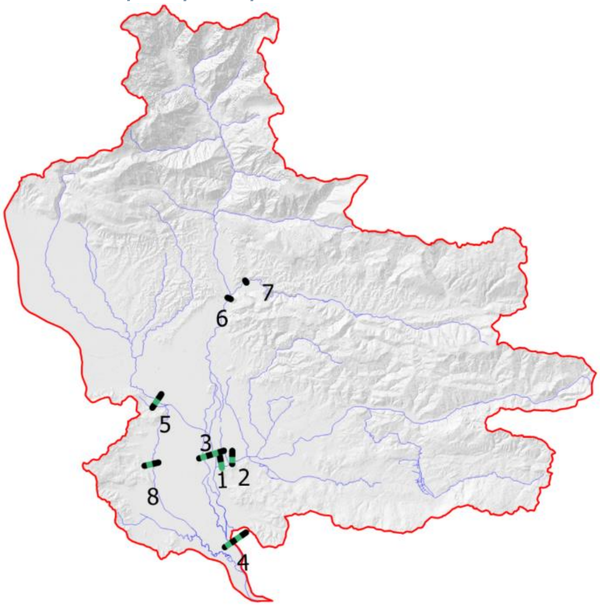


Figure 32: Locations of cross sections used for hydrographs comparisons

Nr.	Cross section
1	Podrečje_4520
2	Vir_4515
3	Vir_4430
4	Bišče_4445
5	Topole_4570
6	Kamnik I_4400
7	Nevlje I_4480
8	Loka_4575

Table 7: Cross sections used for hydrographs comparisons

Cross sections used for hydrographs comparisons NSWRM's naming in FramWat catalogue was adopted from nwrm.eu project (www.nwrm.eu), but some of the Slovenian measures are unique for our catchment and are not list ed in the official catalogue, hence do not have specified coding. This effects NSWRM naming in further chapters.

4.1. NSWRM - Dam retensions (Hydrotechnical – T03)

The main goal of dam retentions is to accumulate excessive precipitation and to gradually release accumulated water after the main precipitation/flooding event. For modelling purposes, we assumed indefinitely high dams with no water releasing wherever possible. If not possible, dam spill deck was positioned at the height of the surrounding terrain (dams' number 2,4,5,6 and 12). Due to strategically selected locations of proposed dams, with accumulation volume/precipitation volume ratio being high enough not to rise accumulated eater level beyond all borders, this approach is justifiable.

Initially, we located 13 possible dam retention locations, which were analyzed in a HH model. Their location is shown on the next Figure.

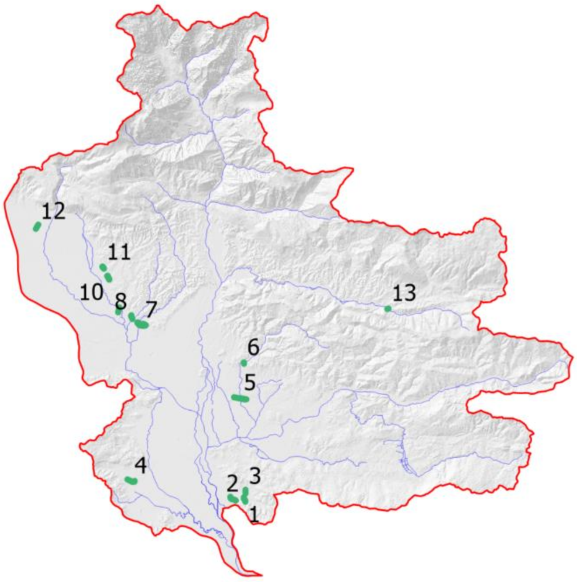


Figure 33: Dam locations numbering (marked in green)

Dam Nr.	River/stream	Max. calculated WSE at Q100 (m.a.s.l.)			Retention volume at Q100 (mil. m^3)			Max dH (m)
		6hr	15hr	24hr	6hr	15hr	24hr	24hr
1	No name	296.66	297.96	299.12	0.07	0.13	0.2	7.6
2	Zabnica	285.66	285.82	285.83	0.05	0.07	0.07	2.3
3	Zabnica	291.93	292.62	293.23	0.04	0.06	0.09	5.7
4	Blatnica	299.01	299.02	299.02	0.03	0.03	0.03	3.5
5	Rovski potok	320.96	322.22	322.46	0.08	0.23	0.27	5.5
6	Rovski potok	347.16	350.08	350.10	0.21	0.49	0.49	10.1
7	Tunjscica	340.58	342.19	343.00	0.30	0.58	0.79	9.0
8	Knezji potok	340.54	342.21	342.97	0.09	0.24	0.34	7.5
9	Psata	342.62	344.26	345.02	0.37	0.89	1.21	7.5
10	Doblic	357.85	360.23	361.42	0.15	0.30	0.44	8.9
11	Dobovsek	359.44	360.69	361.31	0.03	0.07	0.09	6.8
12	No name	397.19	397.21	397.22	0.06	0.06	0.06	4.2
13	Nevljica	474.83	478.31	479.91	0.20	0.33	0.56	15.9
	Total retained volume (mil. m^3)				**1.6**	**3.5**	**4.6**	
	Retained effective precipitation volume (%)				**8**	**10**	**10**	

Table 8: Calculated water surface elevations and accompanying retention volumes at modelled dam retentions

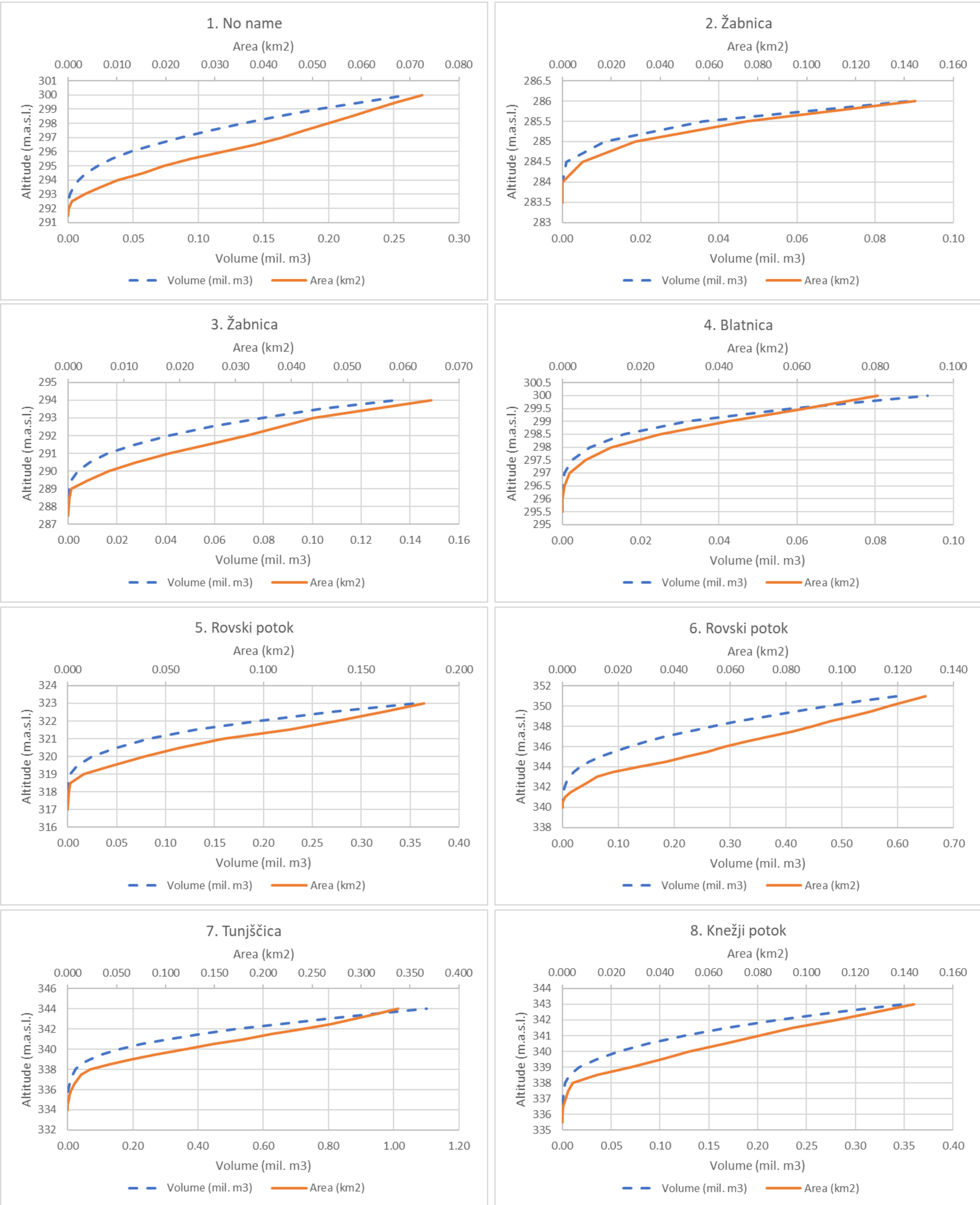


Figure 34: Calculated volume and flooded area for every proposed dam, based on Lidar

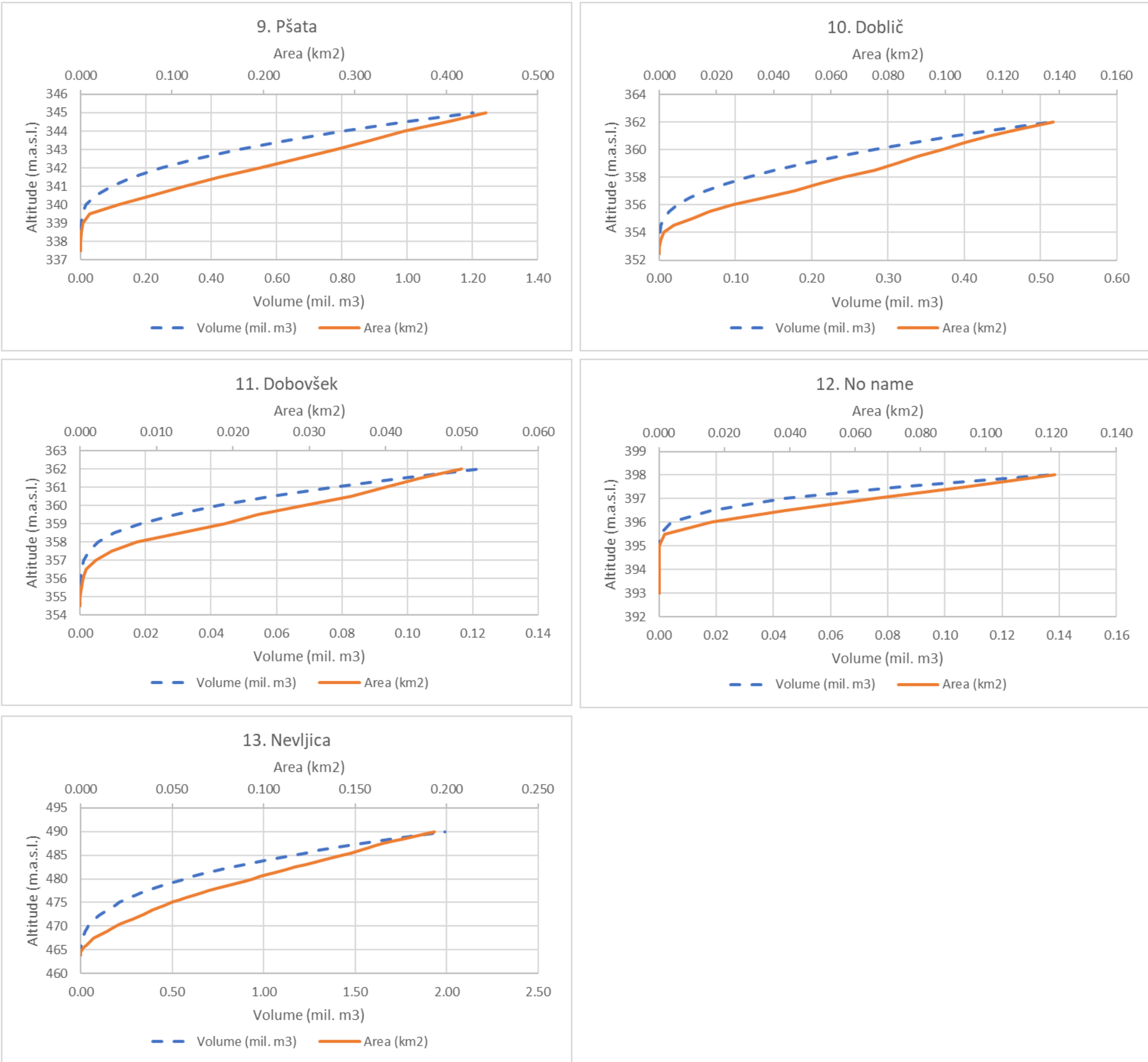


Figure 35: Calculated volume and flooded area for every proposed dam, based on Lidar

Event Q100	DBC outlet (mil. m3)	Volume inside 2D (mil. m3)	Accum. Prec. (mil. m3)	Accum. Infiltr. (mil. m3)	Accum. Effective (mil. m3)
6hr	10.0	9.6	52.1	32.5	19.6
15hr	23.7	11.9	73.9	38.4	35.5
24hr	32.8	13.7	87.6	41.1	46.5

Table 9: Calculated mass balance of hydraulic models

Based on hydraulic model results we can see that the biggest impact of dam retentions in comparison to existing condition is seen right next to dams themselves in the way of reducing peak hydrographs flows. Further on downstream, impact weakens and is hardly evident at the downstream boundary condition of the whole catchment. At Q100 event with 6 hours, 15 hours and 24 hours duration, retained effective precipitation volume by proposed dams regarding accumulated effective precipitation on a basin scale, is roughly 8, 10 and 10 % respectively.

Event Q100	Flooded area-existing (km2)	Flooded area-after measures (km2)	Difference regarding existing area (km2)	Difference regarding existing area (%)
6hr	101.6	99.2	-2.4	-2
15hr	104.4	101.3	-3.1	-3
24hr	99.3	96.3	-3.0	-3

Table 10: Calculated flooded area on the whole catchment for existing stage and stage after implemented NSWRM measures (dams). River streams are included in the flooded area.

Hydraulic model results on the whole catchment scale show less flooded areas after implementing proposed dam retentions up to 3% which roughly equals to flooded area in km^2. Graphical representation is on the next Figure.

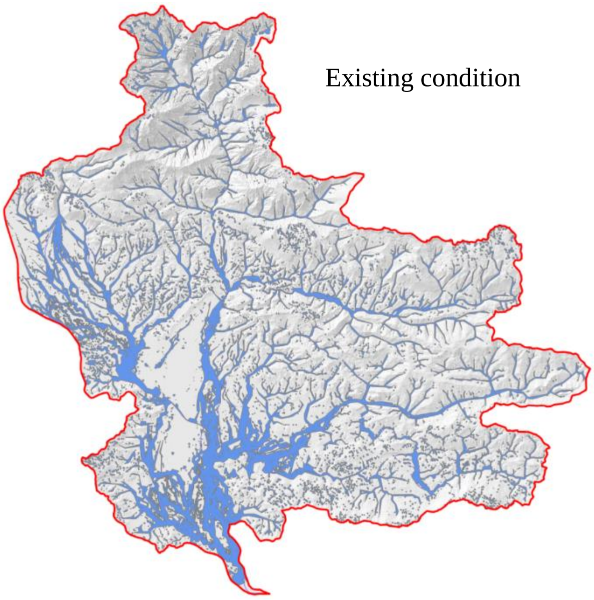


Figure 36: Graphical representation of calculated flooding for 15 hours event with 100year return period. Existing conditions flooding is on the left side, flooding with implemented proposed NSWRM (dams) is on the right. On first look, difference is negligible.

We should emphasise the fact, that calculations were done assuming infinite crest heights of the dams, thus results shown represent maximal theoretical outcome. It is highly unrealistic that sizes of the dams needed to achieve this kind of impact on flooding would be financially and ecologically feasible though. Still the results are meaningful, as cumulative effects of measures that could be expected using realistic dam geometry are worse than calculated in this theoretical scenario.

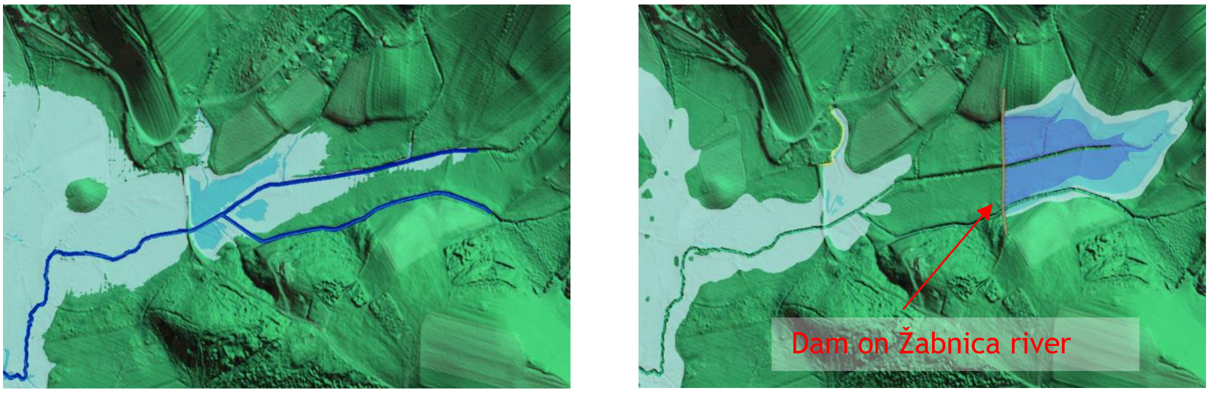


Figure 37: Example - comparison between existing flooding (left photo) and flooding after measures (new dam Nr.3, right photo) on Žabnica river.

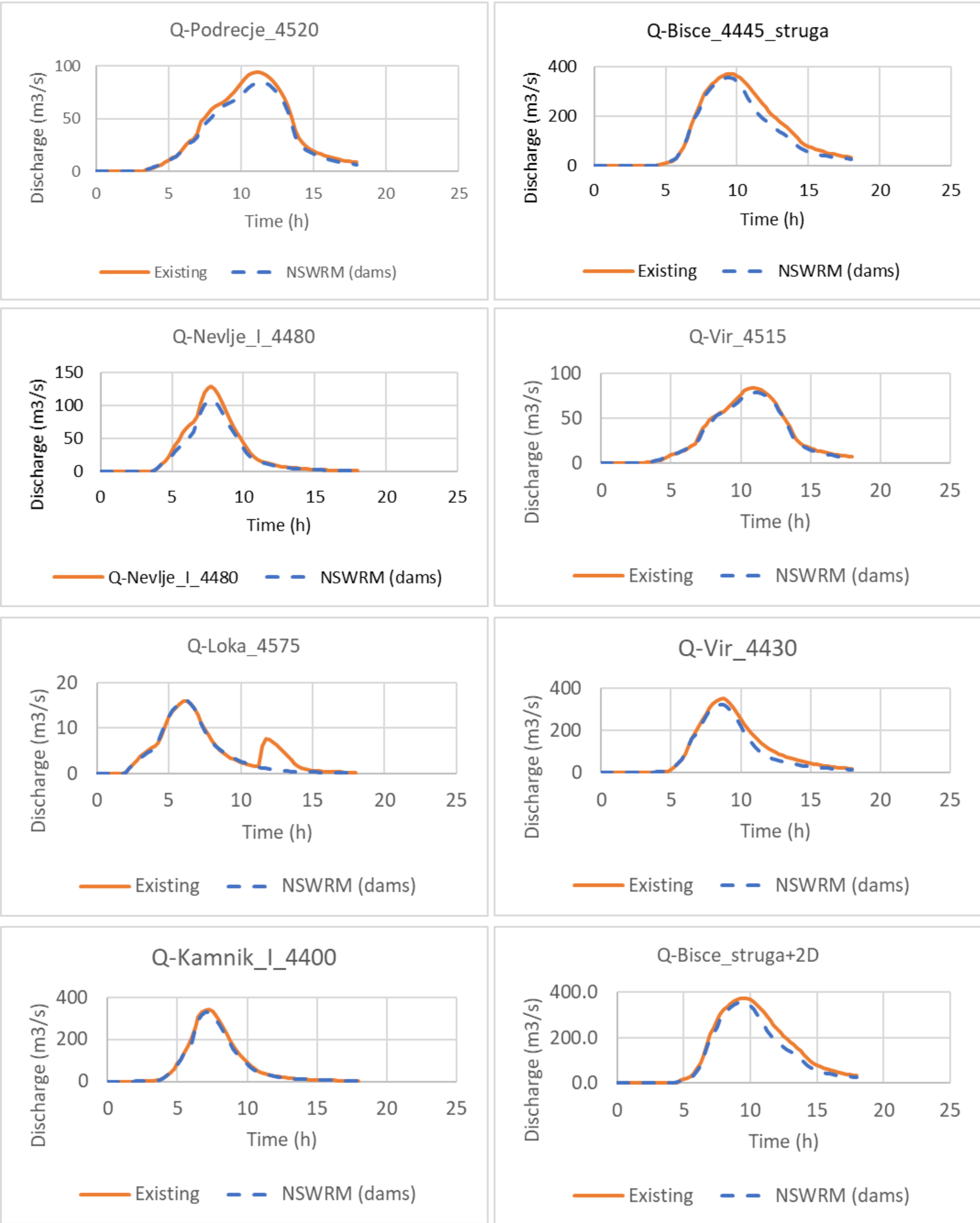


Figure 38: Comparison of computed 6-hour hydrographs with 100-year return period

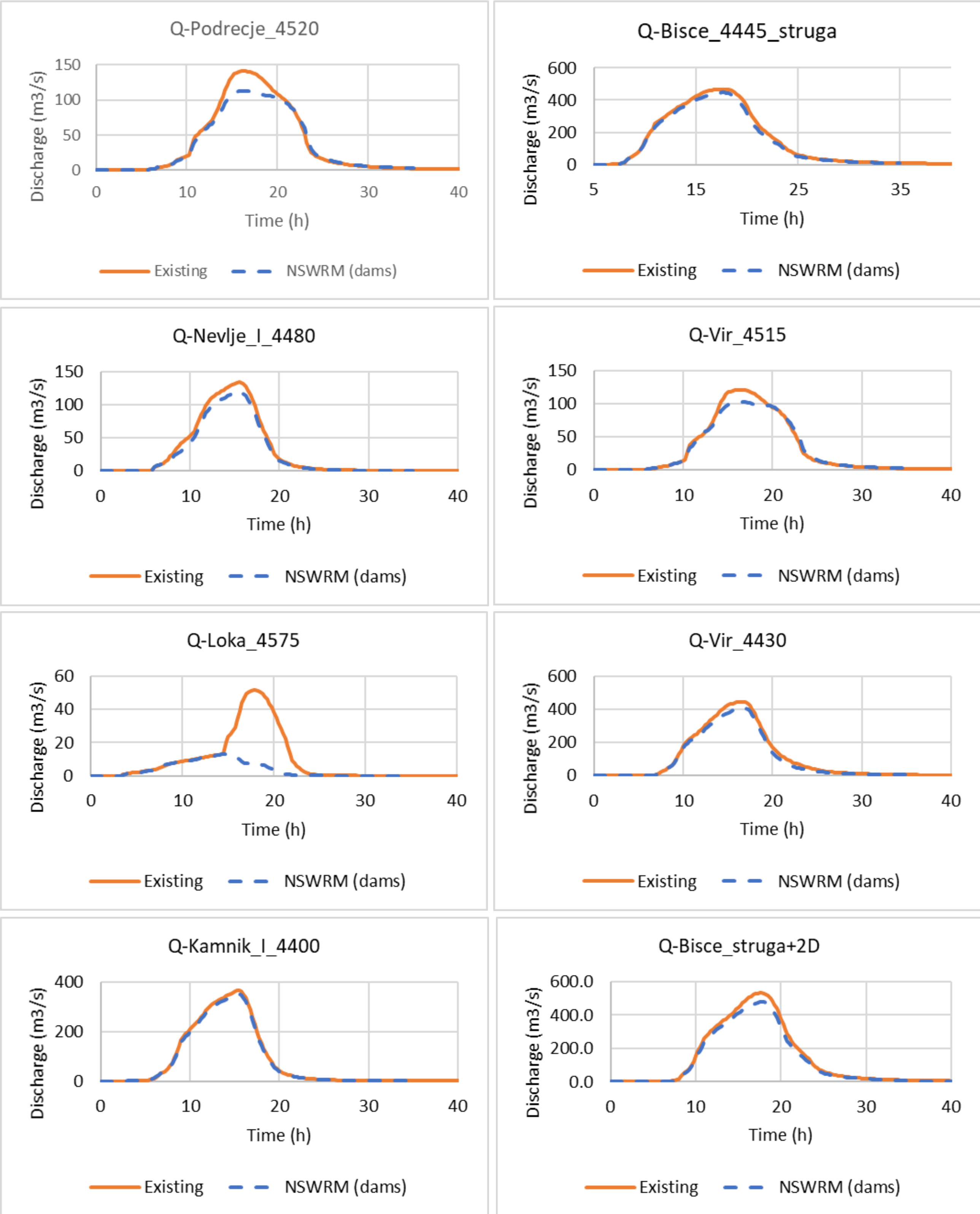


Figure 39: Comparison of computed 15-hour hydrographs with 100-year return period

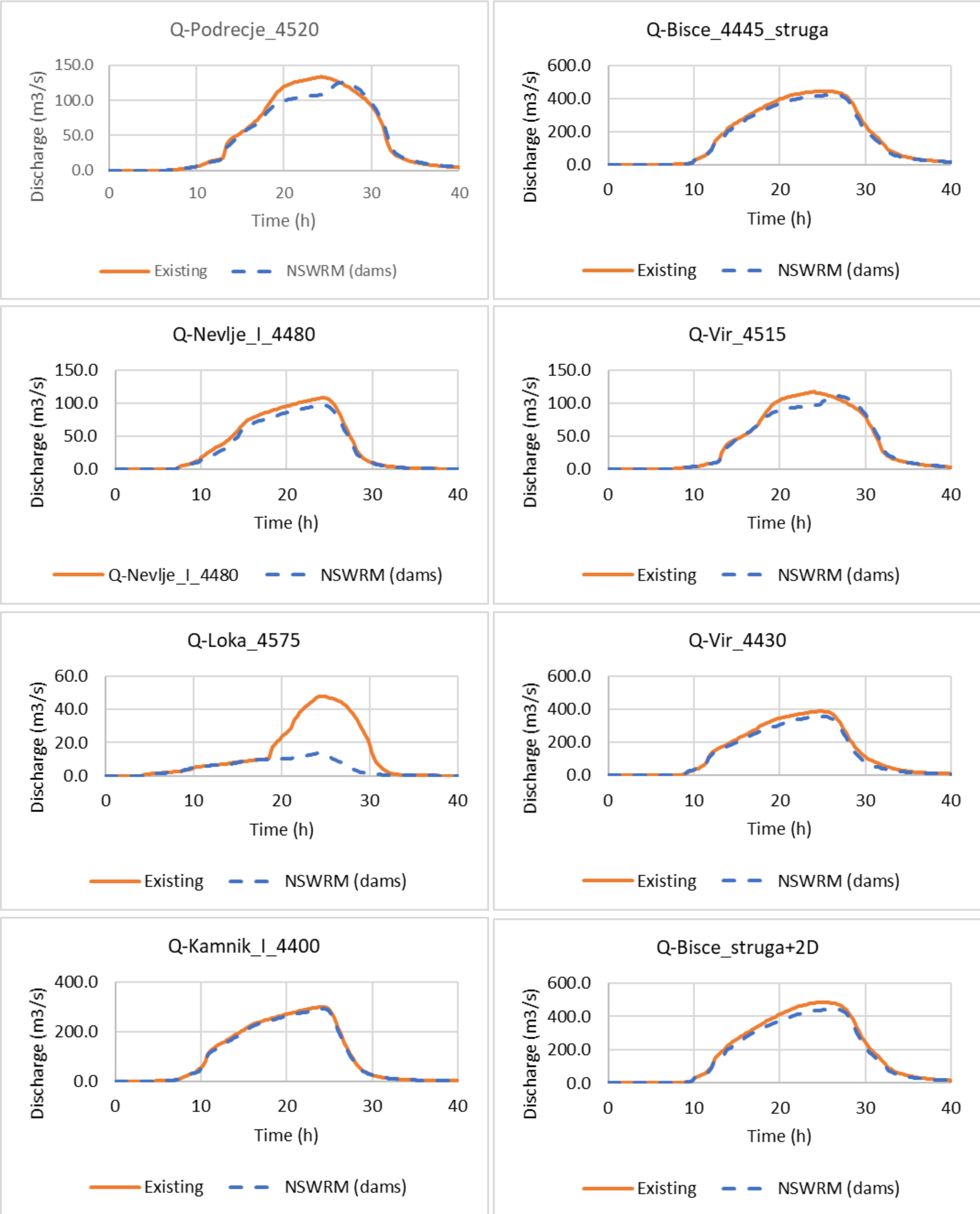


Figure 40: Comparison of computed 24-hour hydrographs with 100-year return period

Proposed measure falls under Hydrotechnical measures T03 (Construction of small reservoirs on rivers) in the catalogue of measures.

4.2. NSWRM – river regulation (Hydro morphology - N05, N08, N10)

River regulation measures are predicted in five locations shown on the next Figure. At preliminary stage, it is hard to predict exact measures needed and appropriate at a specific location, but based on existing situation measures are to be rather conservative – river bed slope regulation, bridge openings optimizations, stream stabilizations, etc. Overall length of the proposed measures is relatively short with beeing slightly longer than 12 km, all alterated sections are located on existing river streams. Some of these measures are specific for Slovenian watershed and do not have official coding from the catalogue of measures. Proposed regulation would comprise of several hydro-morphology measures from the catalogue, N05 (stream bed renaturalization), N08 (riverbed material renatunarization) and N10 (natural bank stabilization).

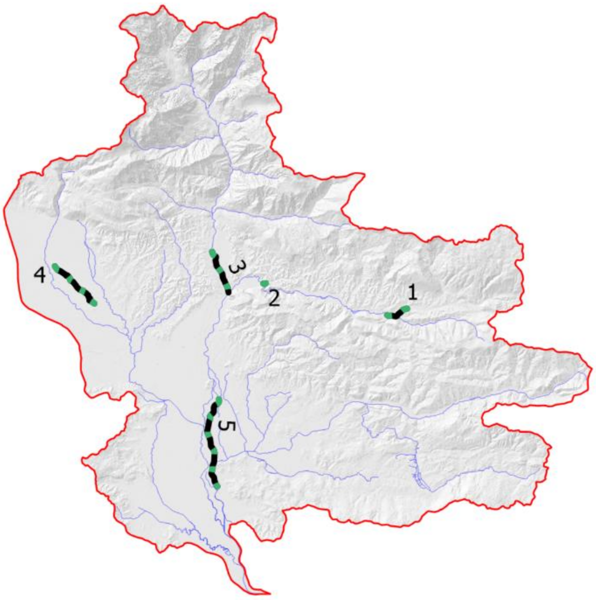


Figure 41: River regulation locations numbering (marked in green-black dashed line)

At hydraulic calculations we compared existing conditions to proposed ones, modelled measures were conservative, and included only minor stream alteration. As expected those measures themselves do not have any significant impact on water retension on the catchment scale. Effects are only local in a sense of different velocity fields (in stream and on flood plains) hence improved shear stress resistance, better stream conveyance etc. With emphasis of the project on water retention effects, we are not showing nor comparing other detected and allready mentioned effects.

Estimated added volume by all regulation measures is less than 10000 m^3, with no significant impact on water retention on catchment scale. On the next Figure, we show the comparisson between existing and modelled condition hydrograph on the catchments outflow for only one precipitation duration, with both beeing identical. Other graphical results are not shown.

Nr.	Stream	Measure	Length (km)
1	Confluence of Tuhinjscica and Nevljica	River/stream regulation	1.3
2	Confluence of Porebrscica and Nevljica	River/stream regulation	0.1
3	Kamniska Bistrica	River/stream regulation	2.5
4	Voje	River/stream regulation	3.3
5	Kamniska Bistrica	River/stream regulation	5.2
Estimated added volume by all regulations (mil m^3)		**<0.01**	
Estimated cumulative retention volume, 6/15/24h (%)		**<<1/<<1/<<1 (negligible)**	

Table 11: List of river regulation locations

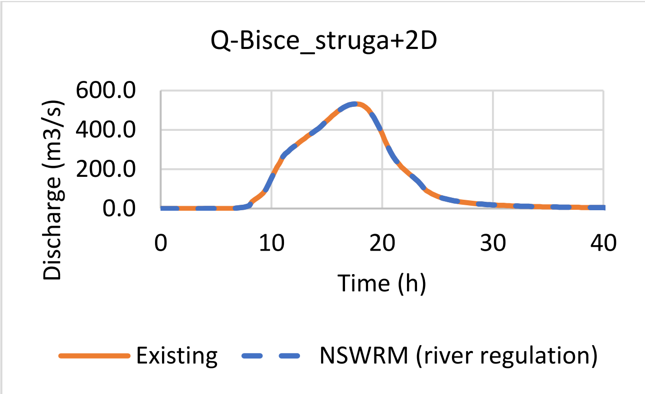


Figure 42: Existing vs river regulation - comparison of computed 15-hour hydrographs with 100-year ***return period***

4.3. NSWRM – erosion control measures (Forest – F09)

Erosion control measures are predicted in two locations shown on the next Figure, their location is on the area known for higher risk of erosion. Some of these measures are specific for Slovenian watershed and do not have official coding from the catalogue of measures. Proposed regulation would comprise of several Forest measures e.g. F09 (sediment capture ponds) and potentially some others not defined in the catalogue of measures.

In uper part of the catchment with narrow waleys, eroded/deposited material can have a significant negative impact on flooding conditions due to narrowing/blocking flow corridors and streams etc, but at the lowlands the negative impact can fade drastically, especially at locations where flooded areas are significant in comparison to river stream sizes.

Currently we do not operate with measured/modelled data regarding bedload transport or erosion on the Kamniška Bistrica catchment, only usable data are rare field observations and reports from concessionaire responsible for river maintenance.

Appropriate erosion measures for Kamniška Bistrica watershed cover plethora of options:
- measures intended to prevent localized erosion (stream stabilization, river geometry alteration by reducing slope and bank inclination, planting plants with higher shear stress resistance)
- measures intended to trap and collect sediment (suspended and bed load sediment) e.g debris trap dams
- measures intended to remove deposited sediment, e.g. machine excavation

According to available field data, erosion and bedload sediment is only a localized problem, as concessionaires report localized erosion (both in river and on the surrounding terrain) and deposit centers (lowland parts of the watershed). Thus, we estimate, that these processes do not affect water retention possibility on a basin scale, and possible negative effects are only local. Sediment excavation on the whole watershed is estimated to less than $20x10^3$ m^3 on a yearly basis.

<u>Hydraulic modelling of the erosion processes is beyond the scope of the project, hence the effects of erosion control measures are only estimated based on avaliable data.</u> Graphical results are not shown, as hydraulic calculations regarding erosion control measures have not been performed.

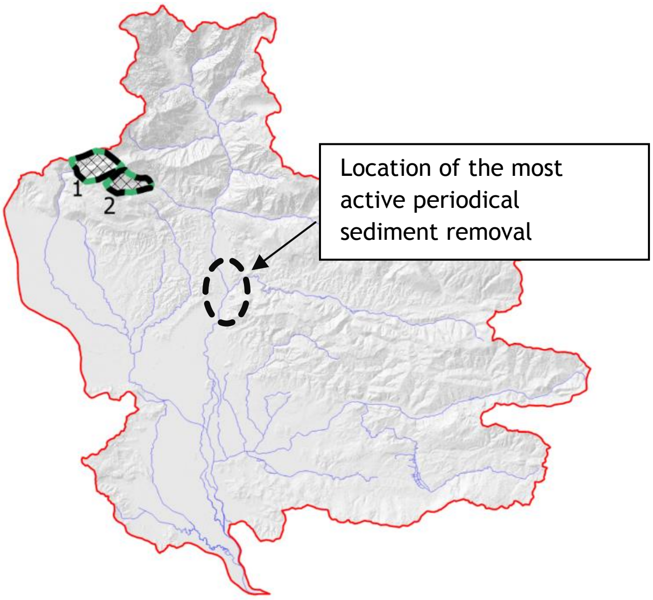


Figure 43: Erosion control measures locations numbering (marked in green-black dashed area)

Nr.	Stream catchment	Measure
1	Reka	Erosion control
2	Bistričica	Erosion control

Table 12: List of erosion control locations

4.4. NSWRM – flood diversion channels

Flood diversion channels are primarily used for carrying excess flood water, whether in surface or underground channels, as a way to improve flood safety on target areas. We have chosen 15 locations appropriate to apply them to. This measure is specific for Slovenian watershed and does not have official coding from the catalogue of measures.

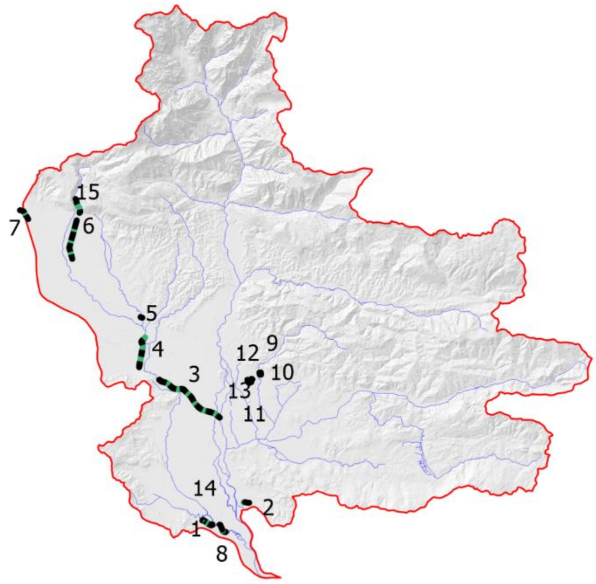


Figure 44: Flood diversion channels locations numbering (marked in green-black dashed lines)

Flood diversion channels per se are not water retention measures, although they can contribute in terms of water retention, but are many times needed to enhance performance of other measures that do have retention effects. Within the scope of the project, flood diversion channels should be treated as a support measures for other NSWRM – specifically dam retentions and protected natural flood retention areas, hence were not calculated separately. Flood diversion channels are shown on the previous Figure.

Nr.	Stream	Description	Length (km)	Estimated retention volume at Q100 6,15 and 24hours (mil m^3)
1	Psata	surface bypass	1.4	0.05
2	Zabnica	surface bypass	0.7	0.003
3	Psata	surface bypass	8.5	0.13
4	Psata	surface bypass	3.7	0.04
5	Psata	surface bypass	0.3	0.0003
6	Reka	surface bypass	4.6	0.03
7	/	surface bypass	1.5	0.004
8	Psata	surface bypass	0.4	0.004
9	Rovski potok	underground bypass	0.1	0.0001
10	Rovski potok	underground bypass	0.1	0.0001
11	/	underground bypass	0.2	0.0002
12	/	underground bypass	0.2	0.0002
13	/	underground bypass	0.2	0.0002
14	Psata	underground bypass	0.4	0.0003
15	Reka	surface bypass	0.9	0.01
Estimated cumulative retention volume (mil m^3)				**0.28**
Estimated cumulative retention volume, 6/15/24h (%)				**1/<1/<1**

Table 13: List of flood diversion channels locations

4.5. NSWRM - protected flood (natural) retention area (Hydro morphology – N03)

Natural retention areas cause flood water retention hence can have positive impact on flood safety and floodwave propagation. Therefore in general, they should not be urbanized, nor should their available volume be decreased in any other way. Four (4) identified locations are shown in the next Figure. Proposed measure falls under Hydro-morphology measures N03 (Floodplain restoration and management) in the catalogue of measures.

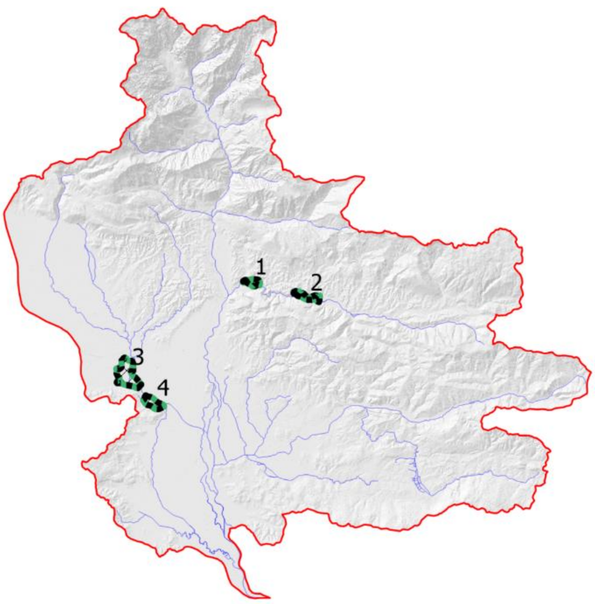


Figure 45: Natural flood retentions locations numbering (marked in green-black dashed areas)

Nr.	River/stream	Retention volume at Q100 (mil. m^3)		
		6hr	15hr	24hr
1	Nevljica	0.1	0.1	0.2
2	Nevljica	0.3	0.3	0.3
3	Pšata	0.6	0.7	0.7
4	Pšata	0.03	0.03	0.04
Total retained volume (mil. m^3)		**1**	**1.1**	**1.2**
Retained effective precipitation volume (%)		**5**	**3**	**3**

Table 14: List of natural flood retentions locations and accompanying retention volumes

Accumulated volume (Q100, 24-hour precipitation) in all identified natural flood retentions is approximately 1.2 mil m^3, which represents roughly 3% of the accumulated effective precipitation on the whole Kamniška Bistrica catchment for the 24-hour event with 100 years return period.

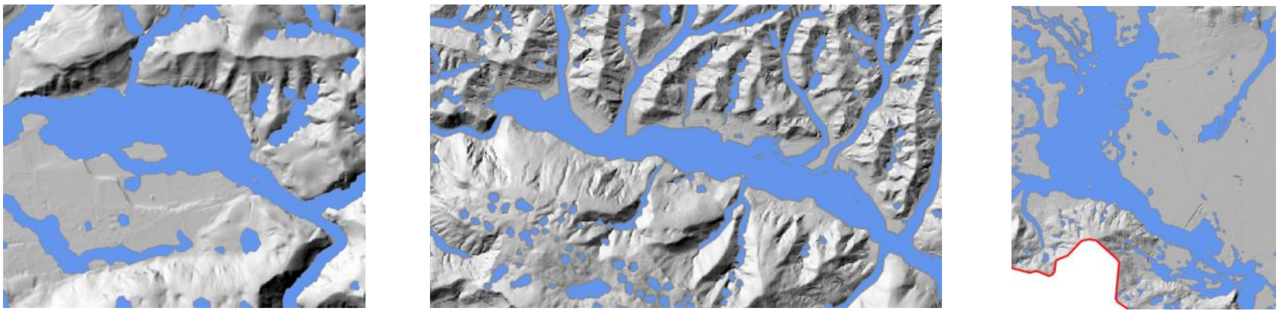


Figure 46: Graphical presentation of natural flood retention areas. Nr.1 (left), Nr. 2 (middle), Nr.3 an Nr.4 (right). Pictures do not have the same scale.

Areas have been identified based on topographical properties, built civil infrastructure and nearby urbanization. Based on quantified retention volumes it is suggested, that these natural flood retentions remain active and are taken in consideration in the future spatial planning process. We strongly advise them not to be urbanized, nor their available volume to be decreased in any other way.

4.6. NSWRM – small water retention measures (Hydro morphology – N01)

Identified/proposed small water retention measures are meant in a way of renaturation of existing or abandoned ponds, wetlands, etc… That measures cause greater flood water retention hence can have positive impact on flood safety and floodwave propagation. Therefore, they should not be urbanized, nor should their available volume be decreased in any other way. Seven identified locations are shown on the next Figure. Proposed measure falls under Hydro-morphology measures N01 (Basins and Ponds) in the catalogue of measures.

Due to a rather small size of these measures, the available volume is only up to 0.4 million m^3 which is roughly 2% compared to total effective precipitation volume for the 6-hour event with 100 years return period. Possibility of enhancing the available volume without aggressive and extensive construction works is limited, nevertheless this should be further investigated.

These measures are already included in all calculations as they already exist in the nature, and just need renaturation. Based on quantified retention volumes it is suggested, that these natural flood retentions remain active and are taken in consideration in the future spatial planning process. We strongly advise their available volume not to be decreased in any way.

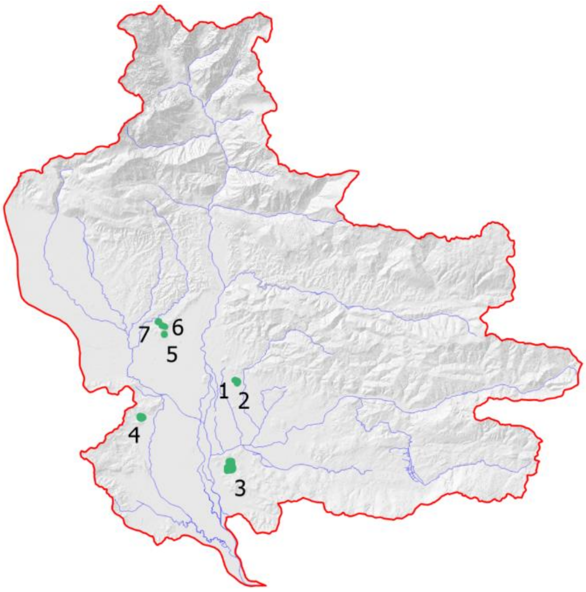


Figure 47: Small water retention measures numbering

Nr.	Measure	Area (km2)	Estimated max. retention volume 6,15,24hours (Up to mil m^3)
1	Existing pond/reservoir	0.002	0.00
2	Existing pond/reservoir	0.013	0.03
3	Existing pond/reservoir	0.122	0.24
4	Existing pond/reservoir	0.030	0.06
5	Pond restoration	0.004	0.01
6	Pond restoration	0.006	0.01
7	Pond restoration	0.005	0.01
Total retained volume (mil. m3)			**Up to 0.4**
Retained effective precipitation volume, 6/15/24h (%)			**2/1/<1**

Table 15: List of small water retention measures locations and accompanying retention volumes

4.7. NSWRM – earth fill removal

Removing excessive amount of earth fill in theory increases available flood retention. In the past, local earth embankments have been done in this identified area, and some of those location lie on potentially flooded areas.

Upon closer inspection it has proven, that the identified location shown on the next Figure is located near the catchment border on the outer side. As such it does not have a direct impact on water retention on the catchment itself, and has therefore not been thoroughly analyzed.

This measure is specific for Slovenian watershed and does not have official coding from the catalogue of measures.

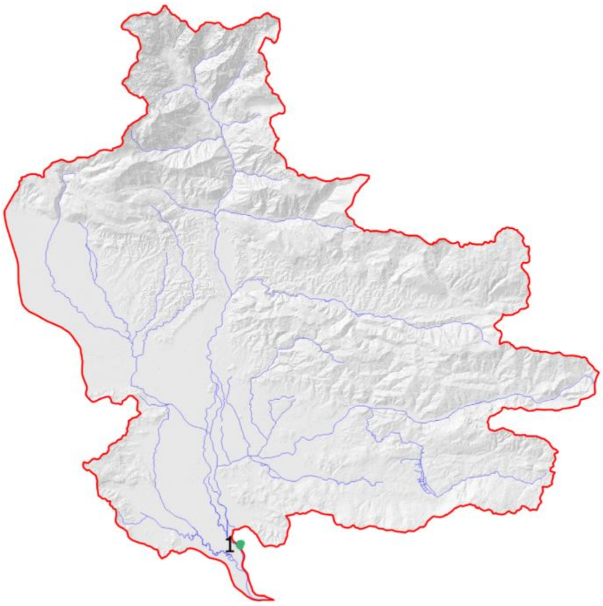


Figure 48: Earth fill removal location numbering

4.8. NSWRM – complex measures

All proposed complex measures are located at the downstream end of the catchment. Measures include levees and road heightening - these two measures could lead to increased water retention, and culverts which do not have significant impact on water retention. All of these measures are primarily meant to increase infrastructure flood safety. These measures are specific for Slovenian watershed and do not have official coding from the catalogue of measures.

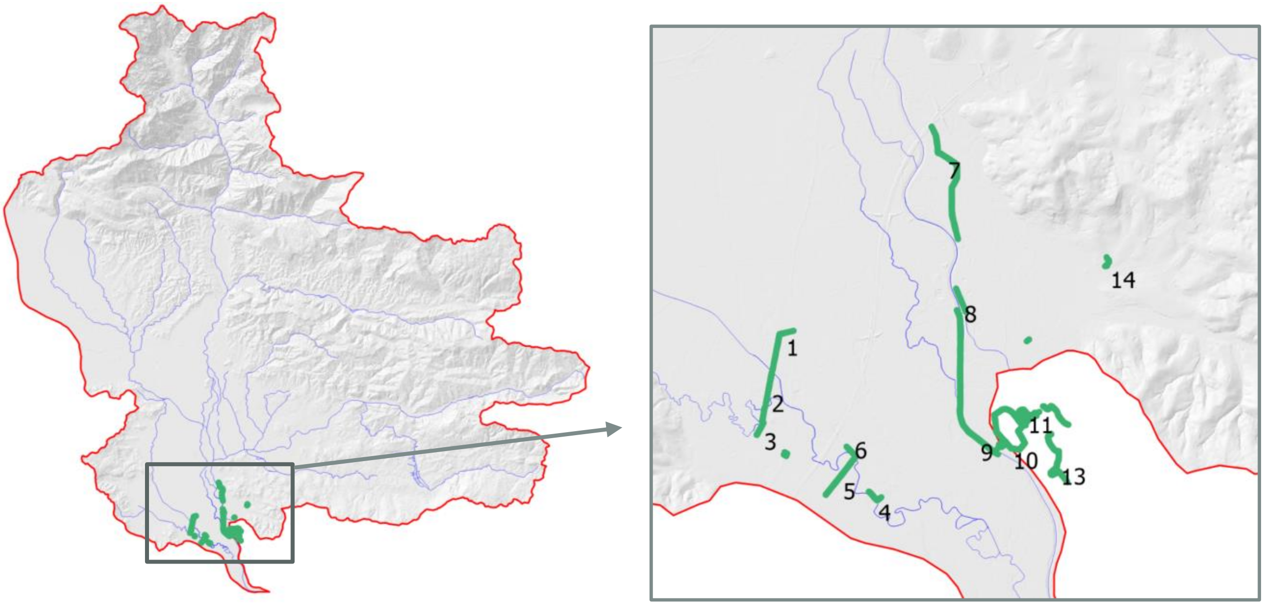


Figure 49: Complex measures numbering. Due to a large number of measures only the biggest in size are numbered

Nr.	Measure	Stream
1	levee	Psata
2	levee	Psata
3	bypass	Psata
4	levee	Psata
5	levee	Psata
6	levee	Psata
7	levee	Kamniska Bistrica
8	levee	Kamniska Bistrica
9	levee	Kamniska Bistrica
10	levee	Kamniska Bistrica
11	levee	Kamniska Bistrica
12	levee	Kamniska Bistrica
13	levee	Kamniska Bistrica
14	levee	Zabnica
15	culvert	Psata
16	culvert	Psata
17	culvert	Kamniska Bistrica
18	culvert	Kamniska Bistrica
19	culvert	Kamniska Bistrica
20	culvert	Kamniska Bistrica
21	culvert	Kamniska Bistrica
22	culvert	Zabnica
23	road heightening	Kamniska Bistrica
24	road heightening	Kamniska Bistrica

Table 16: List of complex measures locations

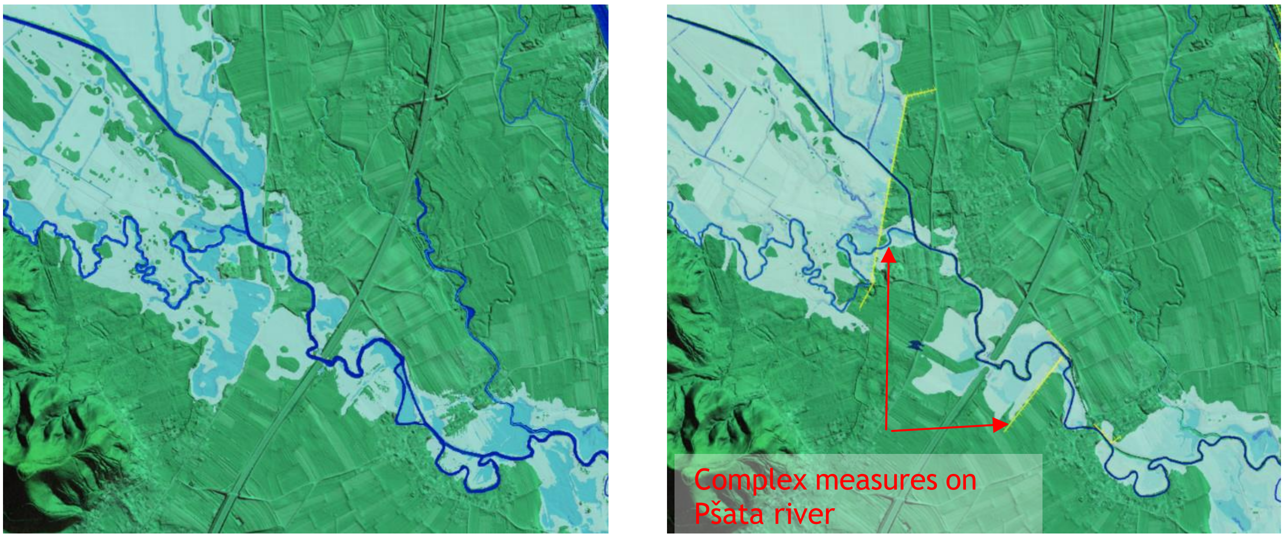


Figure 50: Example - comparison between existing flooding (left photo) and flooding after applying measures (complex measures nr.1,2,3,4,5 and 6, right photo) on Pšata river.

We performed hydraulic analysis and compared existing and proposed conditions where complex measures have been considered. Result show, that effects of complex measures are only local which is logical and in accordance with their intention. Some of the measures have inundation effect and locally redirect overland flow which prevents some previously flooded areas to be flooded again but in some other parts flooded areas and depths become greater as in existing condition. Overall, total area of floods in the catchment after implementing these measures does not noticeably differ from existing condition.

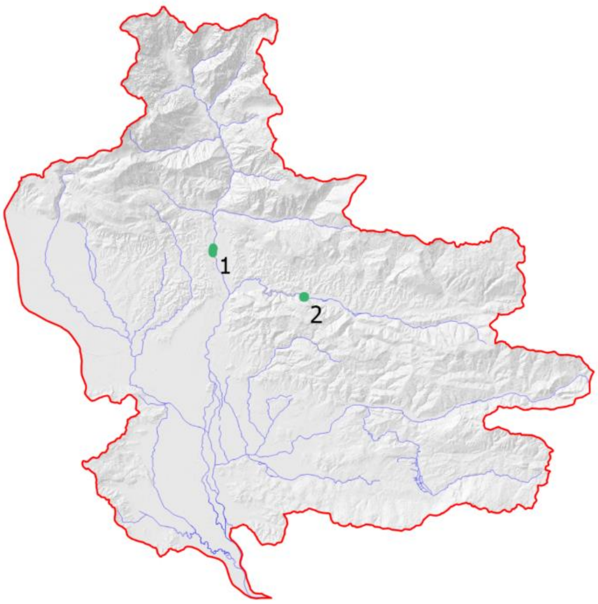
As all proposed complex measures are located at the downstream end of the catchment and are fairly small in size, their impact on watershed scale is not significant.

Event Q100	Flooded area-existing (km2)	Flooded area-after measures (km2)	Difference regarding existing area (km2)	Difference regarding existing area (%)
6hr	101.6	101.6	<0.02	~0
15hr	104.4	104.4	<0.01	~0
24hr	99.3	99.3	<0.01	~0

Table 17: Calculated flooded area on the whole catchment for existing stage and stage after implemented NSWRM measures (complex measures). River streams are included in the flooded area.

4.9. NSWRM – other measures

Other measures include periodically bed load removal performed by concessionaire and facility purchase which is located on area prone to sever flooding. Preliminary estimation was, that none of these measures has any measurable/significant impact on water retention at a watershed scale. These measures are specific for Slovenian watershed and do not have official coding from the catalogue of measures.



Nr.	Measure	Stream
1	Periodical bed load removal by concessionaire	Kamniška Bistrica
2	Facility purchase	Nevljica

Table 18: List of other measures locations

According to available field data, erosion and bedload sediment is only a localized problem, as concessionaires report localized erosion (both in river and on the surrounding terrain) and deposit centers (lowland parts of the watershed). Thus, we estimate, that these processes do not affect water retention possibility on a basin scale, and possible negative effects are only local. Sediment excavation on the whole watershed is estimated to less than $20x10^3$ m^3 on a yearly basis.

<u>Hydraulic modelling of the erosion processes is beyond the scope of the project, hence the effects of erosion control measures are only estimated based on avaliable data.</u> Graphical results are not shown, as hydraulic calculations regarding erosion control measures have not been performed.

Facility purchase is meant as a supporting measure for natural flood retention areas, as it is located on a frequently flooded Nevljica area. This is the only facility in this flooded area, and as such does not have any measurable impact on retention capability of the whole catchment (available volume approximately 150 m^3). We suggest to undergo a feasibility study for facility purchase and replacement.

4.10. NSWRM – all measures combined

The results of analysis regarding all measures combined in one HH model (only the ones that can be modelled, which are explicitly mentioned in previous chapters) are basically the same as results of analysis covering only dams. The biggest impact of effects in comparison to existing condition is seen right next to measures themselves (downstream section) in the way of reducing peak hydrographs flows. Further on downstream, impact weakens and is hardly evident at the downstream boundary condition of the whole catchment.

The prevailing impact on flood conditions is by implementing dams for their water retention capability, effects of other analyzed measures are negligible.

Graphics shown under the point *4.1 – NSWRM Dam retentions* are relevant also regarding analysis of all combined measures, so we do not show those graphics again.

5. Conclusion of model based NSWRM cumulative effects assesment

NSWRM which were proposed at the initial stage have been analyzed and quantified. Based on the hydraulic calculations we can conclude that the biggest impact on the hydraulic conditions in the way of increasing water retention have dam retentions (measure Nr. 1) theoretically followed by natural reserved flooding areas and small water measures (in case of their potential elimination).

Of the three only dam retentions are the ones that add/increase actual water retention as they are currently not existent, other two already exist and is therefore very important to maintain them and prevent any extensive land use on those areas.

By implementing proposed dam retentions, peak flows could be significantly lowered at downstream locations close to the dams themselves, but going further downstream the impact weakens and becomes hardly evident at the very downstream end of the catchment.

Only by using exact inputs (precipitation, land usage, etc.) for analysis, the results of hydrological - hydraulic analysis can be relevant.

It is also important to emphasize, that not all NSWRM's from the catalogue of measures are appropriate for implementation on Kamniška Bistrica catchment, whether it be for topological conditions, existing land usage and farming or other circumstances.

It has shown, that not all proposed measures are appropriate for quantifying analysis with dynamic models, whether their impact is too small to be able to measure or our modeling tools can not sufficiently model their impact from a technical view. In our case effects of Nr.1 – Dam retentions, Nr.5 – Protected flood (natural) retention areas, Nr. 6 - Small water retention measures, Nr. 8 -

Complex measures and combined effects off al of these measures have been analyzed with the HH model. Other measures naming Nr.2 – River regulation, Nr. 3 – Erosion control measures, Nr. 4 – Flood diversion channels, Nr. 7 – Earth fill removal and Nr. 9 – Other measures have not been analyzed using HH model but were estimated or evaluated using other techniques.

With dynamic models growing in size, it also becomes harder to analyze all the details that can contribute to an efficient analysis, hence it is crucial to still use smaller, detailed models to analyze detailed impacts on a smaller scale.

Flood safety is a big issue on the Kamniška Bistrica catchment, which cannot be resolved by only implementing NSWRM but will require a broader targeted approach with other available engineering solutions. Regarding modelled result from our study, we see NSWRM as complementary measures whose impact (in case of proper NSWRM type selection) can greatly contribute to flood safety only on targeted isolated areas (areas located immediately nearby the measures) but not on a bigger scale.

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