Hydraulic modelling of the Vipava river

Document details

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Premise

The VISFRIM project (Interreg V-A Italy-Slovenia Cooperation Program 2014-2020 (targeted call for strategic projects n. 05/2008) aims to achieve efficient management of hydraulic risk in cross-border basins, through the development of methods and technological tools for the implementation of existing Flood Risk Management Plans and their forthcoming update. The project involves governmental bodies and local authorities in developing joint measures and actions in the international Soča and Vipava river basins and in the interregional Lemene river basin. They share data and knowledge, jointly develop flood simulation models and identify mitigation measures to be implemented in the territory, previously evaluated in terms of costs and benefits trough specific IT procedures designed during the project.
In particular, in such a context, several hydraulic modelling activities were performed for the Vipava river in the context of the VISFRIM project and are described in the following.

1. 1D-2D VIPAVA HYDRAULIC MODEL

1.1. Topography and geometric data

Joint 1D-2D hydraulic model of Vipava river was developed in HEC-RAS 6.2 program in cooperation with project partner Autorità di bacino distrettuale delle Alpi orientali (AAWA). Model extends from Zalošče settlement (site of a water gauging station) in Slovenia to the confluence of the Vipava/Vipacco and Soča/Isonzo river in Italy. Modelling area was agreed during previous meetings within the VISFRIM project and represents a section of Vipava basin which is less affected by karst phenomena.

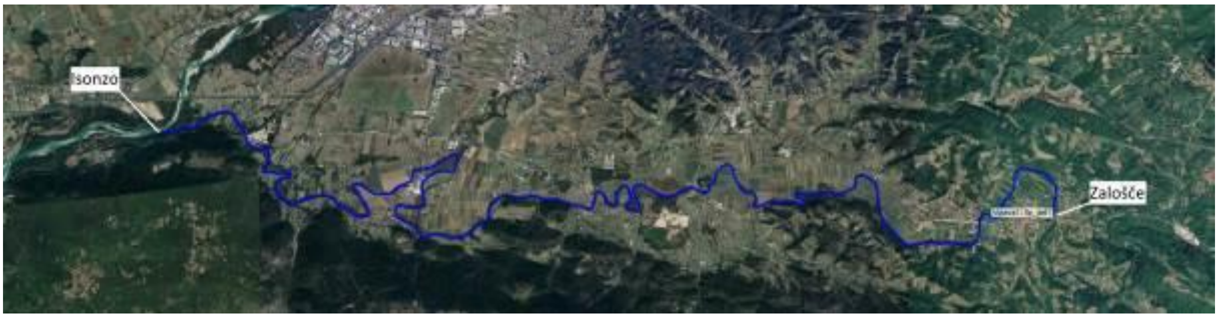


Figure 1: Extents of the Vipava river reach of joint 1D-2D hydraulic model in HEC-RAS

Topographical data was gathered from different sources. A first version of the model was developed by AAWA by including river cross sections from the SIMIS project on Slovenian side and new cross sections that were surveyed by Friuli Venezia Giulia region on Italian side thanks to VISFRIM funding. AAWA also incorporated cross sections from MIKE FLOOD project into the model, which were previously provided by the Slovenian Water Agency (DRSV). These cross sections are located on the entire river bend of Vipava at Miren. Hydraulic structures, such as weirs, were also implemented since they are necessary in order to make more reliable the model and solve simulation's instabilities.

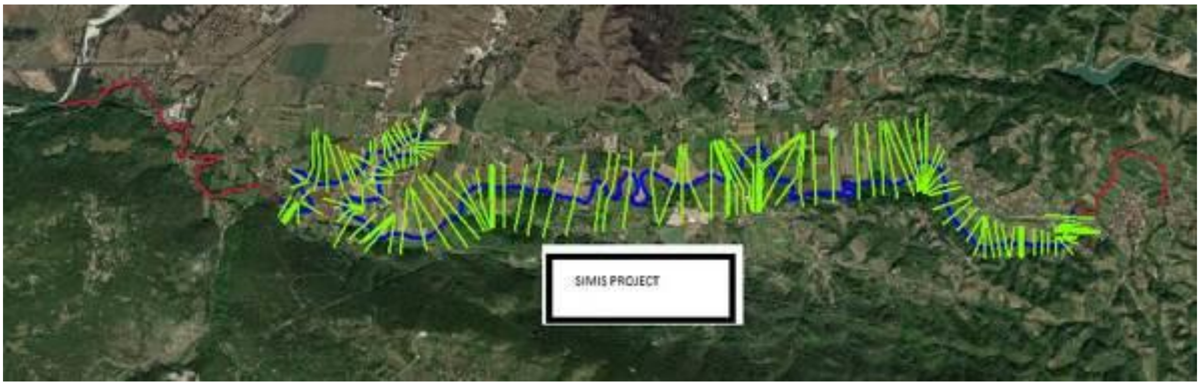
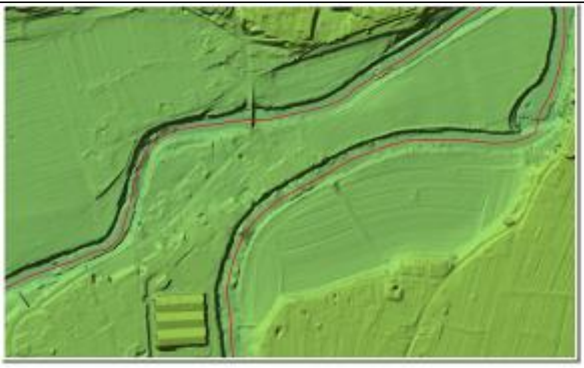
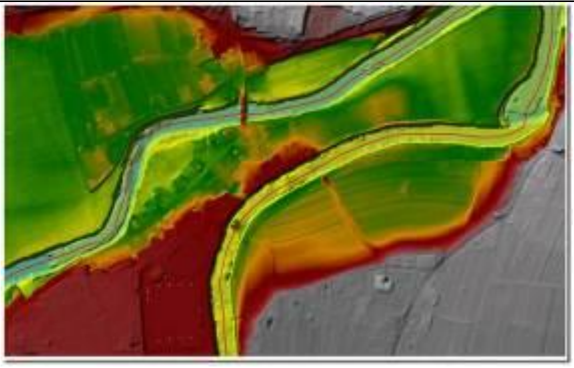


Figure 2: Cross sections used from the SIMIS project

Figure 3: Cross sections measured by FVG topographical survey on Italian side

Other data implemented in the model was also received from AAWA. Terrain was already included in the model: a LIDAR Digital Terrain Model with merged data from Slovenian (source: ARSO, year: 2014) and Italian side (source: Friuli Venezia Giulia region – year: 2020) on the basis of HARMODATA guideline. Some corrections were also performed on the Slovene Lidar DTM, where buildings are still present.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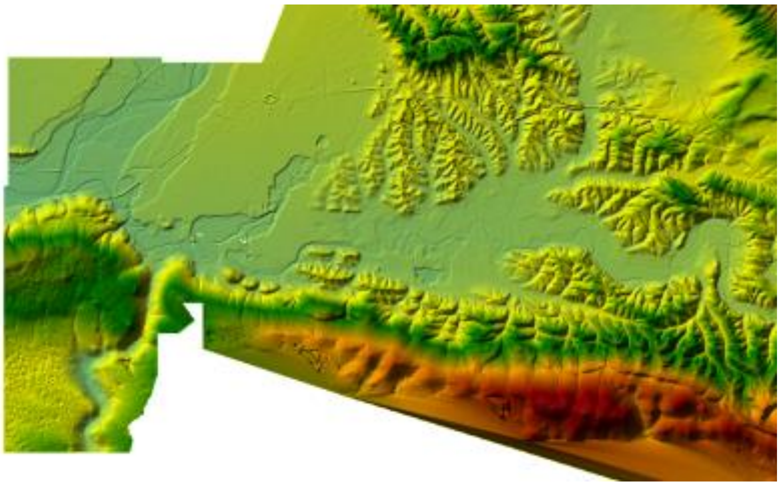

Figure 4: Merged LIDAR Digital Terrain Model (Slovenian + Italian data)

2D flow areas, representing flood plains, were studied with 20m x 20m grid resolution (5m next to defined breaklines) and uniform Manning roughness coefficient (equal to 0.1 $m^{1/3}/s$). Lateral structures, representing connection between 1D river reach and 2D flood plains, were also defined.
DRSV later updated the model with additional cross sections and hydraulic structures. Particularly cross sections on entire river bend, where Vipava river flows around Dornberk settlement, were implemented. Data here was obtained from the contractor and municipality of Nova Gorica, which was also the investor in project survey several years ago. Data was processed in GIS tools (QGIS) and prepared and implemented into the model.

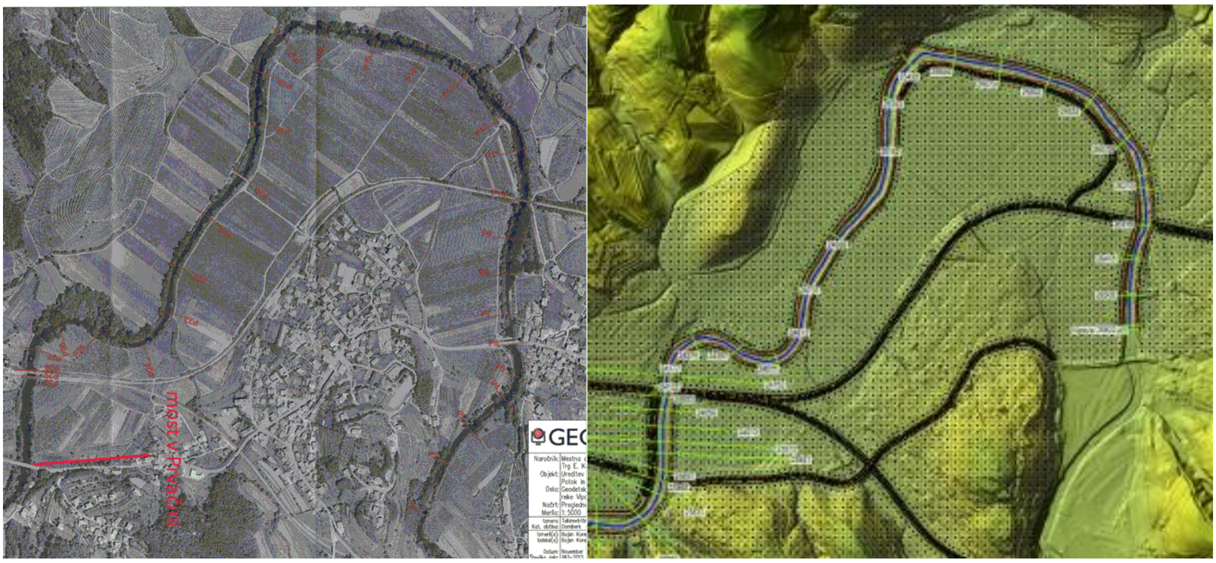

Figure 5: Implemented cross sections on Dornberk river bend

Several adjustments were made, such as updating the profile at Miren I water gauging (location of the water gauging station in Miren), for calibration purposes.

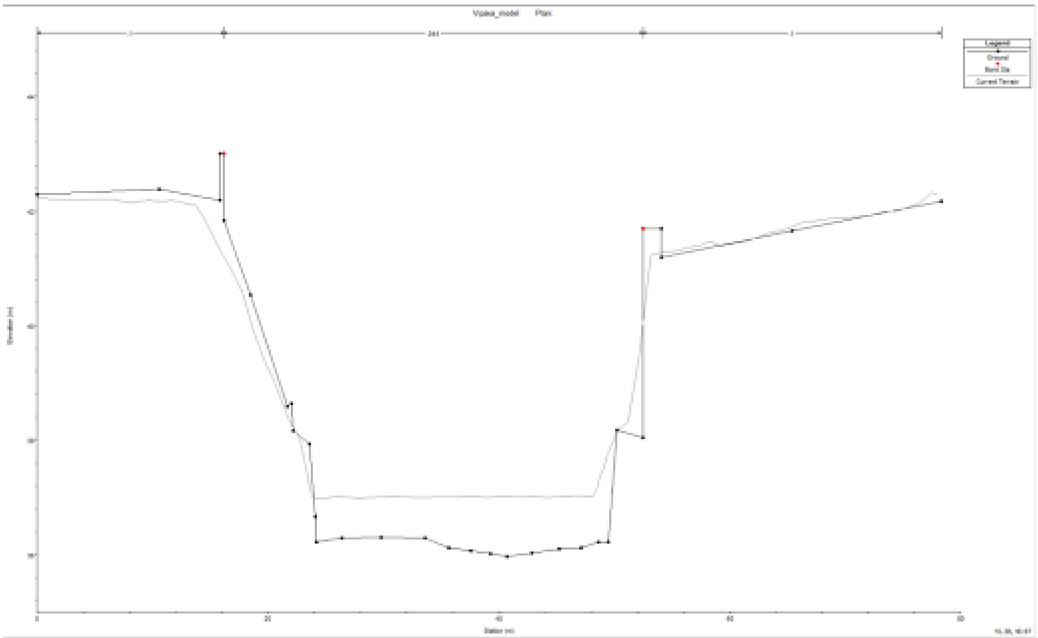
Figure 6: Updated profile at Miren I gauging station

DRSV also updated the model with the bridge in Miren for which data was retrieved from acquired AutoCAD files collected in the database of the VISFRIM project. After preparing the data, the bridge structure was implemented into the model. The same was done for the bridge in Prvačina.

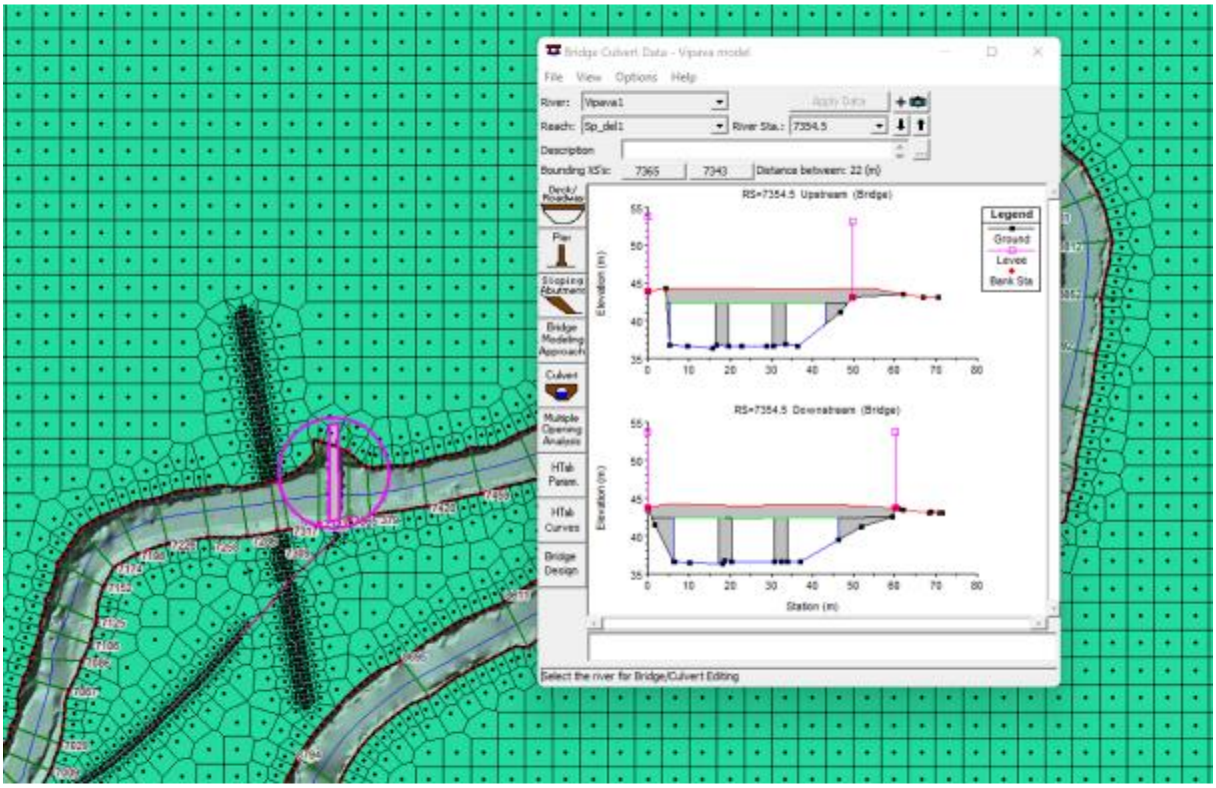

Figure 7: Implemented bridge in Miren

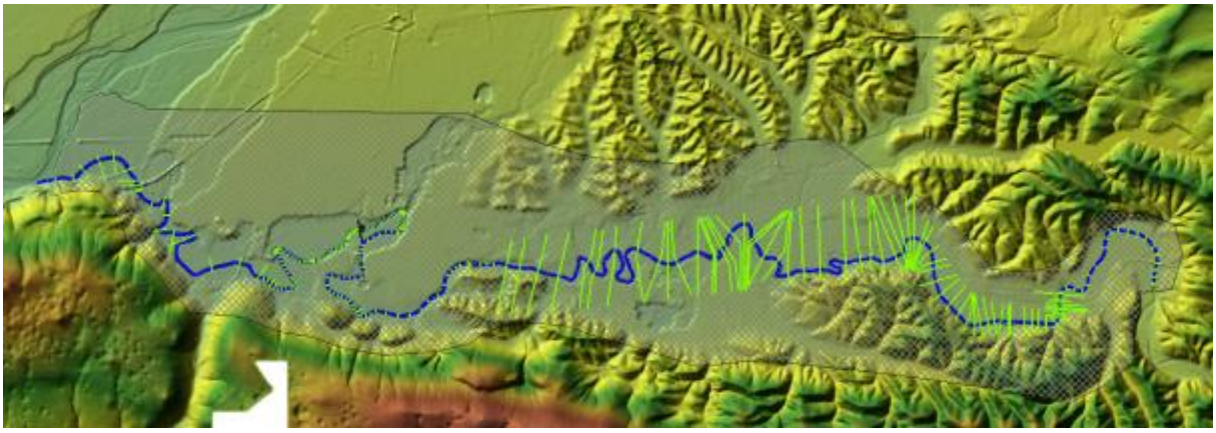

Figure 8: 1D-2D hydraulic model view with some of its key elements in RAS mapper

1.2. Hydrologic data

First simulations were performed by AAWA by taking as reference the flood event occurred in 2010, whose peak flow is comparable with the synthetic one calculated by DRSV for a flood scenario characterized by a return period of 100 years. Measurements during the event were not complete (due to known technical issues with equipment during such events), so therefore DRSV provided flood event hydrographs calculated by HEC-HMS simulations from the new elaborated hydrology (DRSV, 2020): in particular the inflow hydrograph of Vipava river at Zalošče (upstream boundary condition) and lateral inflow hydrographs representing discharge from tributaries of Vipava river. In turn AAWA provided downstream boundary condition: water levels of Soča river recorded at Savogna d'Isonzo gauging station during the event.

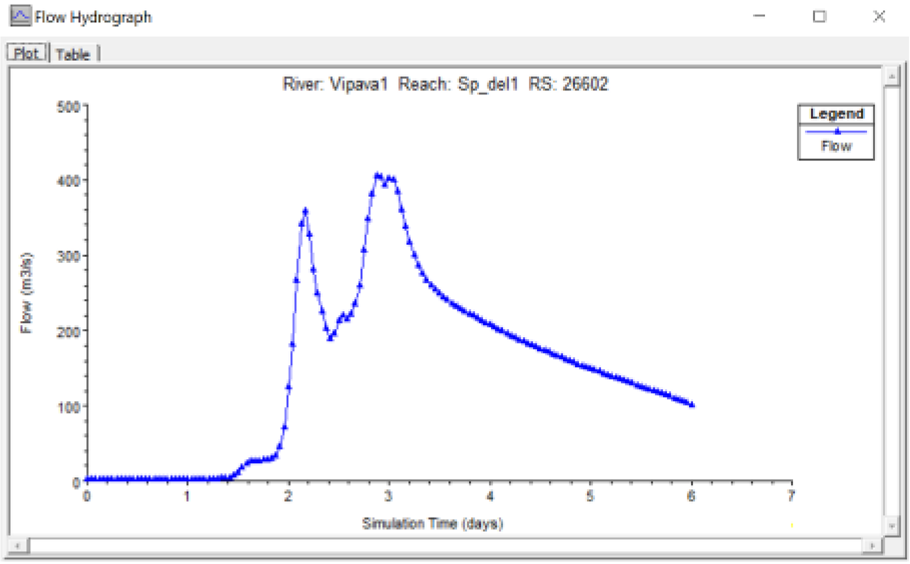

Figure 9: Hydrograph of Vipava river in Zalošče during the 2010 flood event

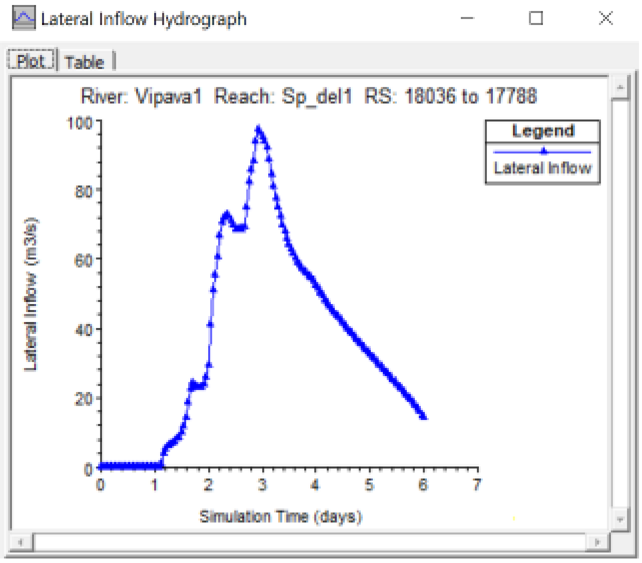

Figure 10: Lateral inflow hydrograph of Lijak (main tributary within the Vipava hydraulic model) during the 2010 flood event

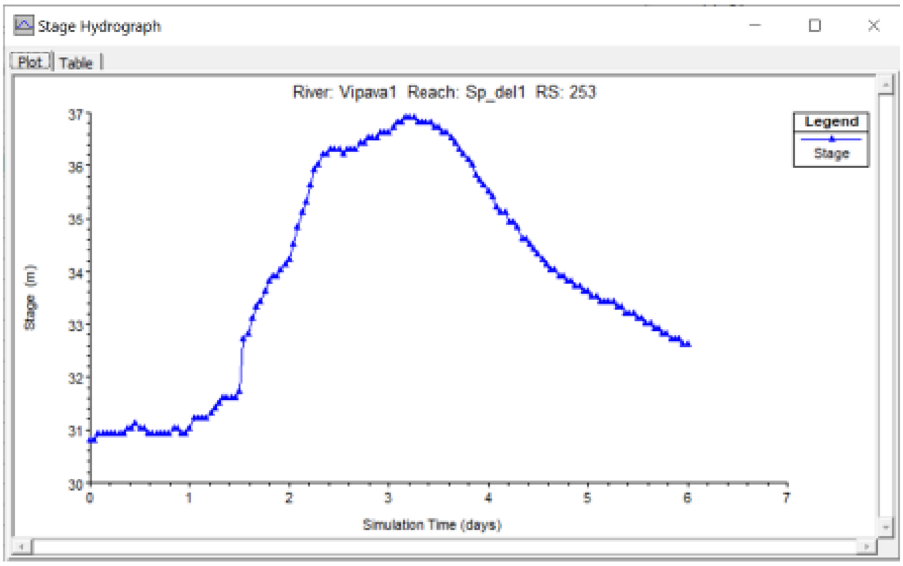

Figure 11: Stage hydrograph at Savogna d'Isonzo during 2010 flood event

1.3. 1st Calibration

First calibration was performed by AAWA, which was based on the recorded extents of flood areas during the 2010 event because of the abovementioned incomplete water level measurements. Peak discharge from a hydraulic simulation modelling resulted in around 550 m^3/s at Miren I station – in which case uniform lateral inflow hydrographs were used (i.e. distributed flows for interbasin contributions). Using inflow hydrograph as determined in hydrological study, peak discharge resulted in approximately 525 m^3/s.

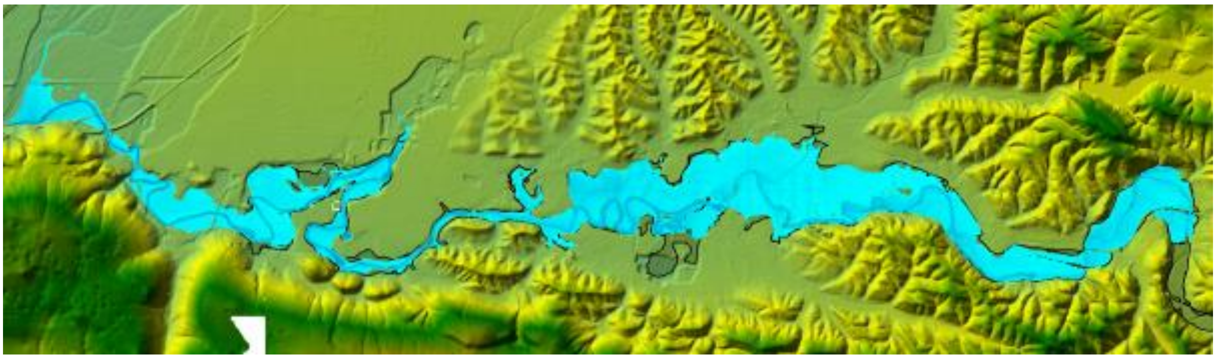

Figure 12: First calibration done by AAWA on the basis of the recorded extents of flood areas during the 2010 event

1.4. Simulation of Q_{100} scenarios

For simulation of synthetic scenarios, hydrological inputs from Slovenian study were used. For Vipava river inflow hydrograph from probability analysis was used, whereas for tributaries hydrographs from hydrological modelling. For tributaries hydrographs from rainfall durations of 12h and 24h were used. Downstream boundary condition was provided from AAWA (results of the Italian Soča hydraulic model simulation related to Q_{100} event) in a form of water levels at the confluence of the Isonzo and Vipava rivers.

Simulations were performed using combinations of 12h and 24h rainfall duration hydrographs from tributaries (in peak discharge coincidence with Vipava river statistical hydrograph) and downstream boundary condition set as constant (water level always set at peak of the modelling result from AAWA) and variable – in coincidence with highest water level of Vipava river at confluence with Soča.

Since the hydrological contributions of the main watercourse and its tributaries had been generated with completely different approaches (statistical approach: main river; rainfall-runoff model: tributaries), that do not allow to take into account reciprocal timing, simultaneity of the incoming peaks was hypothesized to be precautionary, although this combination could result into a more severe flood scenario.

Results were varying from 600 m^3/s to 750 m^3/s and more at Miren/border profile between Slovenia and Italy: this last outcome could be justified by the further inter-basin flow contribution downstream the Miren bridge and because simulations showed also water coming back from 2d areas to 1d domain.

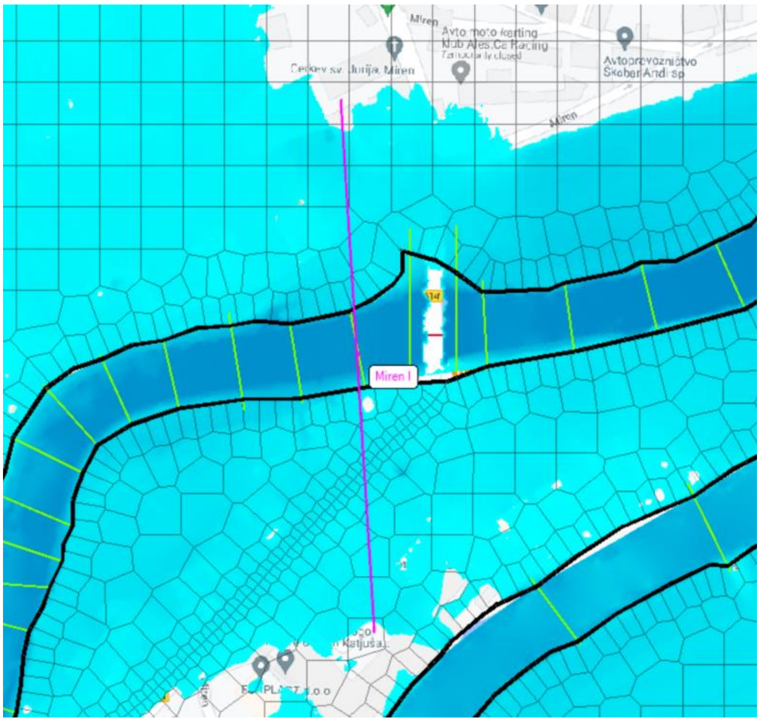

Figure 13: Location of simulation results near Miren (12h simulation)

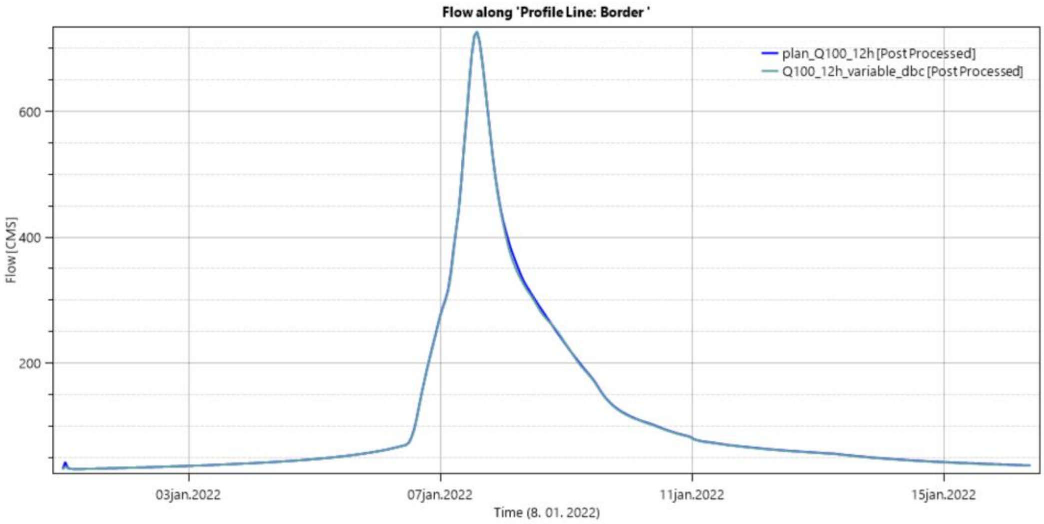

Figure 14: Hydrograph at the border profile showing results of the simulation with 12h rainfall duration input hydrographs

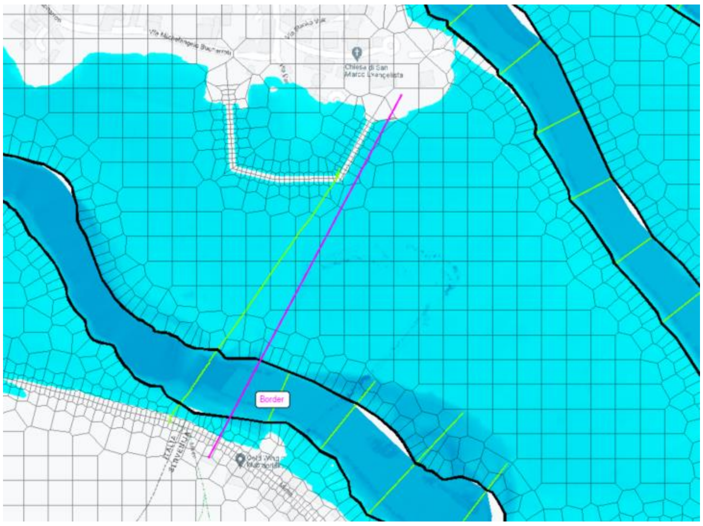

Figure 15: Location of simulation results next to state border (24h simulation)

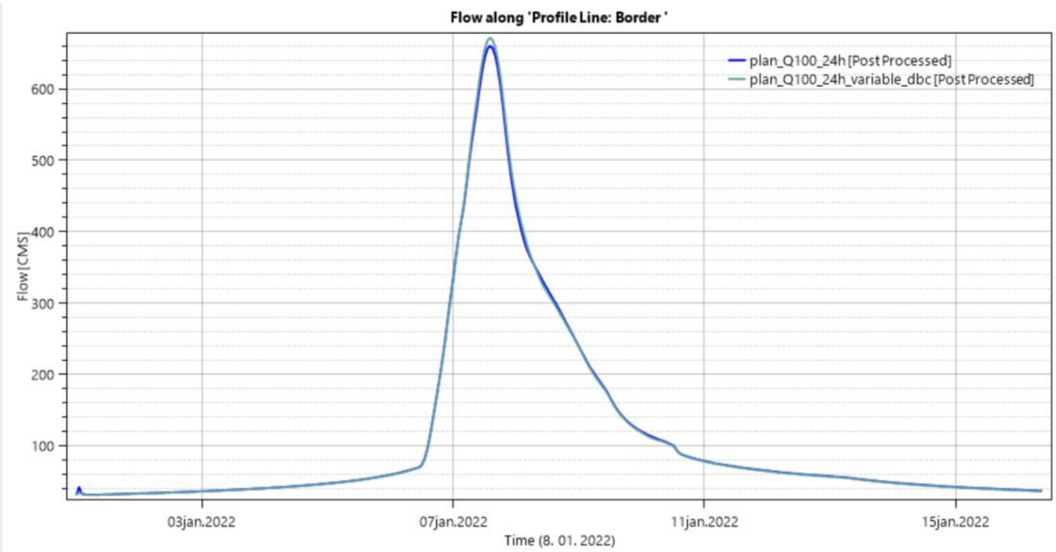

Figure 16: Hydrograph at the border profile showing results of the simulation with 24h rainfall duration input hydrographs

2. 1D VIPAVA HYDRAULIC MODEL

Due to the uncertainties simulating the Tr 100 scenario, in order to find a more reliable coincidence between statistical hydrograph from Vipava river and model tributaries hydrographs, DRSV decided to recalibrate roughness coefficients in the existing Vipava 1D-2D model on the basis of experience of local experts from the field. To achieve this goal, DRSV decided to construct a new 1D model.

2.1. Geometry

1D Vipava model was constructed using existing geodetic river cross section profiles from Vipava 1D-2D model. Profiles were extended to cover the entire floodplain areas, width of which was determined on tha basis of flood extension areas from the 2010 event (measured ones and exported from 1D-2D model simulation).

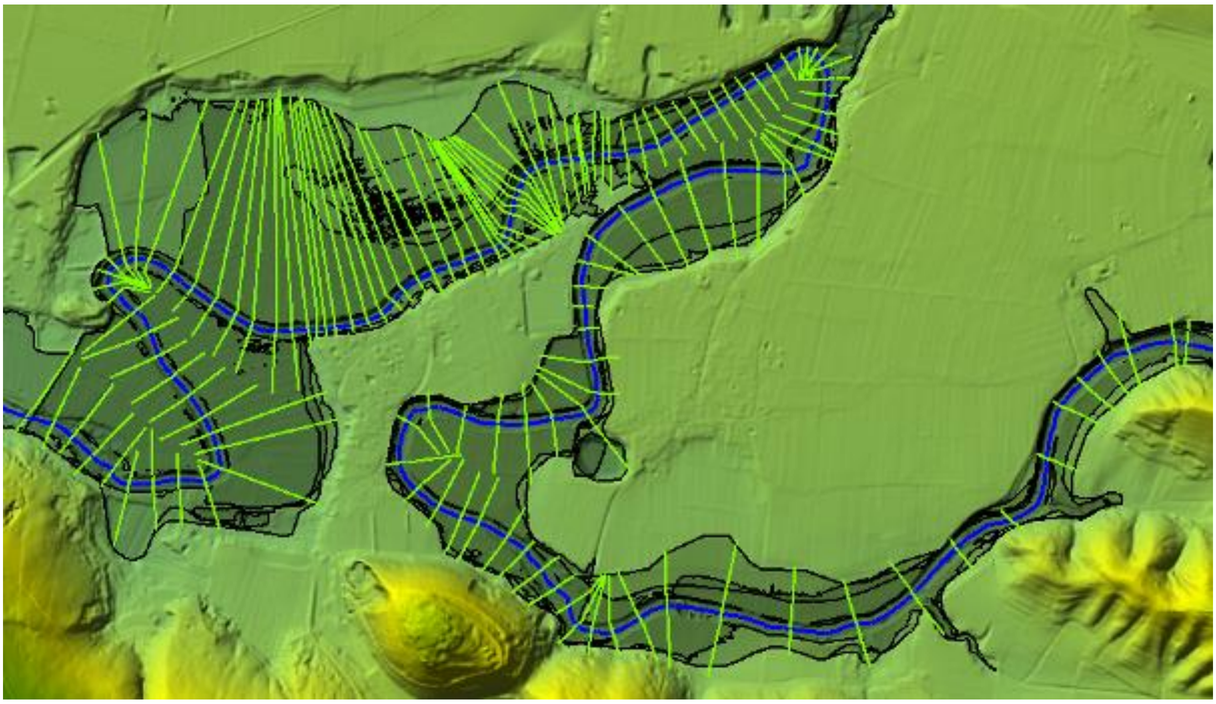

Figure 17: Extended profiles to flood area extension for 2010 flood event

New extended profiles were created based on combined topography of existing profiles and LIDAR data.

2.2. Calibration

Calibration was performed based on the observed discharge (steady flow) and water level marks registered during the 1995 flood event (Fig. 19). The event is dated with respect to the updated geometry of the watercourse assumed into the model (see paragraph 1.1), but it was chosen because of the availability of recorded water levels along the modelling section of Vipava river.

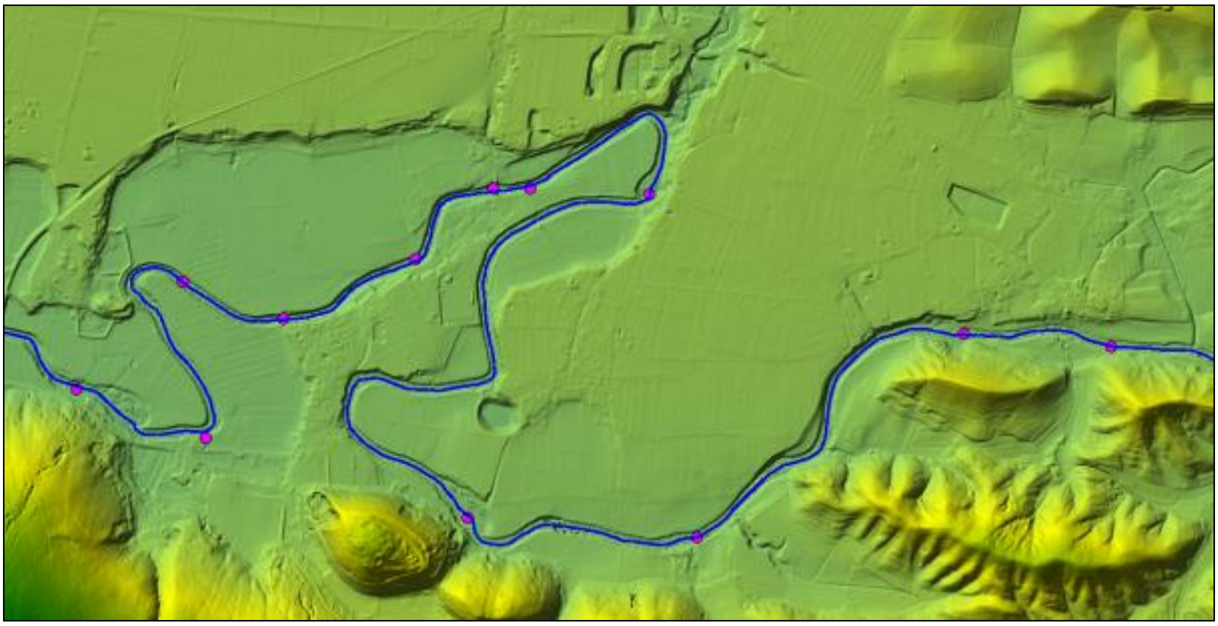

Figure 18: Locations of observed high water marks in 1995 flood event

The option of fixing the water levels according to the observed ones during the event was used for first calibration. Results were used in Manning's equation to calculate roughness coefficients in the profiles. Since roughness coefficients were locally overestimated (due to the backwater effect caused by weirs on Vipava, where weir equation is employed by the HEC-RAS software in place of Manning's equation), therefore they were accordingly reduced with iterations, to fit the measured high water level marks. For floodplains, uniform roughness coefficient was used at 0.1 $m^{1/3}/s$.

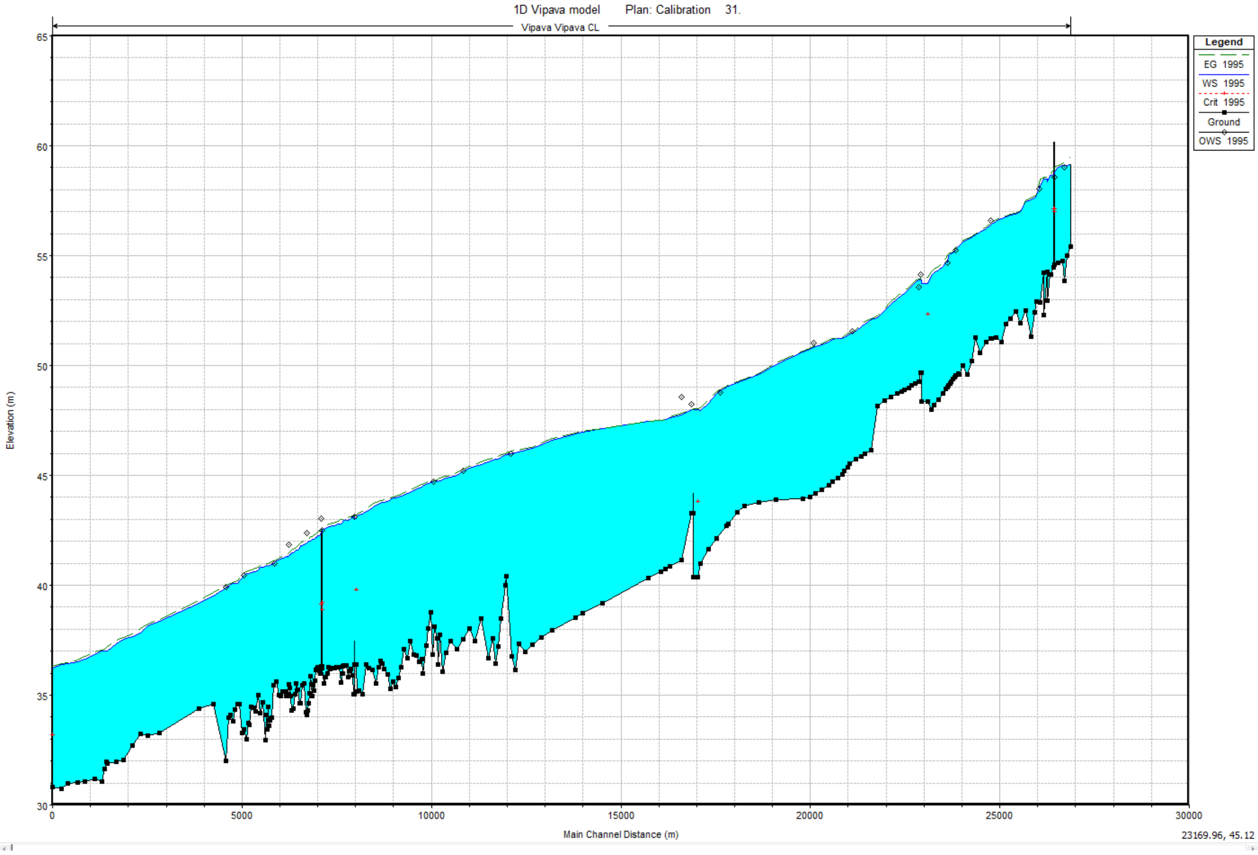

Figure 19: Profile plot of 1D model with calibrated roughness coefficients

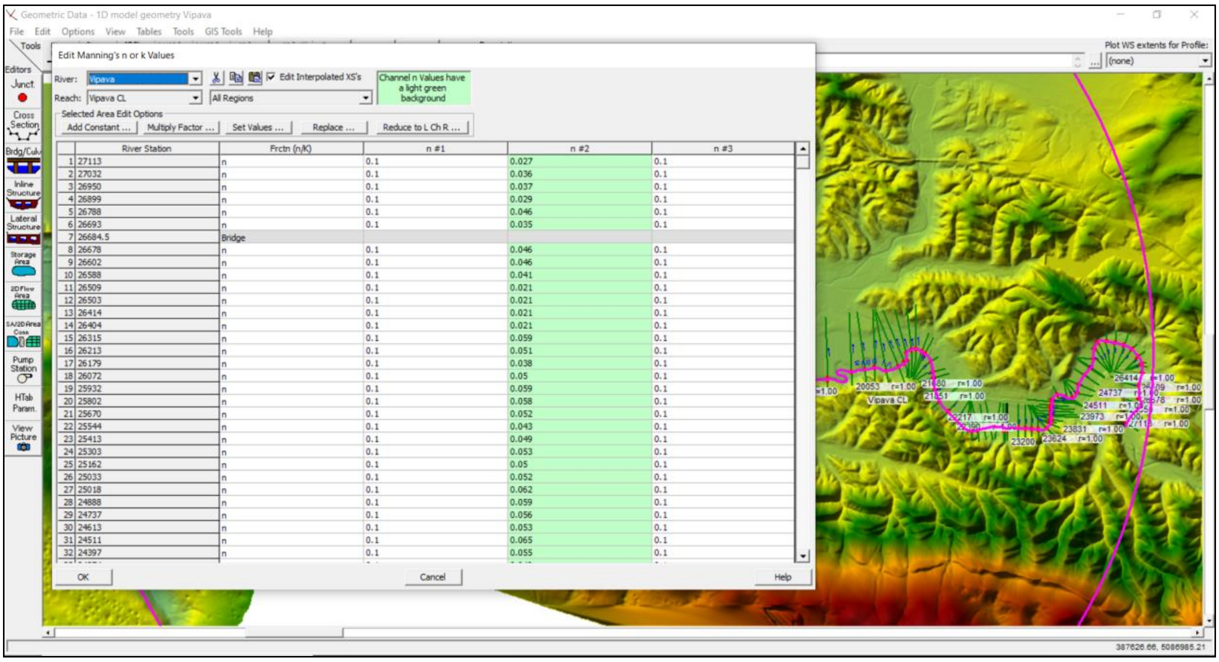

Figure 20: Synthesis about Manning values assumed for calibration purposes

2.3. Verification

For verification, stage and flow hydrographs from 2010 event were used in unsteady simulations trough the previously calibrated 1D flow model. The results are the following:

<u>Miren gauge station profile</u>
Q_{100}=505 m^3/s
W.S. elevation= 43.33 (observed in the event 43.25)

<u>Border profile between Slovenia and Italy:</u>
Q_{100}=494 m^3/s

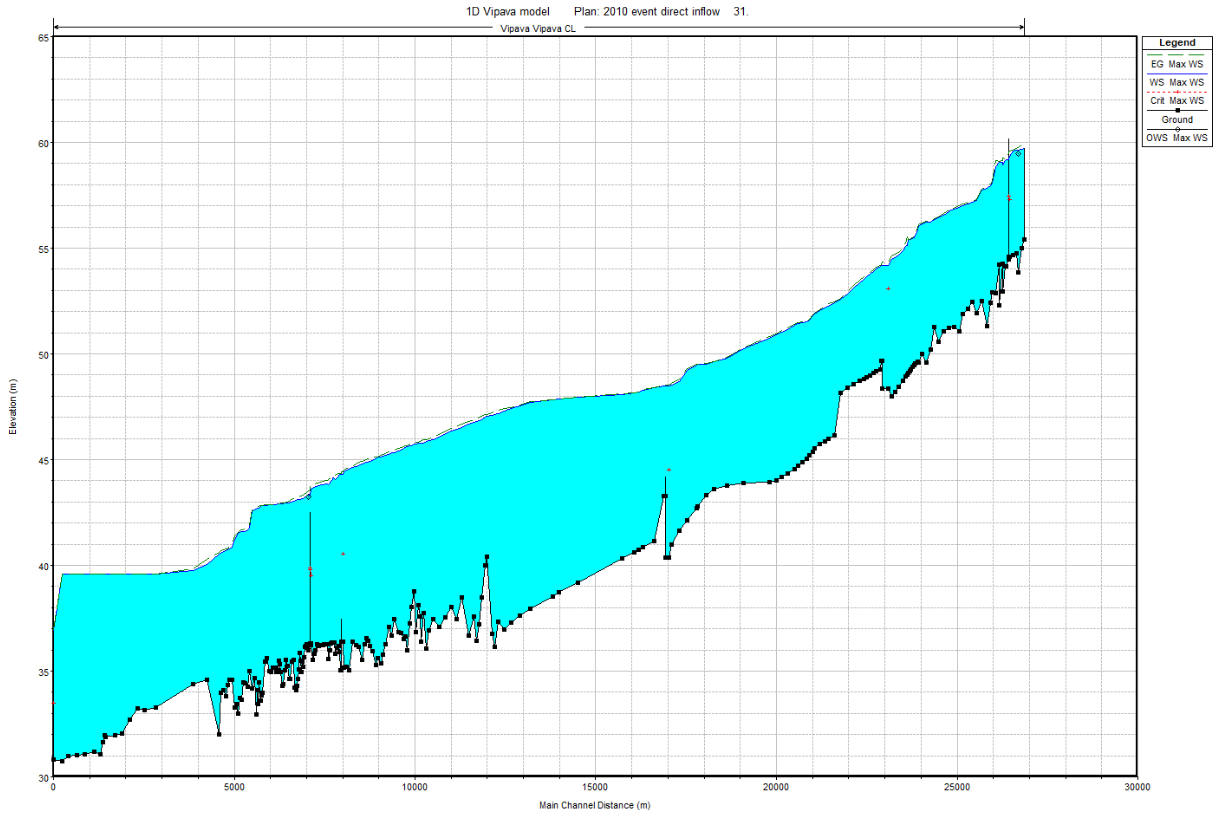

Figure 21: Profile plot with 2010 event simulation

As a result of this new calibration, the updated values obtained for the scenario with 100 years of return time are reported in the following.

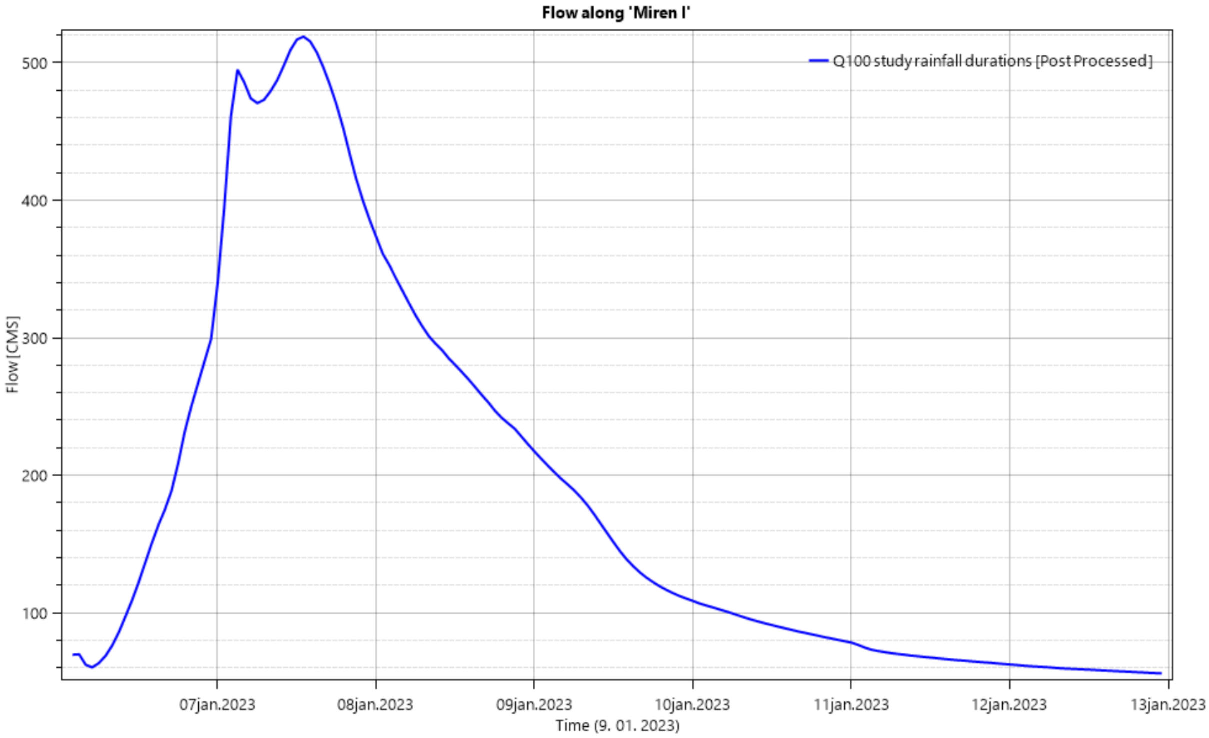

Figure 22: Results of Q100 scenario simulation with updated roughness values at gauging station Miren I

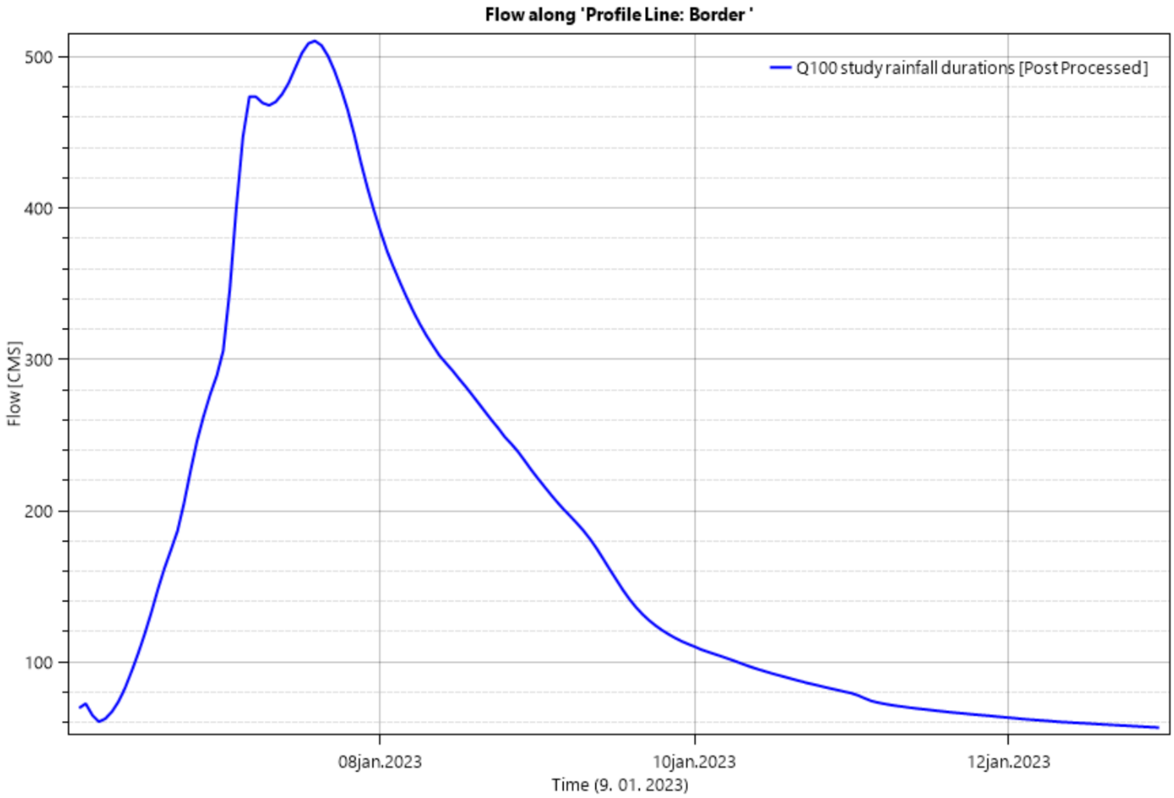

Figure 23: Results of Q100 scenario with updated roughness values at border profile

3. STRUCTURAL FLOOD PROTECTION MEASURES

Two structural flood protection measures, funded by the VISFRIM project, were later implemented inside the joint 1D-2D hydraulic model of Vipava: flood protection wall located in Grabec (Miren) and embankment in Prvačina. Both investments are located on the Vipava watercourse, in detail inside the agreed modelling area.

Figure 24: Flood mitigation measures analysed in the modelling area

Coordinates from the situation plan of investments were used to situate the location of the measures into the domain of the model. Structural measures are located inside the 2D flow areas acting as floodplains, so therefore SA/2D connection option was used to make the hydraulic structures inside 2D flow area. Since structural measures are located in the nearest proximity of the existing lateral structure, acting as a connection between 1D river reach and 2D flow areas, 2D flow area boundary had to be slightly adjusted to allow the simulation to run in the HEC-RAS program.

Dimensions and elevations of the investments were implemented into 1D-2D model. They were implemented as a lateral structure with appropriately adjusted heights as a weir/embankment structure type.

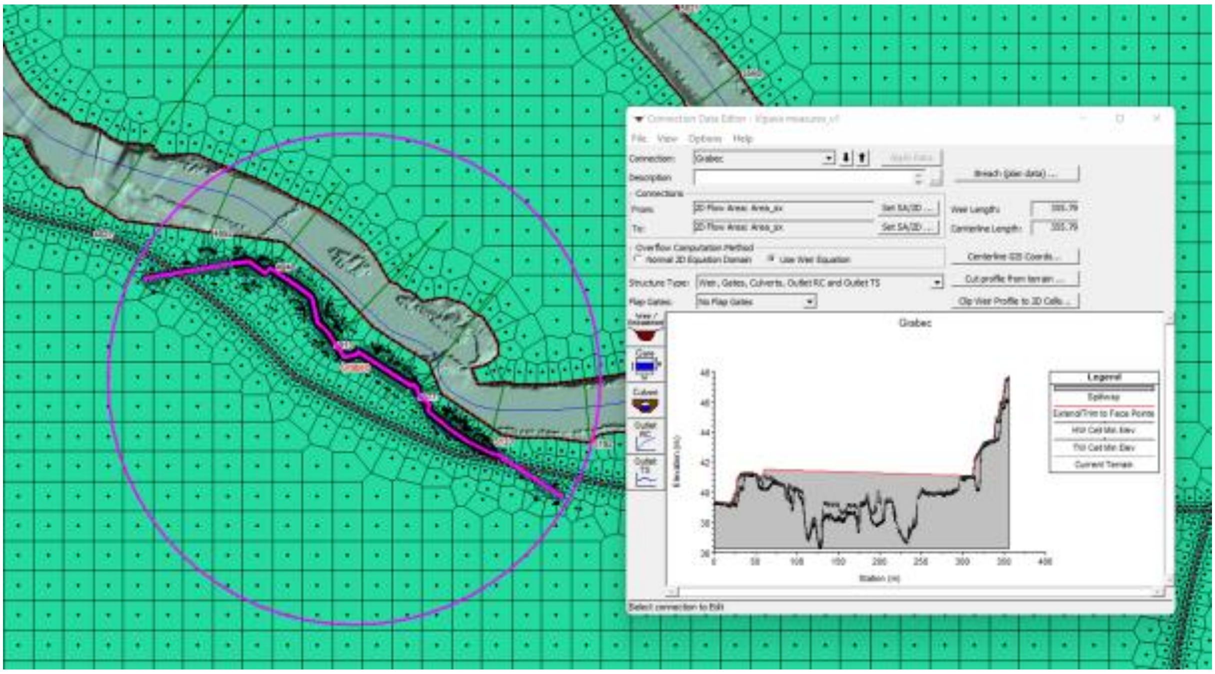

Figure 25: Implemented flood wall in Grabec-Miren into the 1D-2D HEC-RAS model of Vipava

Figure 26: Implemented embankment in Prvačina into the 1D-2D HEC-RAS model

Simulations of scenarios with 100 year return periods are presented in the following pictures. Boundary conditions for TR 100 scenario were the following:

- Upstream: statistical flow hydrograph of Vipava at Zalošče (Dornberk) – middle wave
- Internal: lateral inflow hydrographs from hydrological model with 3h rainfall duration, except Lijak with 12h duration; downstream: Isonzo water level set at constant 37.24 m.a.s.l.

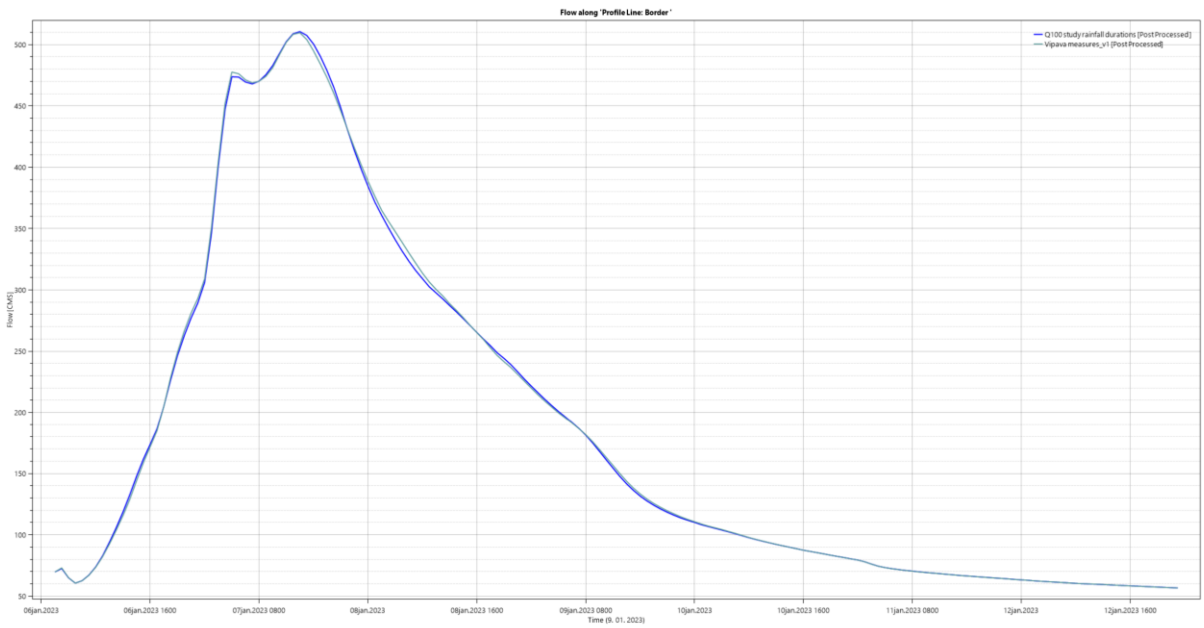

Figure 27: Difference between ante and post operam scenario simulations in hydrograph at the border profile

Resulted hydrographs did not show significant differences between ante and post operam scenario simulations (in terms of a peak discharge, simulations showed 1 m^3/s less in post operam scenario).

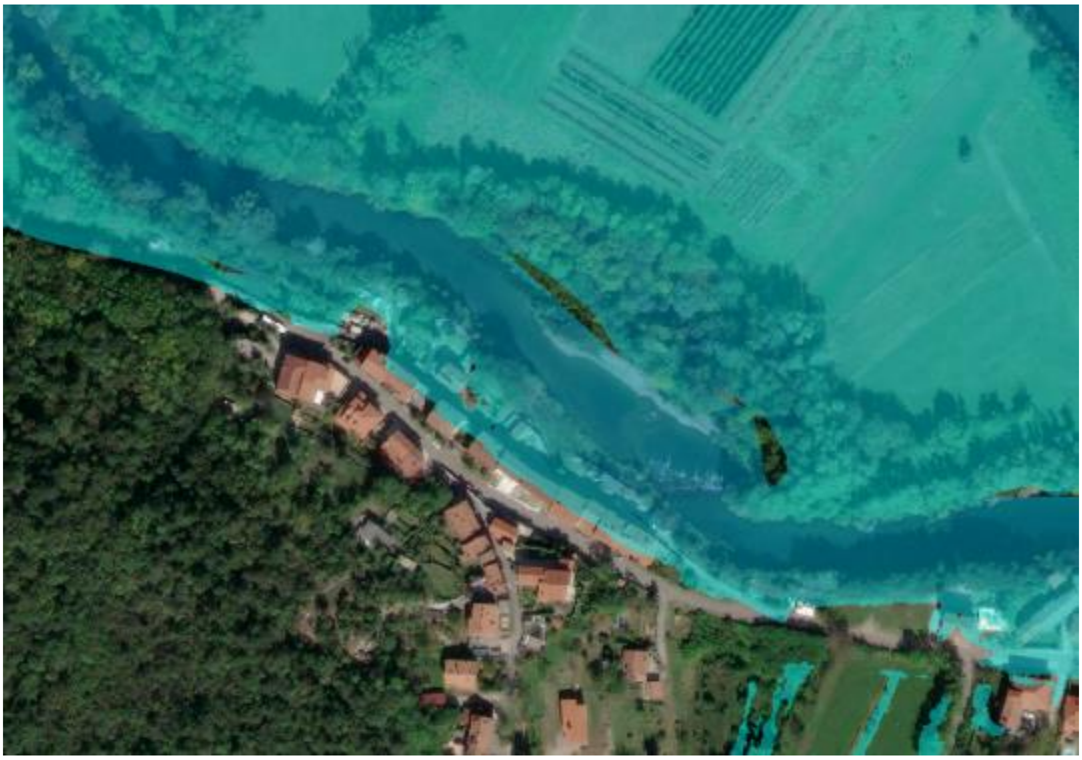

Figure 28: Ante operam scenario for Q_{100} event at Grabec Miren

Figure 29: Post operam scenario for Q_{100} event at Grabec Miren

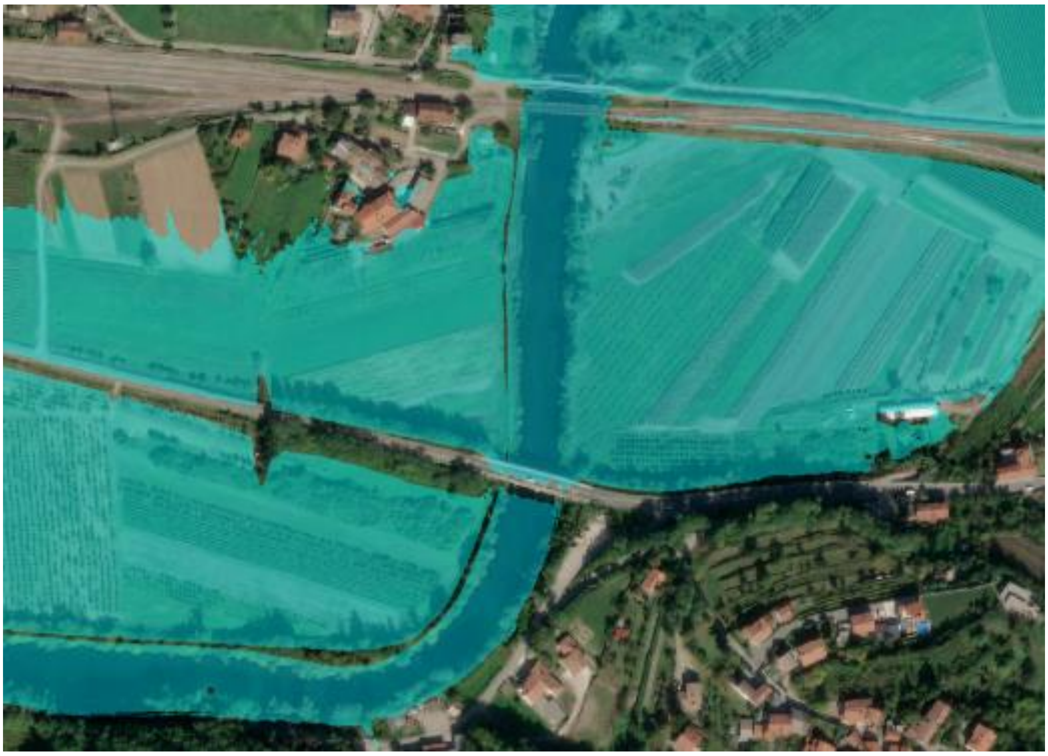

Figure 30: Ante operam scenario for Q_{100} event at Prvačina

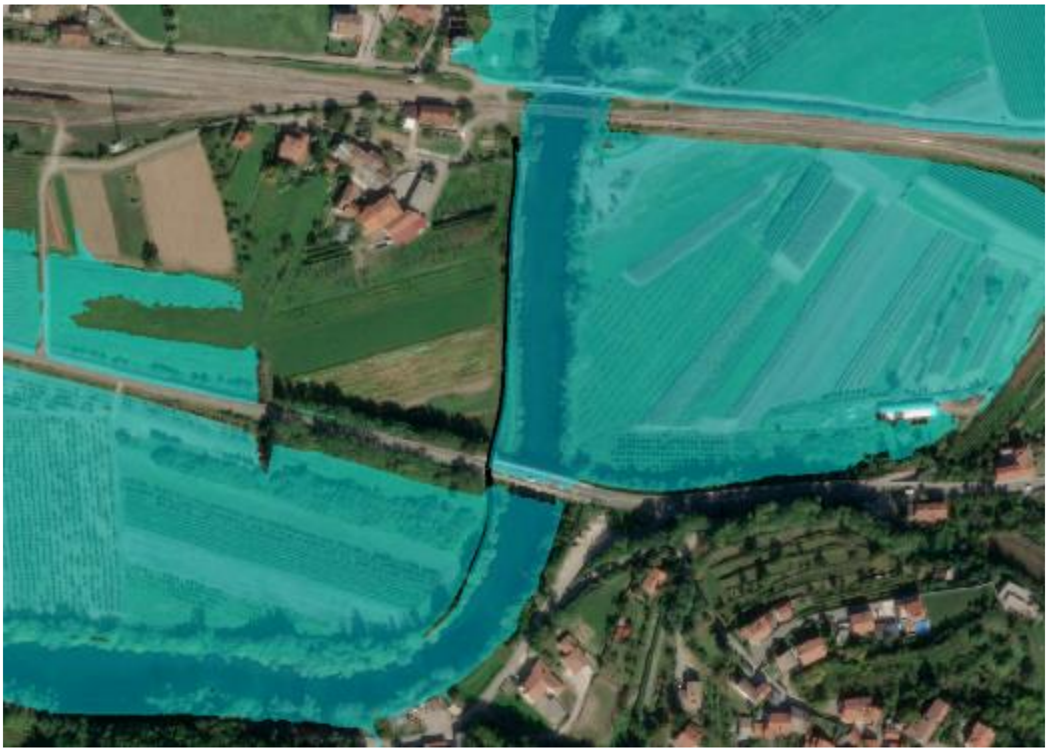

Figure 31: Post operam scenario for Q_{100} event at Prvačina

On the basis of above-mentioned modelling results elaborated by DRSV, AAWA finally employed the software developed in the VISFRIM project in order to perform cost-benefit analysis of such flood mitigation measures.

Figure 32: Water depth ante-operam

Figure 33: Velocity ante-operam

Figure 34: Water depth post-operam

Figure 35: Velocity post-operam

In detail the following outputs resulted:

- Estimated economical damage ANTE-OPERAM: 94.480.398,07 €
- Estimated economical damage POST-OPERAM: 94.291.278,80 €

4. FINAL RESULT AND AGREED CONSENSUS

Since varying results were obtained, mainly due to the presently limited knowledge of peak flow timing among the Vipava river and its tributaries, agreed consensus was reached between the two sides, which is that 100 year return period discharge at the Italian-Slovenian border is estimated in the range between 480 m^3/s to 600 m^3/s. This uncertainty will be reduced in future with greater number of hydrometric observations and update of hydrology study of Vipava river and tributaries.

Modellazione idraulica del bacino del Vipacco

Il progetto VISFRIM mira a realizzare una gestione efficiente del rischio idraulico nei bacini transfrontalieri, attraverso lo sviluppo di metodologie e strumenti tecnologici funzionali all'attuazione ed all'aggiornamento dei Piani di Gestione del Rischio Alluvioni (PGRA) esistenti. In particolare, in tale contesto, sono state realizzate diverse attività di modellazione idrologica ed idraulica per il fiume Vipacco, che vengono descritte in questo specifico deliverable.
Sulla base delle attività svolte, è stato raggiunto un accordo tra le due autorità transfrontaliere (Slovenia: DSRV; Italia: Autorità di Bacino Distrettuale delle Alpi orientali): ovvero che la portata con tempo di ritorno di 100 anni al confine italo-sloveno è stimata tra 480 e 600 m^3/. Questa incertezza sarà ridotta in futuro attraverso la realizzazione di un maggior numero di misurazioni idrometriche e l'aggiornamento dello studio idrologico da parte dei partner sloveni.

Hidravlično modeliranje reke Vipave

Cilj projekta VISFRIM je doseči učinkovito obvladovanje poplavne ogroženosti v čezmejnih porečjih z razvojem metod in tehnoloških orodij za izvajanje obstoječih načrtov za zmanjševanje poplavne ogroženosti in njihovo prihodnjo posodobitev. Zlasti v tem kontekstu je bilo za reko Vipavo izvedenih več aktivnosti hidrološkega in hidravličnega modeliranja, ki so opisane v tem izdelku.
Na podlagi izvedenih aktivnosti je bil dosežen dogovor med obema vključenima pristojnima inštitucijama (Slovenija: DSRV; Italija: AAWA), da je pretok reke Vipave s 100-letno povratno dobo na italijansko-slovenski meji ocenjen v območju med 480 m^3/s in 600 m^3/s. Ta negotovost se bo v prihodnje zmanjšala z večjim številom hidrometričnih meritev in posodabljanjem hidroloških analiz s strani slovenskega partnerja.