HyMoCARES Project
WPT3. EFFECTS OF HYDROMORPHOLOGICAL MANAGEMENT AND RESTORATION MEASURES
D.T3.3.1 Technical note on the evaluation of physical and ecological effects of river restoration works

Case study: Drava River (Slovenia)

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1 Introduction

Pilot study area reach upstream boundary point is just downstream of Melje dam near the city of Maribor, where Drava River channel divides into two reaches – one, artificial derivation channel, leading to HPP Zlatoličje powerhouse (installed flow 530 m^3/s) and other, natural Drava river channel (bypassed reach) running at the foothills of Slovenske Gorice. This reach has a predefined environmental flow of 11 m^3/s in the winter months (from November to February) and 22 m^3/s in the warmer season (from March to October). These two channels meet again just upstream of Ptujsko lake inlet.

1.1 Hydromorphological restoration/management

Alteration of the Drava River natural channel morphology between the Melje dam and the Ptujsko lake inlet is mainly a consequence of dam construction in 1970, city of Maribor wastewater treatment plant outlets and intensive croplands development in the riparian areas and along the main tributaries:

- Dam construction acts as a barrier in the river thus causing changes in the river hydraulics and consequently alterations to the morphology (channel clogging and/or incision, flow regime alteration, sediment transport alteration – mainly suspended matter, etc.),
- Wastewater treatment plant is in operation since 2002, however some minor organic substance is still present and flocculating, causing some (low-significant) alterations in the channel morphology, ie. alteration of aquatic/terrestrial habitat),
- Cropland development is exposing topsoil to the rainfall erosion and thus causing soil washing off the fields into river (causing channel silting, fine sediment accretion on gravel bars).

Hydromorphological restoration works in the pilot area are mostly to improve hydraulic capacity and flood protection in the area, since the area has been regularly flooded in the last 15 years. Restoration works like removing sediments to slow down vegetation encroachment are however in part limited with the introduction of the Natura 2000 nature conservation legislative system to maintain the state of aquatic habitats.

1.2 Objectives of the hydromorphological restoration

The main objectives of hydromorphologial restoration are to increase habitat/physical heterogeneity and increasing flow variability. In order to improve hydromorphological conditions in the area through focal points, ie. decreasing channel clogging, improving flood protection and increasing substrate heterogeneity, certain actions have to be implemented. With Drava River pilot site in Slovenia, hydromorphological restoration effects are not analysed by focusing on one site being a part of a particular restoration project but by analysing the effect of proposed hydromorphological restoration actions on the whole pilot site with the introduction of certain tools, mainly hydrodynamic and sediment transport numerical model. Implementation of restoration actions through these tools provides the insight to short- and long-term effects to pilot area hydromorphological state.

Main identified restoration action in this pilot area is the introduction of dynamically regulated environmental flow synchronized with (planned or already executed) regular riverbed maintenance works by river management service. These actions are expected to decrease levels of suspended sediment deposits and at the same time increasing habitat heterogeneity.

2 Monitoring approach

Type of monitoring design implemented on the pilot area was chosen based on the fact that there is limited data of past to present restoration in the pilot area and even that only as a part of regular riverbed maintenance works, so pertinent comparisons are not possible. We chose the appropriate monitoring design based on classification by Roni et al. (2013) which classfifies monitoring designs/approaches to 5 generic types.

The chosen monitoring design was a mix of BA (Before-and-After) and IPT (Intensive-Post-Treatment) since data at microsites chosen within the pilot area are sparsely available. On figure 1 the example of BA monitoring design with the introduction of 4 new groynes is presented.

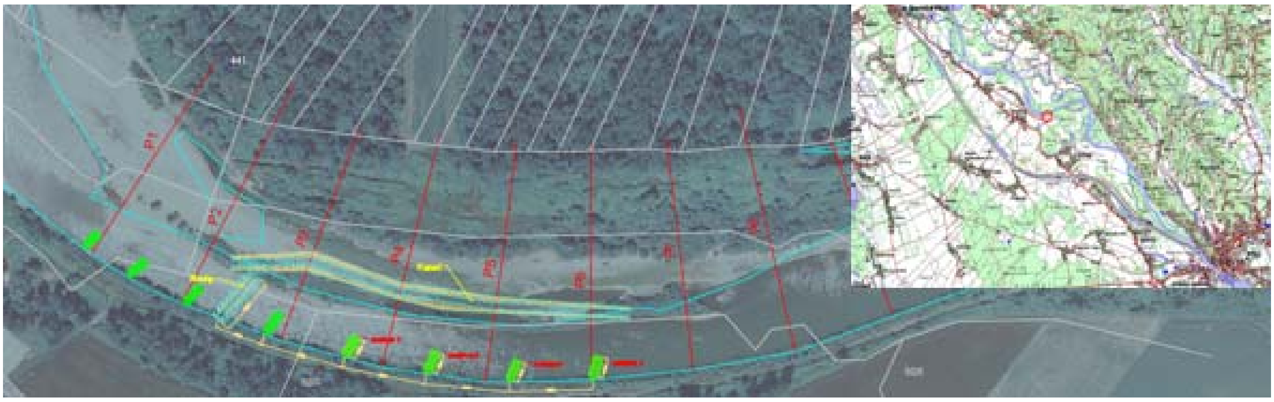


Figure 1: Introduction of 4 new groynes – comparison of pre- and -post bathymetry

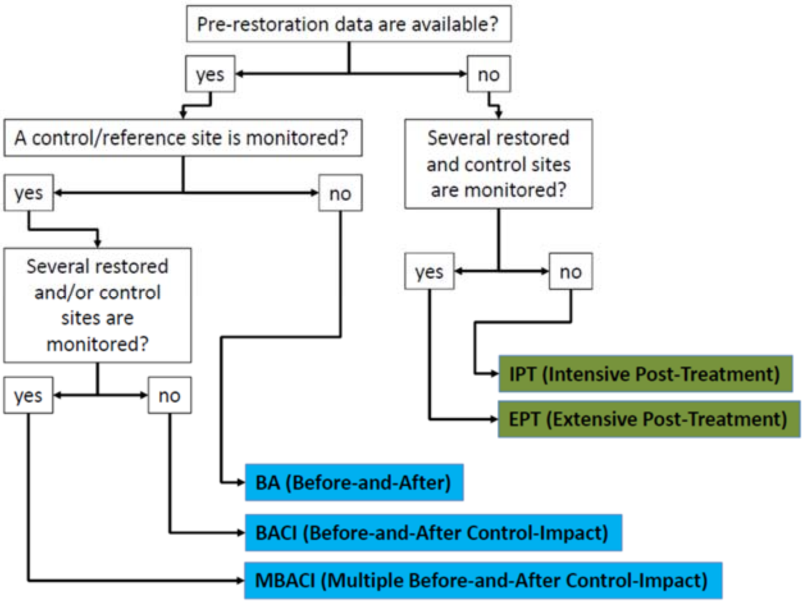


Figure 2: Simplified chart for the determination of the type of monitoring design used to evaluate the effects of restoration projects (inspired from Roni et al., 2013)

2.1 Physical monitoring

Physical monitoring on the Drava study area consisted of the following:

- Suspended sediment measurements; 3 campaigns of measurements, with 2 campaigns of 10 individual measurements on 2 separate locations at regulated "dry-winter" and "wet-summer" discharges and one at increased discharges (700 m³/s and above). This is to determine the effect of various scenarios (e-flow increase, etc.) on fine/suspended sediment remobilization in the channel.

- Bank erosion levels on a chosen location (one-time). A basis to determine the level/amount of eroded material from the banks at predetermined locations to evaluate the contribution of bank eroded (fine grained) sediment to sediment transport.

Based on this, results serve as a basis data for the modelling phase:

- sediment deposits/erosion locations and levels by 3D comparison of available terrain/bathymetry,
- discharge-sediment concentration relation based on suspended sediment monitoring,
- statistical analyses of hydrologic datasets (low/mean/high monthly/annual discharges, distributions, etc.),
- bank erodibility measurements of a selected bank profile.

2.1.1 Drava River (Slovenia) case study – suspended sediment measurements

Three suspended sediment monitoring campaigns were conducted to assess suspended sediment concentration in relation to time and discharge.

First campaign was conducted at the location of Duplek bridge at three separate locations along the bridge (left, middle and right) and at one single location near Zlatoličje in February and March of 2018, consisting of 10 separate measurements on 10 different days. This campaign was done at the constant winter E-flow of 11 m³/s with point-integrated 1l sampler, which was modified at the sampler intake due to low flow velocities. Each sample was then analysed in the laboratory according to the following standard *SIST EN 872:2005 (Water quality - Determination of suspended solids - Method by filtration through glass fibre filters)*.

We conducted second campaign at the same locations as the first, winter campaign, in September of 2018, consisting of 10 separate measurements on 10 different days. Campaign was performed at the constant summer E-flow of 23 m³/s with the same point-integrated 1l sampler, which was modified at the sampler intake due to low flow velocities.

Figure 3: 3 locations (yellow dots) of suspended sediment concentration monitoring at Duplek bridge


Figure 4: Location of suspended sediment concentration monitoring near Zlatoličje (yellow dot)

Third campaign happened at the end of October 2018 when high discharges between Q_5 and Q_{10} occurred. Our intention was to measure the suspended sediment concentration relation to unsteady flow conditions. Measurements were only at the Duplek Bridge because of the safety precautions. Monitoring campaign began at 796 m^3/s and ended after 40 separate sample collecting every 1-3 hours. Corresponding discharge was measured at the HPP Melje just upstream of the monitoring site.

2.1.2 Bank erosion measurements on Drava River in Slovenia near Zlatoličje

BOKU from Vienna, Austria conducted bank erosion measurements on 28. 6. 2018 to assess the erodibility of the fine-grained bank sediment with Jet test device and to assess the shear strength of the sediment with respect to shear failure, which is critical for the riverbank stability with Borehole shear test.

2.2 Ecological monitoring

Basis to ecological monitoring is an official regular ecological monitoring (water quality monitoring), run by the Environmental Agency of the Ministry of the Environment. In addition recent ecological monitoring data acquired from the relevant institutions (Fisheries, Nature conservation, etc.) based on the proposed modelling scenarios (habitat modelling) is used.

The ecological status of surface water is determined based on the biological quality elements, chemical and physico – chemical quality elements and the hydro morphological quality elements.

Hydrological monitoring includes monitoring:
- Water table,
- Flow velocity,
- Water temperature,
- Concentration of suspended material/turbidity,
- Section geometry measurement.

Water quality monitoring includes measuring to define:
- Chemical status,
- Ecological status.

Both statuses are depending on pollutants characterised in pilot area.

Obtained data, together with forementioned recent monitoring data was used as an input for habitat modelling. Within habitat modelling, fish fauna monitoring data acquired from relevant institutions is key to optimal modelling.

Table 1: Location and measurement type of ecological monitoring on Drava pilot case study area

Location	**GKY**	**GKX**	**Measurement type**
Jez Melje	551941	157691	Hydrological monitoring
Starše	559455	148193	Water quality monitoring
Krčevina pri Ptuju	564403	144277	Water quality monitoring
Ptuj	567102	141737	Hydrological monitoring

2.2.1 Drava River (Slovenia) case study - habitat modelling

Habitat modelling determines the suitability of habitat based on a small number of selected environmental factors whose interactions largely determine the properties of the habitat. It compares individual zones (territorial units) in space and time and make it easier to design different, minimal invasive interventions in nature and the measures to improve the quality of the habitat.

In habitat modelling two major groups of the input data are used: numerical data (in this case hydraulic data: the depth of water and the velocity of the water flow obtained through numerical modelling), and the descriptive information together with the indexed data (particle size of the substrate and the type of hiding areas).

3 Physical effects

3.1.1 Drava River (Slovenia) case study – results of suspended sediment monitoring campaigns

Three suspended sediment (SS) monitoring campaigns were conducted in 2018 to 1) Assess the relation of SS fluctutation over time in case of steady E-flow at winter and summer discharge regime conditions and 2) Assess the SS relation to discharge at unsteady river discharges.

Figure 5 on the left shows levelled SS concentration on average at 1,5 - 2 mg/l with few exceptions in the middle of the campaign probably due to slightly elevated SS transport as a late consequence of the upstream section rainfall erosion. On the right side, on figure 6, descending SS concentration levels are observed across the campaign in September 2018. On average SS concentrations in 2nd, summer SS monitoring campaign are up to 10 times higher than in winter campaign, most likely because of late August rainfall period initiating elevated sediment transport discharges. These observed relations serve as a basis to design (boundary conditions) and later interpretate sediment transport model results at currently set E-flow conditions.

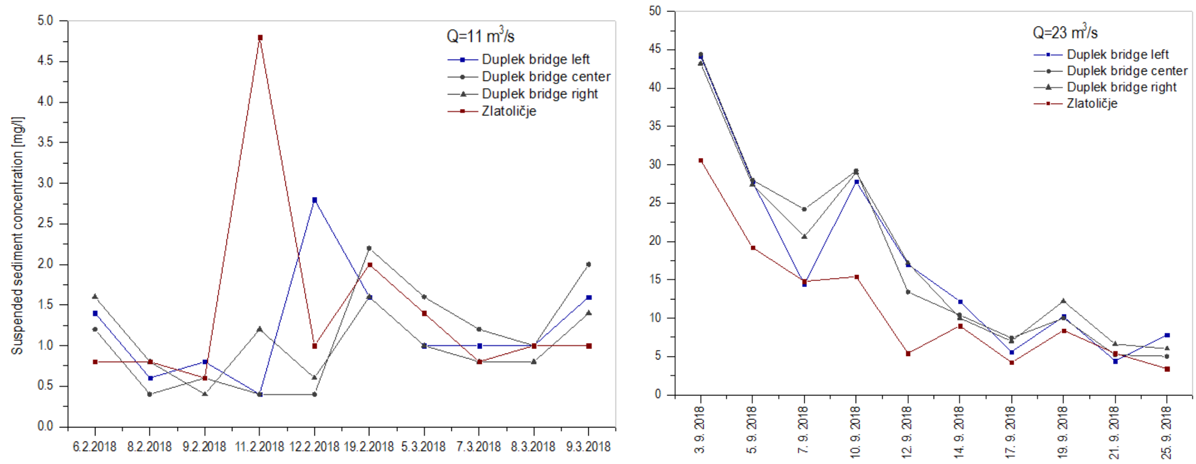


Figure 5 and 6: Fluctuation of suspended sediment concentrations at steady discharges of 11 m³/s and 23 m³/s in winter and summer discharge regime

Meteorologic and hydrologic conditions dependent was the third set of SS monitoring as it was the goal to measure the SS dependency on unsteady river discharges being at least at the estimated magnitude of approx. 700 m³/s, which initiate the sediment transport in run-of-the-river HPP reservoir hydraulic conditions. Such event occurred in late October 2018. Measurements began at 796 m³/s on 29. 10. and ended 48 hours later at the same discharge.

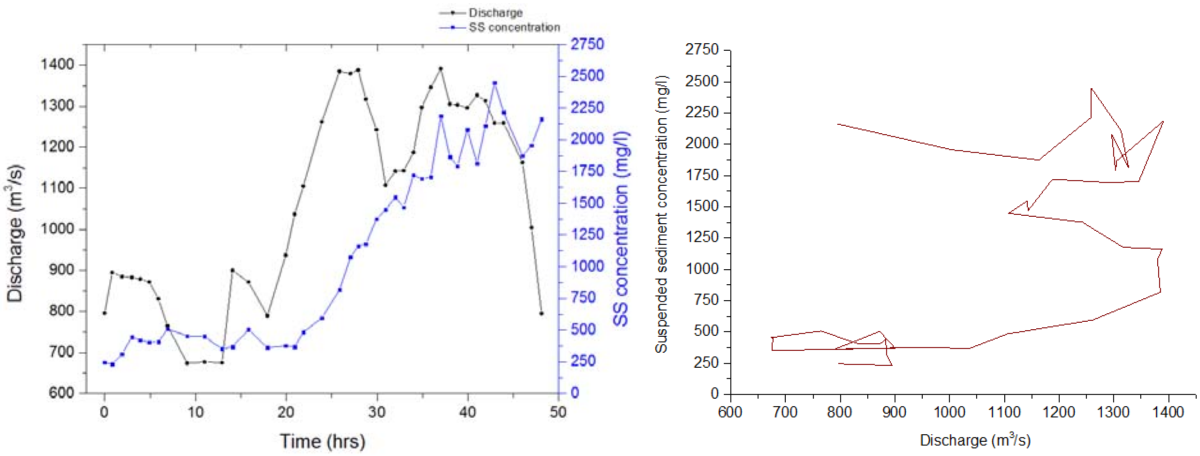


Figure 7 and 8: Fluctuation of suspended sediment concentration at unsteady discharges period in late October 2018 (left) and hysteresis loop of discharge vs. sediment concentration relation (right)

40 measurements were done along with 40 samples collected from the Duplek Bridge every 1-2 hours. We synthetically extended measured natural

hydrograph on both lower ends to include the lowest discharges. Discharges were "added" to the original natural hydrograph in a way to attain as much lower discharges' diversity as possible. These additional lower discharges were then used to test the amendment of the existing E-flow procedures.

We synchronized this synthetical hydrograph with measured SS concentrations as an upper boundary condition in sediment transport model, also as a model - validating tool.

As seen on the figure 7, the SS concentration peaked with time lag compared to the discharge hydrograph peak. This phenomenon is likely due to high cohesiveness of the suspended sediment trapped in spaces between larger, gravel, pebble-like riverbed fractions and to delayed SS discharge coming from upstream sections of the HPP chain. The most significant effect of SS transport on the hysteresis loop on figure 8 is the effect of the delayed SS settlement causing (due to depth-averaged 2D numerical model) elevated SS concentrations on the descending part of the Drava River discharge hydrograph.

3.1.2 Drava River (Slovenia) case study – bank erosion measurements

Bank erosion measurements were done with a general purpose to estimate the bank retreat and interaction with the depositing sediment, which is supplied from upstream.

Right riverbank, lateral from the mid-channel bar was investigated (see figure 9).

Figure 9: Bank erosion measurements at Drava River pilot site in Slovenia

Main results from the bank erosion tests are:

- From borehole shear test – cohesion shear strength (bank geotechnical stability) being 15,5 kPa with friction angle of 36,4° (figure 10),
- From jet test – erosion rate (m/s) dependance on shear stress (Pa) (bank fluvial erodibility) on figure 11.

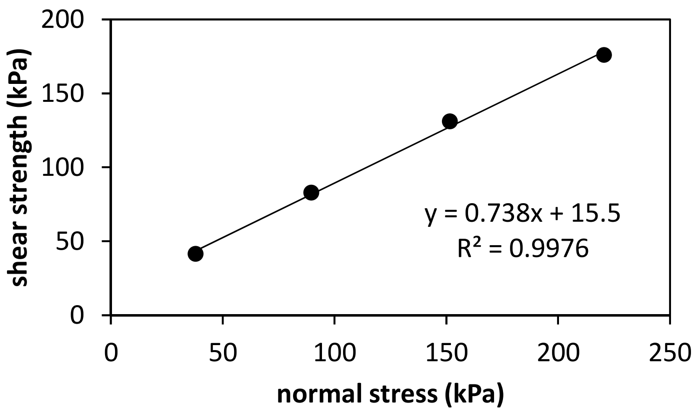


Figure 10: Bank geotechnical stability rate on shear strength

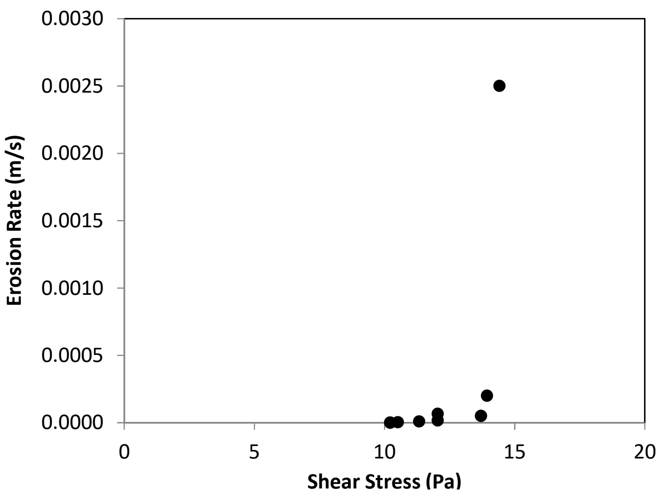


Figure 11: Bank fluvial erodibility rate

3.1.3 Drava River (Slovenia) case study – WPT2 tools applications

In this section, tools selected in WPT2 to assess physical effects of the river channel forms/processes after restoration.

3.1.3.1 HyMoLink and CHEVO

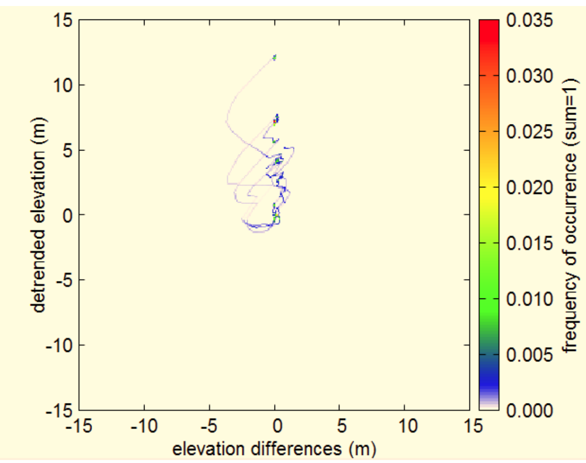
HyMoLink (XS) and CHEVO were developed by BOKU (Vienna, Austria). Each of them is based on pre- and post-event cross section data, mean discharge, riverbed slope and roughness coefficient (Manning n_g), with HyMoLINK also on input text data of "biofields" representing distance between the water surface and the threshold to layers containing significant portions of finer sediment (d $\leq$ 2 mm).

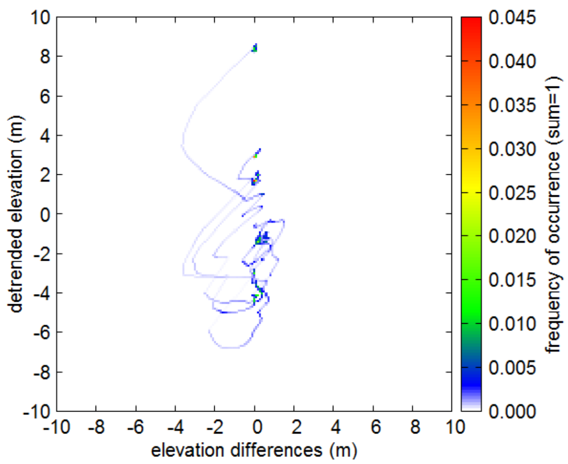
3.1.3.1.1 HyMoLink

The subsection near Zlatoličje/Starše village inside Drava River pilot case in Slovenia was selected because of additional 4 groynes being built in 2013 (in addition to 4 already functioning). Three (3) river cross sections were derived from bathymetry data pre- and post-groynes construction and compared through HyMolink tool. Few selected discharges were selected to test the tool (11, 23, Q_{mean_annual}=260, 700 and 2533 $m^3/s=Q_{100}$), "biofields" data was used in the following table. On figures below, we present selected diagrams (at 11 and 700 m^3/s).

Table 2: Biofields data as an input for HyMoLink tool

potential pioneer vegetation		**potential spawning habitat**		**potential bird bank nests**	
0.1	0.8	0.1	-0.3	-1000	0
1000	0.8	1000	-0.3	-1	0
1000	0.5	1000	-1000	-1001	-1000
0.1	0.5	0.1	-1000	-2000	-1000



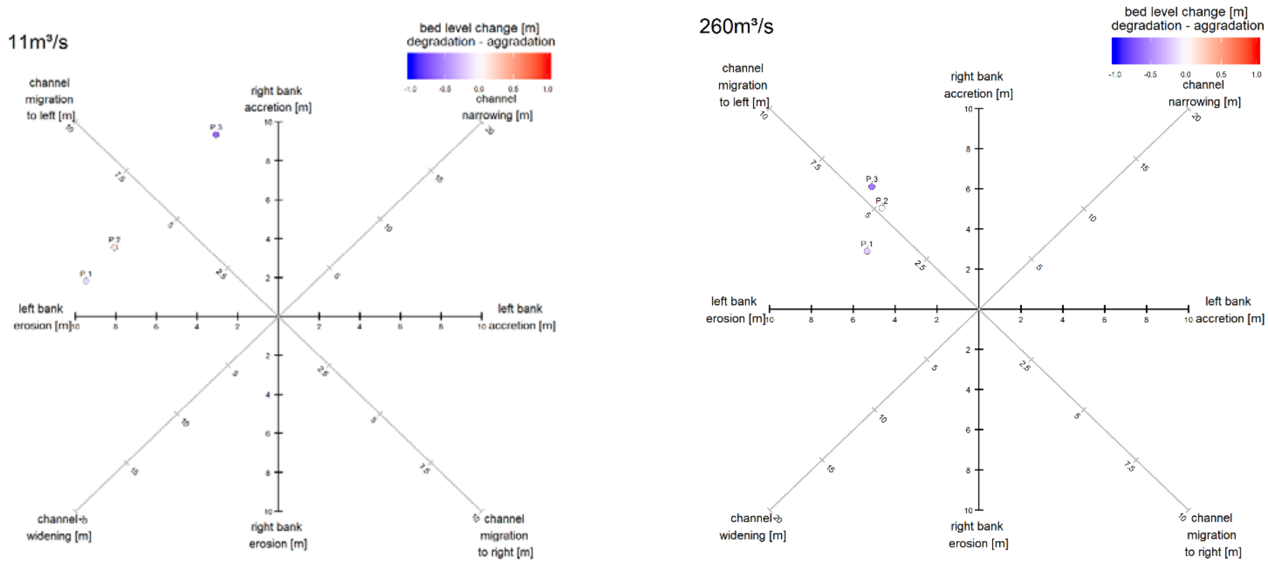


Figures 12 and 13: Detrended elevation to the elevation differences at 11 and 700 m^3/s (right)

From the previous figures, one can see that most of the areas show little to moderate bed changes (up to 0,5 m) at 11 m³/s (winter regulated E-flow) and moderate bed changes at Q=700m³/s, with areas with significant bed changes being in minority (less than 0,1%) at both presented discharges.

3.1.3.1.2 CHEVO

CHEVO is a tool to assess channel changes in a standardized manner through similar input data as HyMoLink, bar the "biofields" data, so, consequently same input files serve as a basis for the 3 selected cross section evaluation. There is a slight difference of testing tool only for small/mean discharges of 11, 23 and 260 m³/s.



Figures 14 and 15: Channel evolution diagrams at 11 m³/s and 260 m³/s (Q_{mean})

3.1.3.2 SRH-2D, MIKE21C and CCHE2D-Sed

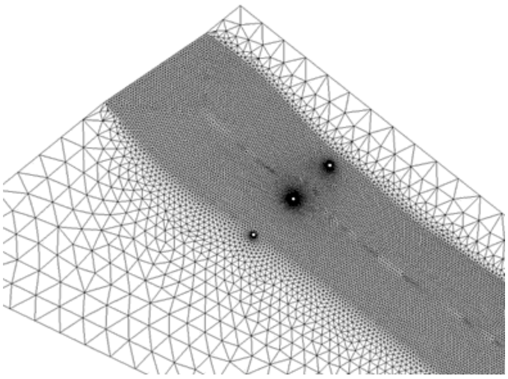
3.1.3.2.1 SRH-2D

SRH-2D solves the 2D dynamic wave equations, i.e., the depth-averaged St. Venant equations. Its modeling capability is comparable to some existing 2D models but SRH-2D uses a flexible mesh that may contain arbitrarily shaped cells. A hybrid mesh achieves the best compromise between solution accuracy and computing demand. A unique total-load approach was developed and used in which the suspended load, bedload, and mixed-load are modeled simultaneously. The module adopts the time-accurate, unsteady formulation for mobile-bed modeling which includes the time-accurate bed evolution, the non-equilibrium sediment transport equation, and the multi-sediment-size representation. It includes the capability to account for secondary flow and gravity effects on sediment movement in streams within stream bends.

Two locations within the pilot area were chosen to analyse 1) the effect of riverbed restoration by constructing additional groynes near Zlatoličje village and 2) the level of Malečnik road bridge columns scouring before and after major floods of November 2012, which caused substantial changes in Drava River morphology.

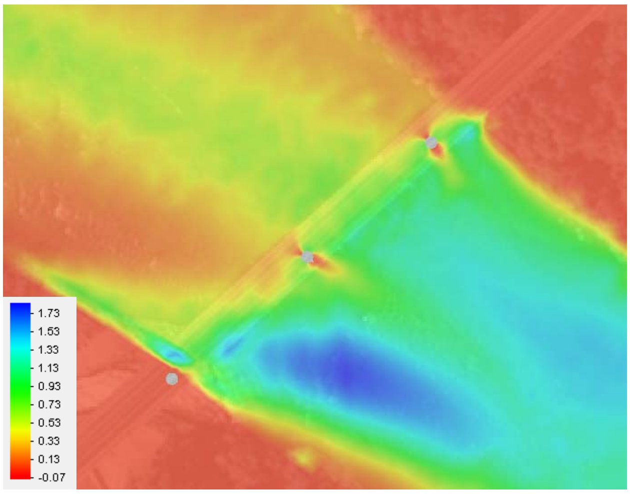
- <u>Malečnik bridge columns scouring analysis</u>

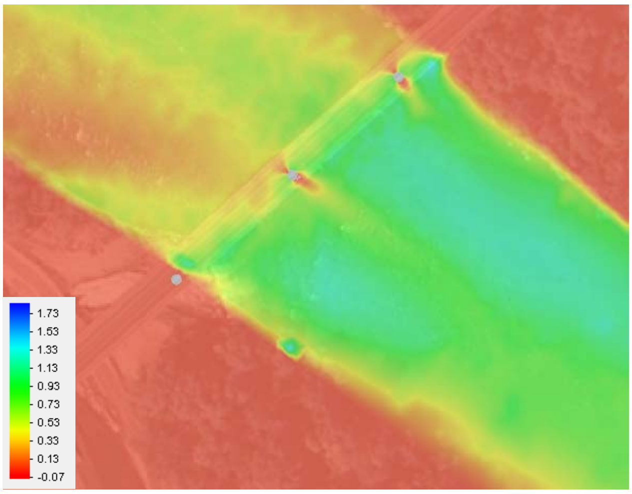
In practice, the hybrid mesh of quadrilateral (riverbed) and triangular (floodplains) cells is recommended but since the columns had to be implemented into mesh, dense triangular grid was created for riverbed (1 m) and in average up to 10-times sparser for floodplain areas.




Figures 16 and 17: Numerical mesh – (left) and representative cross-section (orange line)

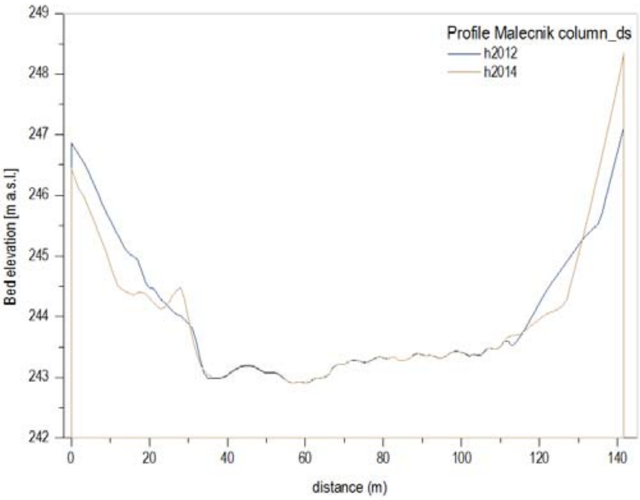
Two different bathymetries (before 2012 floods and after) were used to compare the effect of steady flow duration of 18 hours on erosion/deposition intensity. Steady flow of 1391 m^3/s was used since this was a peak flow at the real hydrologic event on 30th October 2018 (SS samples were collected and SS concentration was measured).

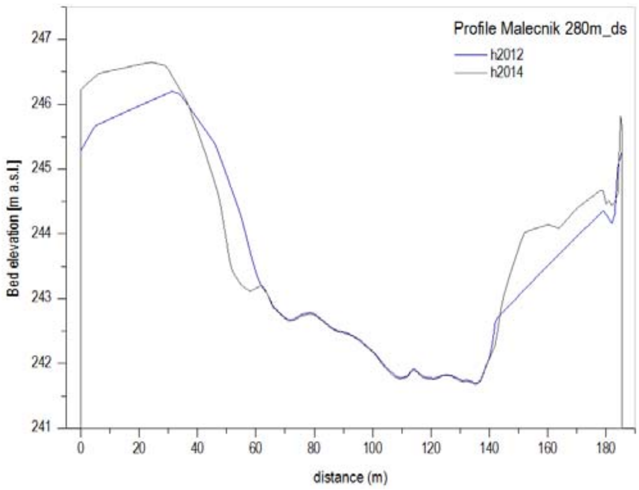




Figures 18 and 19: Erosion (and deposition – red) after 18 hours of 1391 m^3/s steady flow – before 2012 floods (left) and after (right)

Figures above depict elevated erosion intensity between and downstream of the columns. Erosion near the columns, perpendicular to the flow direction is significantly higher than along the river course. Erosion intensity is approx. 10-20% higher before riverbed altering due to the floods in 2012 than after the floods. Assumption was that only fractions up to 0.125 mm (very fine sands) were transported during this event (within this river section).





Figures 20 and 21: Cross section comparison (state of pre-2012 and 2014) at two locations, just downstream of Malečnik bridge columns and 280 m downstream of bridge columns

Previous figures show erosion processes on the right bank and accretion on the left bank. Riverbed levels in general show little changes.

Note: this comparison is presented only to show the erosion level as a consequence of such event; at the time of analysis, the foundation depth was unknown, so the actual threat of scouring to possible bridge column instability is not known and has to be monitored regularly.

- Zlatoličje bank stabilization by groynes reconstruction

Same modelling assumptions were used to evaluate the effect of additional 4 groynes construction in 2013 to further alleviate right bank erosion effects near Zlatoličje village.

In 2012 first 4 groynes (approx. size 3x10x1m, pyramidal shape) were constructed (instead of planned consecutive weirs) in addition to existing riprap. Four additional groynes (in total 8, see figure 22) were constructed in 2013 to further lower the bank erosion intensity, together with reconstruction of one existing groyne, damaged in November 2012 floods.

Figure 22: 8 groynes near Zlatoličje village

Sediment transport simulation was performed for the state of 4 and state of 8 groynes separately. Contrary to Malečnik Bridge scouring analysis, actual "synthetic" unsteady flow event of October 2018 was used as an upstream boundary condition. This hydrograph was then reconstructed with added representation of low flows.

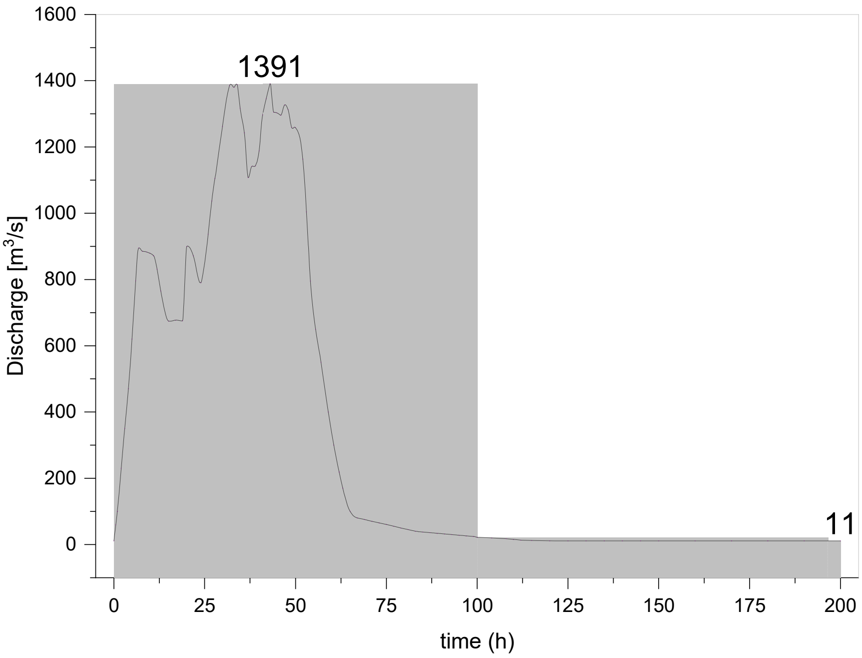
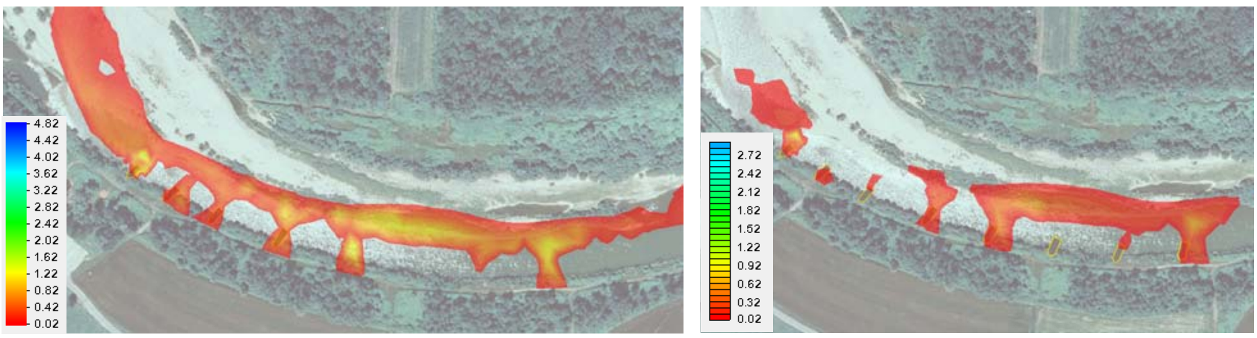
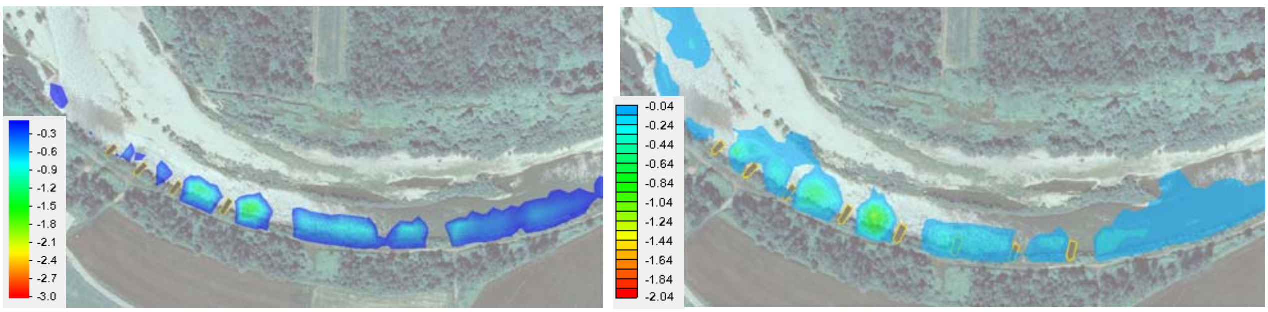


Figure 23: Input synthetic hydrograph as an upper boundary condition



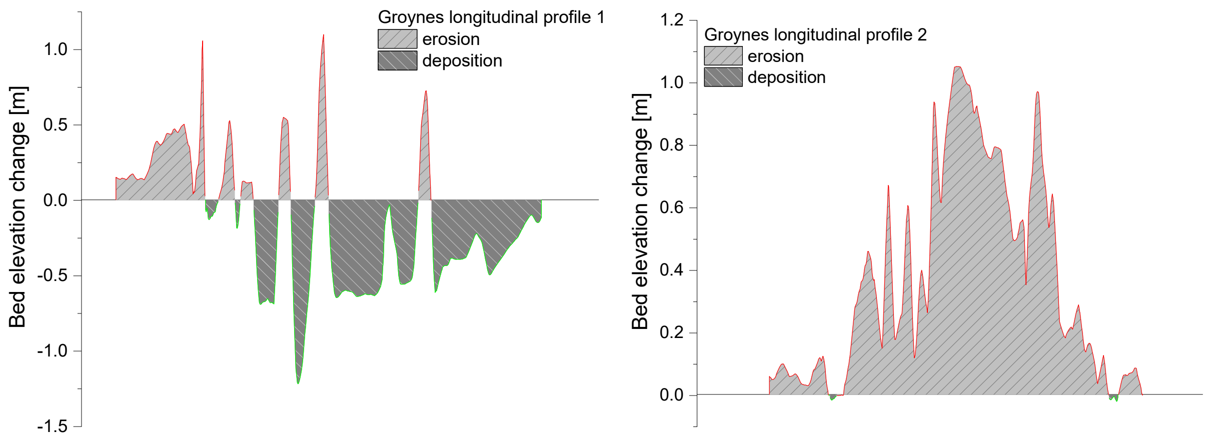
Figures 24 and 25: Maximum erosion levels for the 4 (left) and 8 groynes (right)



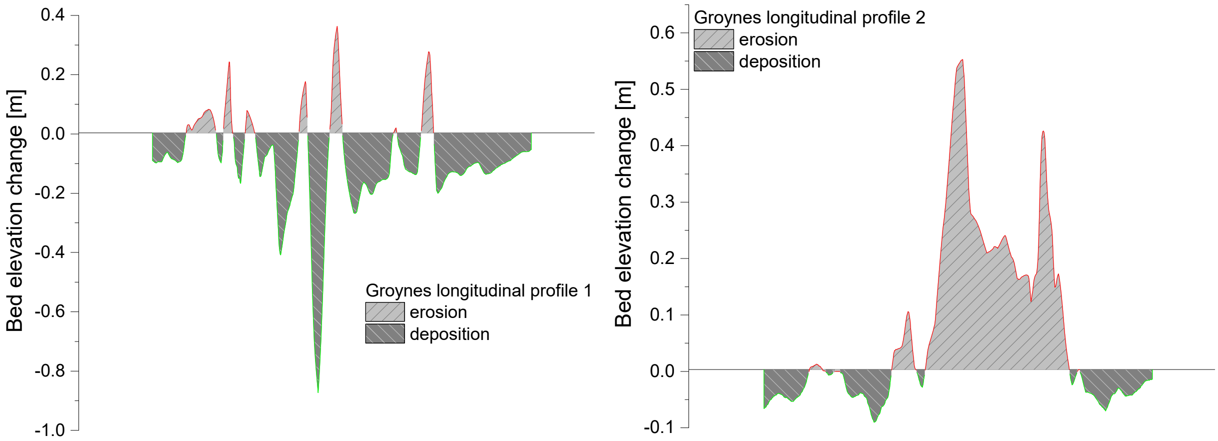
Figures 26 and 27: Maximal sediment deposition levels for the 4 (left) and 8 groynes (right)

Previous figures show the effect of construction of 4 groynes in 2013 (in addition to existing 4 from 2012), especially by decreasing sediment erosion levels and to lesser extent sediment deposition levels. Riverbed and bank stabilization effect of groynes is thus evident.

Figure 28: Groynes reconstruction section longitudinal comparison profiles



Figures 29 and 30: Bed elevation changes along longitudinal profiles 1 and 2 (before groynes restoration in 2013)



Figures 31 and 32: Bed elevation changes along longitudinal profiles 1 and 2 (after groynes restoration in 2013)

Tendencies from figures 29 to 32 show the reduction of deposition levels along longitudinal profile 1 and reduction of bed erosion levels along longitudinal profile 2 thus by constructing new groynes, the general effect is, getting closer to establishing sediment balance in this river section.

3.1.3.2.2 MIKE-21C

MIKE-21C is a special module of the MIKE 21 software package based on a curvilinear (boundary-fitted) grid, which makes it suitable for detailed simulation of rivers and channels, where an accurate description of bank lines is required. The numerical grid is created by means of an user-friendly grid generator. Areas of special interest can be resolved using a higher density of grid lines at these locations. The MIKE 21C is particularly suited for river morphological studies and includes modules to describe: flow hydrodynamic, helical flow (secondary currents), sediment transport, based on various model types (e.g. van Rijn, Meyer-Peter&Müller, Engelund-Hansen, Engelund-Fredsoe, Yang, or user defined empirical formulas), alluvial resistance, scour and deposition, bank erosion and plan form changes.

MIKE-21C was tested with a single simulation of steady flow 650 m^3/s with duration of 24 hours. Input concentration of suspended sediments was set at arbitrary value of 500 g/m^3. Bedload was not modelled. In following figure results are represented after 24-hour simulation as bed level change. We can observe sediment erosion in the channel up to 0,05 m and local sediment deposition in the area of natural floodplains.

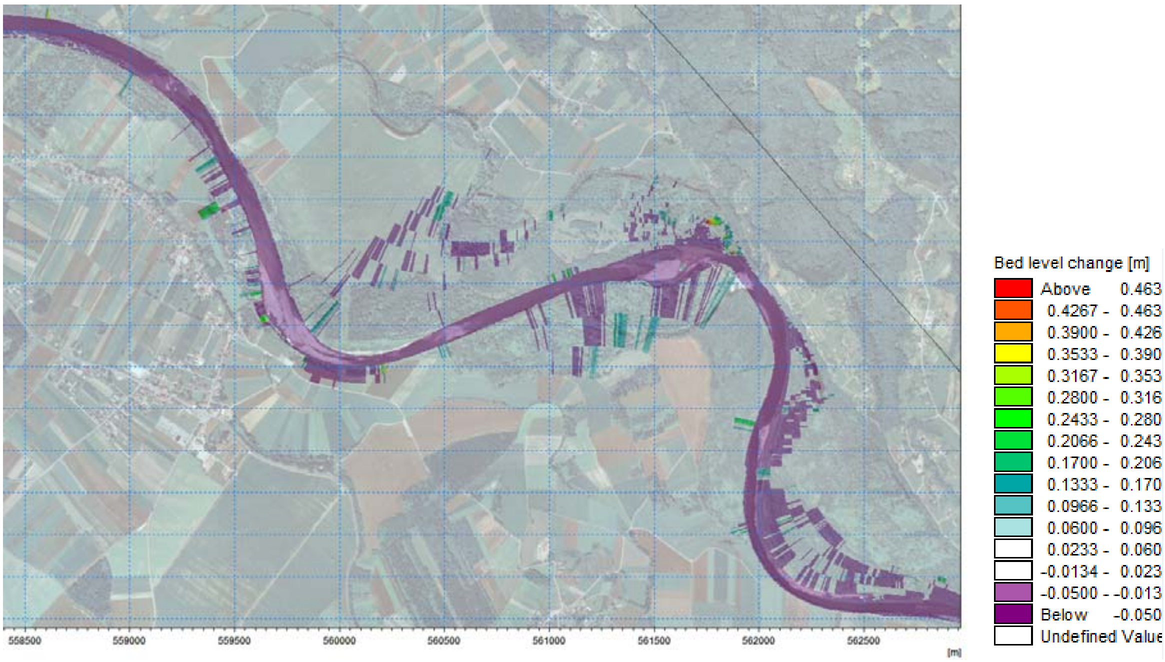


Figure 33: Bed level change at 650 m^3/s steady flow (MIKE-21C model)

3.1.3.2.3 CCHE2D-Sed

CCHE2D-Sed was used to determine parameters of habitat suitability for predetermined species in the pilot area between HPP Melje and Ptujsko Lake, ie. to determine pilot area morphology alterations for habitat modelling. In this section we present the boundary conditions and results of sediment transport modelling, and in next chapter we cover the part which deals with subsequent phase, the habitat modelling.

Bathymetry was provided by laser scanning of the terrain (LIDAR) and bathymetry scanning, performed in 2014 within a project LIVEDRAVA (DOPPS – BirdLife Slovenia, 2018). The data accuracy is 1x1 m cell size.

First step in model creation was to design a numerical mesh. Density of the mesh is around 3m (cross section) by 10 m (longitudinal section) in river stream and riparian section, with lower mesh density in inundation areas. Overall the model consists of almost 400.000 nodes. Two boundary conditions were defined. Upstream (inlet to the model), a representative synthetic hydrograph (figure 34) was defined. The model ends at the outlet to Ptujsko Lake reservoir, which has more or less constant water level at 220.00 m a.s.l. This value was used as an outlet boundary condition at the end of the model.

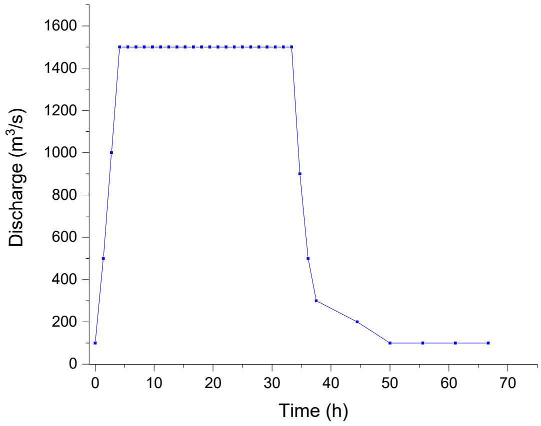


Figure 34: Synthetic hydrograph as an upper/inlet boundary condition

CCHE2D-Sed sediment transport modelling is made of two separate parts – first one evaluates hydraulic parameters, ie. water levels/depths and flow velocities (see figure 35) at Q=1400 m^3/s.

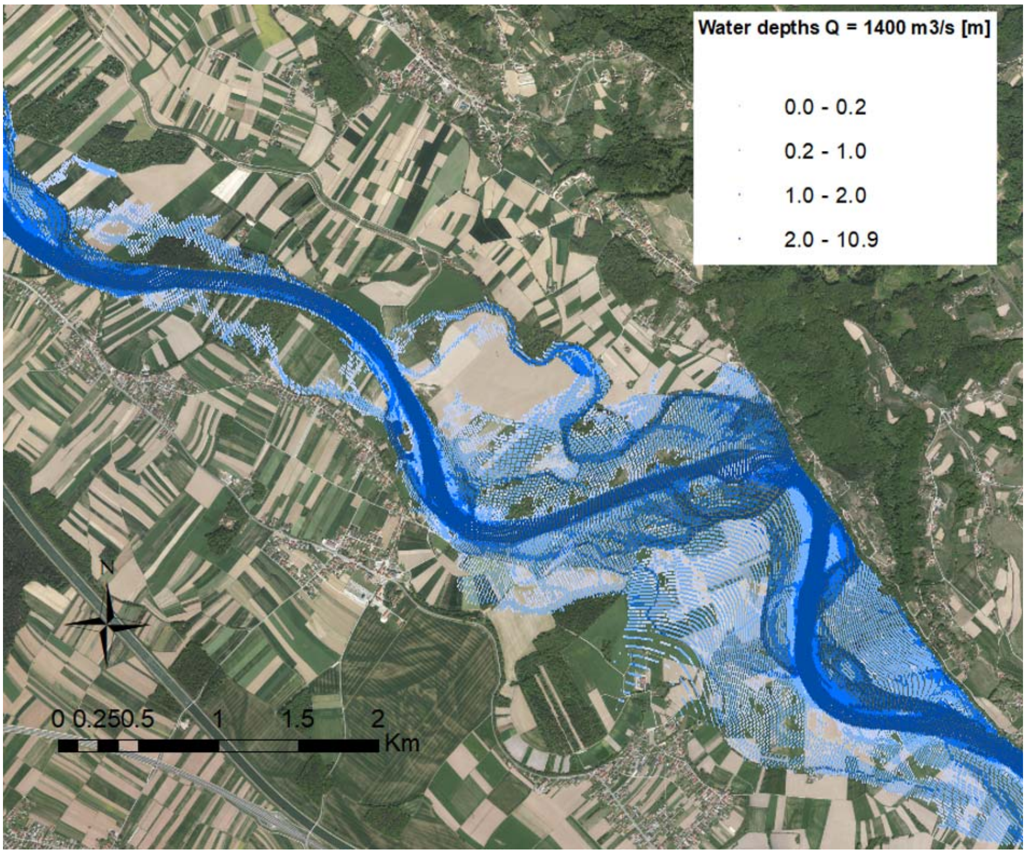


Figure 35: Water depths on the Pilot Case Drava section at Q = 1400 m^3/s

Second part is a part of sediment transport modelling based on hydrodynamic model results. Due to the nature of requirements of habitat modelling, we had to design a model to suit both components - suspended sediment and bedload. Relation between suspended sediment load and flow discharges as an inlet boundary condition was determined on the basis of previous measurements of suspended sediment load on Pilot Case Drava. The last was performed at the end of October 2018, when high water wave appeared (Chapter 3.1.1.).

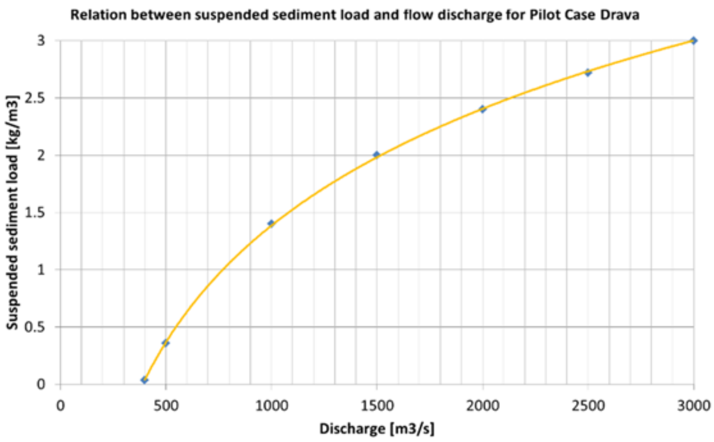


Figure 36. Relation between suspended sediment load and flow discharge

To determine the relation between bedload and discharge, we used an extensive research on river Ebro (Lopez et al. 2014), which is hydrologically and morphologically similar. Also, dams in upstream section exist, which is similarly the case for Drava river. Next figure shows the determination of the curve for relation between bed load transport and flow discharges defined based on bedload research on river Ebro with extrapolation for lower and higher discharges on the basis of potential curve.

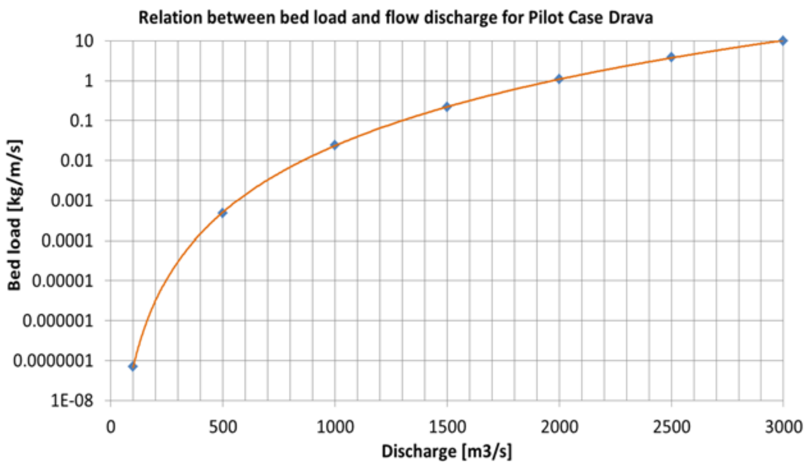


Figure 37. Relation between bed load and flow discharge

For the modelling purposes within the CCHE2D-SED, a time depending sediment transport amounts (correlating to the flow from the hydrograph) are determined with determination of representative particle size classes and their shares. Next two tables give the used values for the simulation.

Table 3: Time-dependent suspended sediment load by particle size

	Suspended sediment load		Particle size [m]				
Time [s]	Q [m^3/s]	Transport [kg/m^3]	0.00001	0.0001	0.001	0.01	0.1
0	100	0.005	0.6	0.4	0	0	0
5000	500	0.036	0.5	0.5	0	0	0
10000	1000	1.4	0.5	0.5	0	0	0
15000	1500	2	0.45	0.5	0.05	0	0
120000	1500	2	0.45	0.5	0.05	0	0
125000	900	1.2	0.5	0.5	0	0	0
130000	500	0.36	0.5	0.5	0	0	0
135000	300	0.08	0.6	0.4	0	0	0
160000	200	0.01	0.6	0.4	0	0	0
180000	100	0.005	0.6	0.4	0	0	0
240000	100	0.005	0.6	0.4	0	0	0

Table 4: Time-dependent bedload by particle size

	Bed load		Particle size [m]				
Time [s]	Q [m^3/s]	Transport [kg/m/s]	0.00001	0.0001	0.001	0.01	0.1
0	100	0*	1	0	0	0	0
5000	500	0*	0.45	0.25	0.2	0.1	0
10000	1000	0.024	0.1	0.25	0.3	0.25	0.1
15000	1500	0.22	0.1	0.2	0.3	0.3	0.1
120000	1500	0.22	0.1	0.2	0.3	0.3	0.1
125000	900	0.013	0.1	0.25	0.3	0.25	0.1
130000	500	0*	0.45	0.25	0.2	0.1	0
135000	300	0*	0.55	0.35	0.1	0	0
160000	200	0*	0.65	0.3	0.05	0	0
180000	100	0*	1	0	0	0	0
240000	100	0*	1	0	0	0	0

Final data needed for the sediment transport simulation is determination of bed material grain-size distributions and its thickness. Since the data was not available or was defined only for some points, we applied homogenous material for entire model area (see next table) with thickness of 10 m.

Table 5: Bed material grain-size distribution

Porosity	0.00001	0.0001	0.001	0.01	0.1
0.40	0.2	0.2	0.2	0.2	0.2

Next figure shows the first preliminary results of sediment transport simulation where areas with erosion and areas with sedimentation processes are presented. The results are preliminary, next work will be focused on calibration and verification of all steps. Major deficiency of the input data is a part of bed material, especially in the case where bed rock is already exposed. Namely, in this areas or sections the bed should be more stable, so the erosion will be limited.

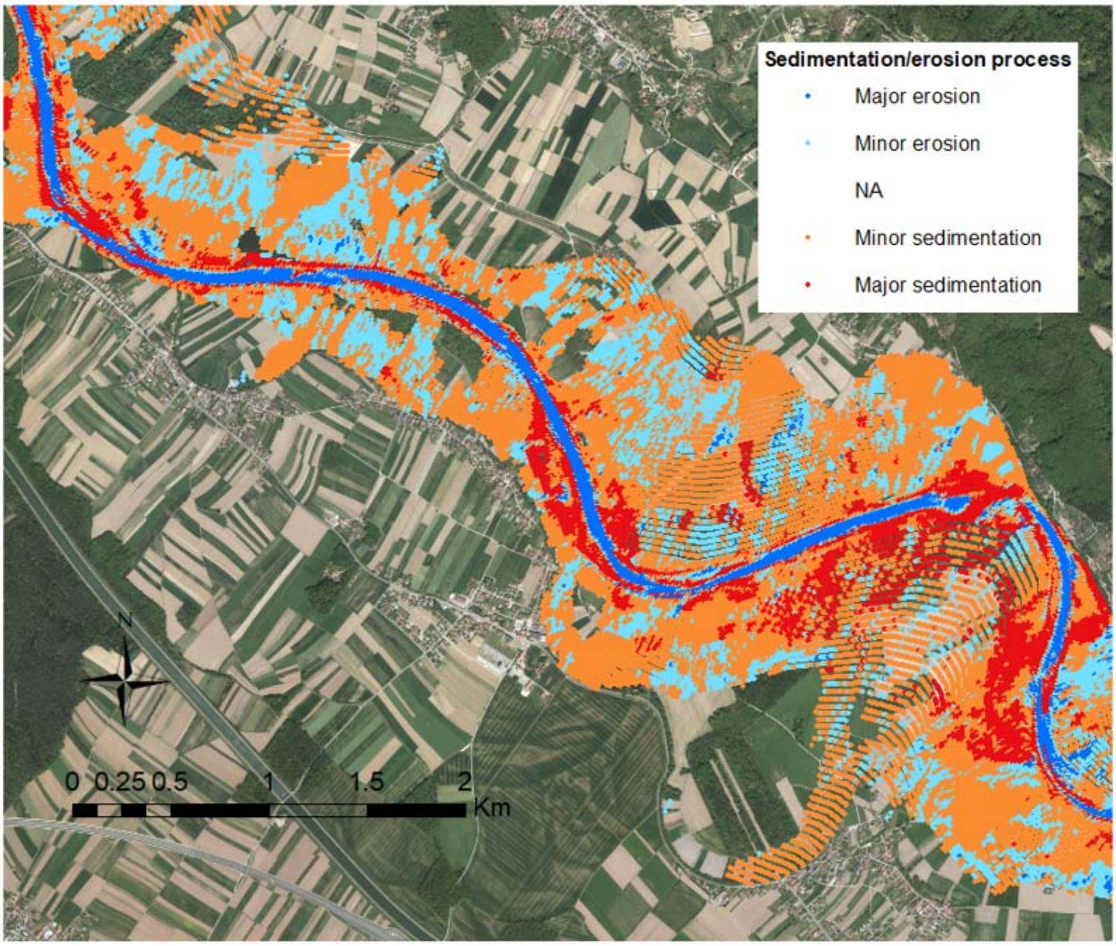


Figure 38. Presentation of preliminary results of sediment transport analysis with assignments of areas with erosion and/or deposition/sedimentation

4 Ecological effects

4.1.1 Drava River (Slovenia) case study

Ecological monitoring program on Drava River (Slovenia) case study is made of two parts. First part is actually the summary of official regular ecological monitoring (water quality monitoring) as conducted by the Environmental Agency of the Ministry of Environment and Spatial Planning. Second part is basically ecological monitoring based on proposed modelling scenarios, ie. habitat modelling. Contrary to plan in D.T 3.1.1, biota sampling as a basis to habitat model was not and will not be specifically carried out, since we decided to use the most recent existing biota monitoring data (specifically fish) from the Fisheries Research Insitute of Slovenia.

4.1.1.1 Official national monitoring

The monitoring offreshwater ecological status includes monitoring of biological, physico-chemical, hydromorphological quality elements and analyses of river basin specific pollutants in Slovenian rivers, lakes, coastal and territorial sea. The monitoring is carried out in accordance with the Decree on the Status of Surface Waters andother legal regulations.

Table 6: Ecological monitoring locations within the pilot area

Location	GKY	GKX	Measurement type
Starše	559455	148193	Water quality monitoring

In the following table we present the summary of the monitored elements from 2009-2015.

Table 7: Ecological monitoring summary of the period 2009-2015

Waterbody name	BIOLOGICAL ELEMENTS				PHYSICO-CHEMICAL ELEMENTS				ECOLOGICAL STATUS
	Phytobenthos and macrophytes		Benthic invertebrates		General physico-chemical elements			Special pollutants	
	Saprobity	Trophicity	Saprobity	Hymo degradation	BPK5	Nitrates	Whole phosphorus		
Drava Dravograd - Maribor	GOOD	GOOD	GOOD	POOR	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	MODERATE OR WORSE
Drava Maribor - Ptuj	**GOOD**	**GOOD**	**VERY GOOD**	**GOOD**	**VERY GOOD**	**VERY GOOD**	**VERY GOOD**	**GOOD**	**GOOD**
Drava Ptuj - Ormož	GOOD	GOOD	VERY GOOD	GOOD	VERY GOOD	GOOD	GOOD	GOOD	GOOD

After that period, only data of special pollutants (municipal wastewater treatment plant) of the pilot area is currently available (very good status). Fish species degradation status is available through the data of Fisheries Institute wihin the habitat modelling. In previous table, we decided to, in addition to the pilot area in bold, present the ecological status in the upstream and downstream Drava River reach near Maribor.

4.1.1.2 Habitat modelling

To support an evaluation of different measures, e.g. increased Environmental flow, construction of groynes, bottom weirs etc., habitat modelling was applied. On the basis of discussion with Slovenian Fishery Institute as a representative fish species as indicator Hucho hucho (Danube salmon) was selected. In the past (before construction of the dams with insufficient longitudinal connectivity and hydropower water abstractions) Danube salmon was abounded in pilot case Drava.

For the habitat modelling we considered main physical parameters: flow velocity, water depths and substrate. Also cover is main physical parameter but for the adult Danube salmon, predator fish on the top of the river food chain, what is the case, we did not apply it. Next figure shows preference functions for the considered main physical parameters which are normalized. To evaluate/calculate the habitat suitability the mesh of hydrodynamic 2D model was used. For certain cell i at first values for all considered physical parameters are calculated on the basis of corresponding preference curve for analysed water discharge, for water depth Di is calculated, for water velocity Vi is calculated and for substrate Si is calculated. Suitability of a cell i suitability SI_i which ranges from 0 to 1, is then expressed as:

$$SI_i = D_i \cdot V_i \cdot S_i \,.$$

For evaluation of Habitat suitability we used characteristic weighted usable area (WUA), for each analysed water discharge j WUA_j is expressed as:

$$WUA_{Qj} = \sum_1^n A_i \cdot SI_i \,,$$

where Ai is corresponding area of cell i and Q_j is analysed water discharge.

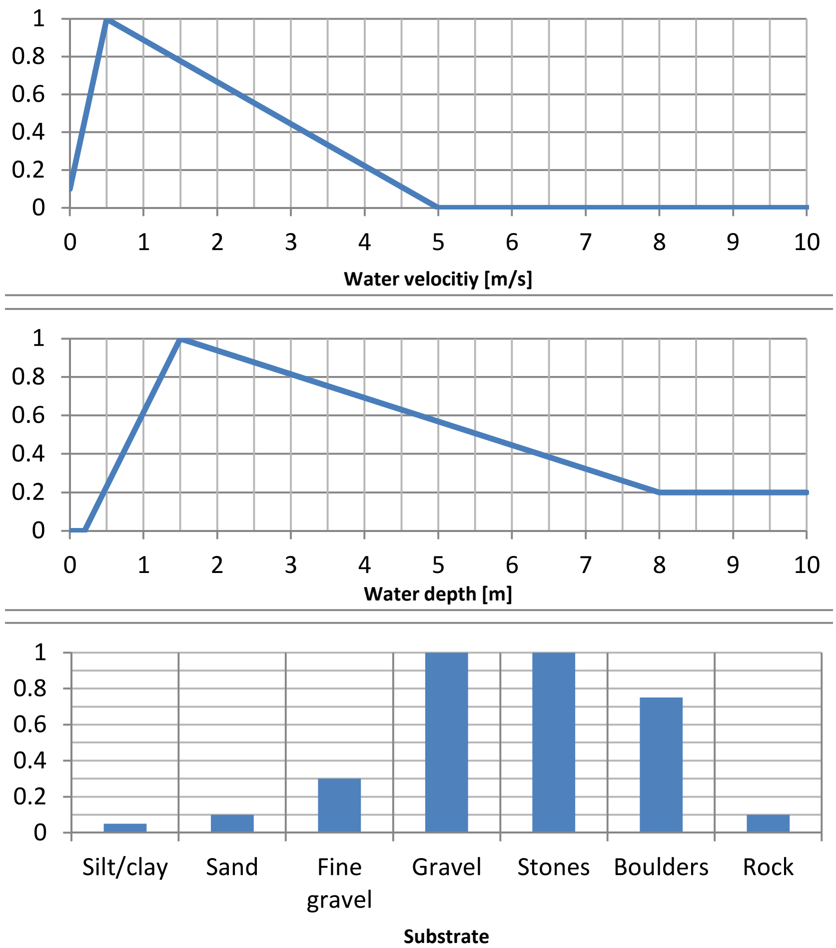


Figure 39. Normalized preference curves for adult Danube salmon for habitat suitability modelling

Habitat suitability was analysed for a series of discharges from 10 m^3/s to 60 m^3/s with a step of 10 m3/s and from 80 m^3/s to 300 m^3/s with a step of 20 m^3/s. In total 18 water discharges were analysed. Q = 300 m^3/s is also a mean discharge of Drava river in Pilot case Drava.

Total number of analysed cells was defined with wetted area in the case of highest analysed water discharge, Q = 300 m^3/s. In total wetted area of Pilot case Drava in case of discharge Q = 300 m^3/s is around 2.41 MIO m^2 or 241 ha. Next figure shows WUA in areas corresponding to certain selected classes of values of SI. It can be observed that WUA with highest value of SI, from 0.75 to 1.00 is highest at discharge around Q = 140 m^3/s, but in the case WUA is defined with summation of areas with SI from 0.50 to 1.00, highest WUA is more than Q = 300 m^3/s. In similar way if WUA is defined with summation of areas with SI from 0.20 to 1.00, what is also acceptable since SI is a product of three parameters, highest WUA is around Q = 220 m^3/s.

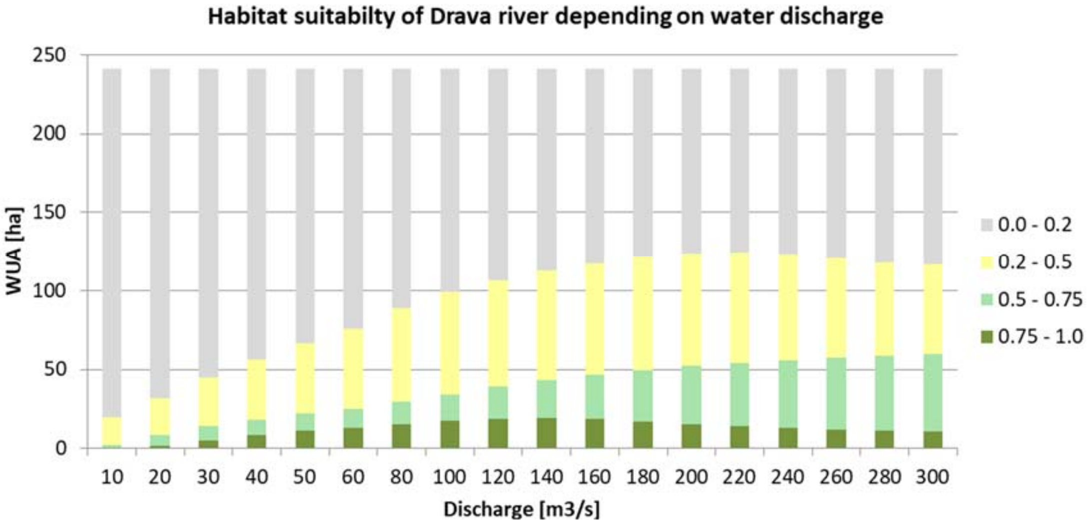


Figure 40. Habitat suitability of pilot case Drava depending on discharges presented in total number of wetted cells at discharge Q = 300 m^3/s

Next figure shows another presentation of the results where WUA for analysed discharges is presented in the case SI is from 0.75 to 1.00. Next line (red) shows increase or decrease with increase of water discharge. It can be observed that highest increase is in the case when discharge is increased from 30 m^3/s to 40 m^3/s, almost 4 ha. Increase is still very high, more than 2 ha, when discharges are elevated up to 60 m^3/s, and more than 1 ha, when discharges are increased up to 100 m^3/s.

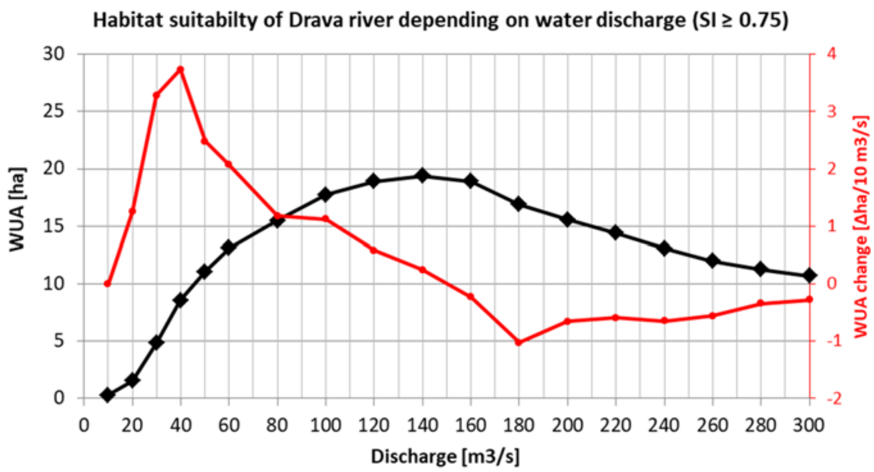


Figure 41. Habitat suitability presented with WUA in SI range from 0.75 to 1.00 and presentation of the WUA change in [ha] due to the water discharge increase

These are preliminary results, which should be verified in next steps of research. Especially in the case of substrate determination, because the data on substrate were not sufficient and the substrate was defined on the basis of sediment transport modelling.

5 Conclusions and perspectives

To evaluate the effects of measures to improve the ecological and hydromorpohological state of Drava River in section between Melje dam and Ptujsko Lake on availability of ecosystem services in the area, we applied these measures together with results of monitoring programs to a few separate sediment transport models (measure location dependent) including the habitat model. Monitoring data within our pilot site was in part obtained through already finished recent studies and in part through monitoring campaigns specifically done for the purposes of HyMoCARES project.

Two separate groups of monitoring campaigns were done for the purposes to obtain the crucial input data to properly execute the sediment transport model. First group of monitoring campaigns was done to obtain the data of suspended sediment concentration in relation to constant (environmental) flow in winter, summer and in case of an extreme hydrological event. Data, obtained from these campaigns (especially from the extreme hydrological event, which occurred at the end of October 2018) was used as an input data to evaluate the effect of restoration projects already done on one hand (groynes) and to assist at properly developing the habitat model.

Increased (dynamic) environmental flow and groynes were recognized as key measures we needed to concentrate on within our sediment transport and habitat modelling. Effect of groynes was evaluated by analysing the sediment erosion and deposition levels changes before and after additional groynes construction whereas increase of environmental flow was evaluated by applying various low-level discharges and observing the effect on river morphology. In addition, difference to the sediment transport model used to study the groynes effect was the addition of bedload component to the habitat model as opposed to groynes effect analysis where only suspended sediment component was considered through model input data.

Effect of groynes reconstruction near Starše village is clearly evident by applying an actual hydrological event from end of October 2018 to the sediment transport model. There is a significant reduction of sediment erosion and deposition when comparing pre- and post groynes reconstruction state. Groynes effect on the availability of ecosystem services, eg. Provisioning of habitat for biodiversity and flood risk mitigation is positive. On other hand, no particular detrimental effect is identified of groynes reconstruction on the ES availability.

No particular restoration was done at the Malečnik bridge columns, however due to the patches of eroded sediment due to long-term scouring, we tested the idea of longer-lasting (up to Q_{10}) steady high discharges effect on bridge columns scouring. Similar to groynes reconstruction analysis, we compared the erosion/deposition intensities before and after the 2012 floods. Results show more intense sediment erosion/deposition dynamics before the floods, most likely due to abundance of smallest sediment fractions. Extreme discharges of 2012 brought larger sediment fractions downstream, thus, erosion/deposition levels are lower.

Habitat modelling was performed to help evaluate main identified measures within the pilot area, ie. increased Environmental flow, construction of groynes, etc. *Hucho hucho* was selected as a representative species, due to the abundance of this species before the dams breaking longitudinal connectivity. Hydrodynamic and sediment transport model helped us evaluate Habitat suitability of the selected representative species through *weighted usable area (WUA)*. Discharges ranged from 10 to 60 m^3/s (intervals of 10 m^3/s) and then from 80 to 300 m^3/s (intervals of 20 m^3/s). Suitability index (SI) was calculated for each cell of the numerical mesh as a product of water depth, water velocity and substrate data. Model is now still in its (pre)verification phase, so these are only initial, preliminary results. These results show WUA according to 4 selected SI class/interval summations, eg. SI is 0.2 – 1.0, then highest WUA is at approx. Q = 220 m^3/s and SI is 0.75 – 1.0, then highest WUA is at approx. Q = 140 m^3/s. We also discovered that the highest increase of WUA for *hucho hucho* is when discharge is elevated from 30 to 40 m^3/s.

This latest finding is a suitable basis to the amendment of environmental flow, especially when considering positive effects on identified ES availability in this pilot area, eg. habitat provisioning, tourism and recreation, water for non-drinking purposes, etc. In this case, however the increase of environmental flow conflicts with the availability of water generated energy (hydropower).

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