Technical note about the monitoring of hydromorphological restoration/management of the Drava River in Slovenia

List of involved PPs

IzVRS

1. General presentation of the study site

Drava River is a transnational river, originating in the south-tyrolean Alps near the border with Austria. It runs through Italy, Austria, Slovenia and Croatia, where it becomes the fourth largest tributary of Danube near the city of Osijek. Drava River is Slovenia's most water-rich river, since it has large basin area with some of its tributaries in the upper reaches originating from the glaciers in the High Turracher Alps. Upstream Drava River reaches have steep slopes, transporting large amounts of sediment (bedload); however, run-of-the-river hydropower plants (HPP) in Austria and Slovenia (ten (10) in Austria, eight (8) in Slovenia) influence the sediment transport downstream. Geologically, Drava River runs mainly through the Southern Alpine Crystalline and especially Southern Alpine Mesozoic and tertiar structures with some recent sediment deposits in Slovenia.

In Slovenia, Drava River has rain-snow runoff regime with the initial peak in June and a second, weaker peak in October. Mean annual precipitation in the area is 1000 mm. From the Austrian-Slovenian state border, Drava River runs through the Drava valley southbound of Kozjak and northbound of Pohorje hills, while receiving many torrential tributaries along the way. Upstream of Maribor, the valley widens and Drava River reaches the heavily populated urban areas. Below the urban area of Maribor, in the ice age, Drava River has created a large Drava Field alluvial fan into which it has cut the present valley near the foothills of Slovenske Gorice.

The study site of Drava is located in the eastern Alpine region in Slovenia near the second largest city in Slovenia, Maribor.

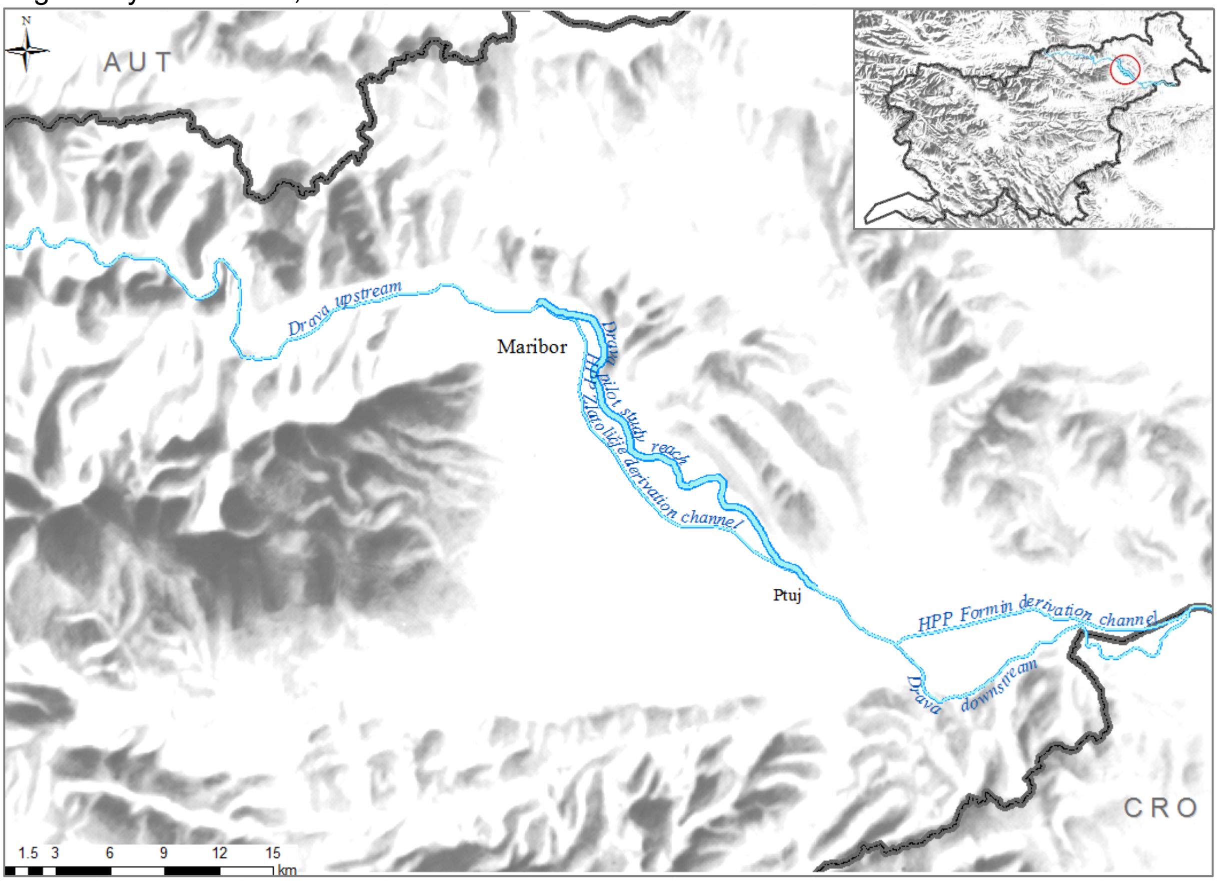

Figure 1. Pilot area reach as a part of Drava River in Slovenia
Table 1. Main physical features of the pilot site

Pilot Site	Pilot site upper boundary	Pilot site lower boundary
Drainage area (km²)*	13.450 km^2	13.664 km^2
Location	46°33'28'' N/15°40'47''E	46°25'10'' N/15°51'44''E
Length of the study reach (km)	26,45	
Active channel width (m)	45 ÷ 55	
Channel slope (m/m)	0,0011	
Planform morphology	Wandering	

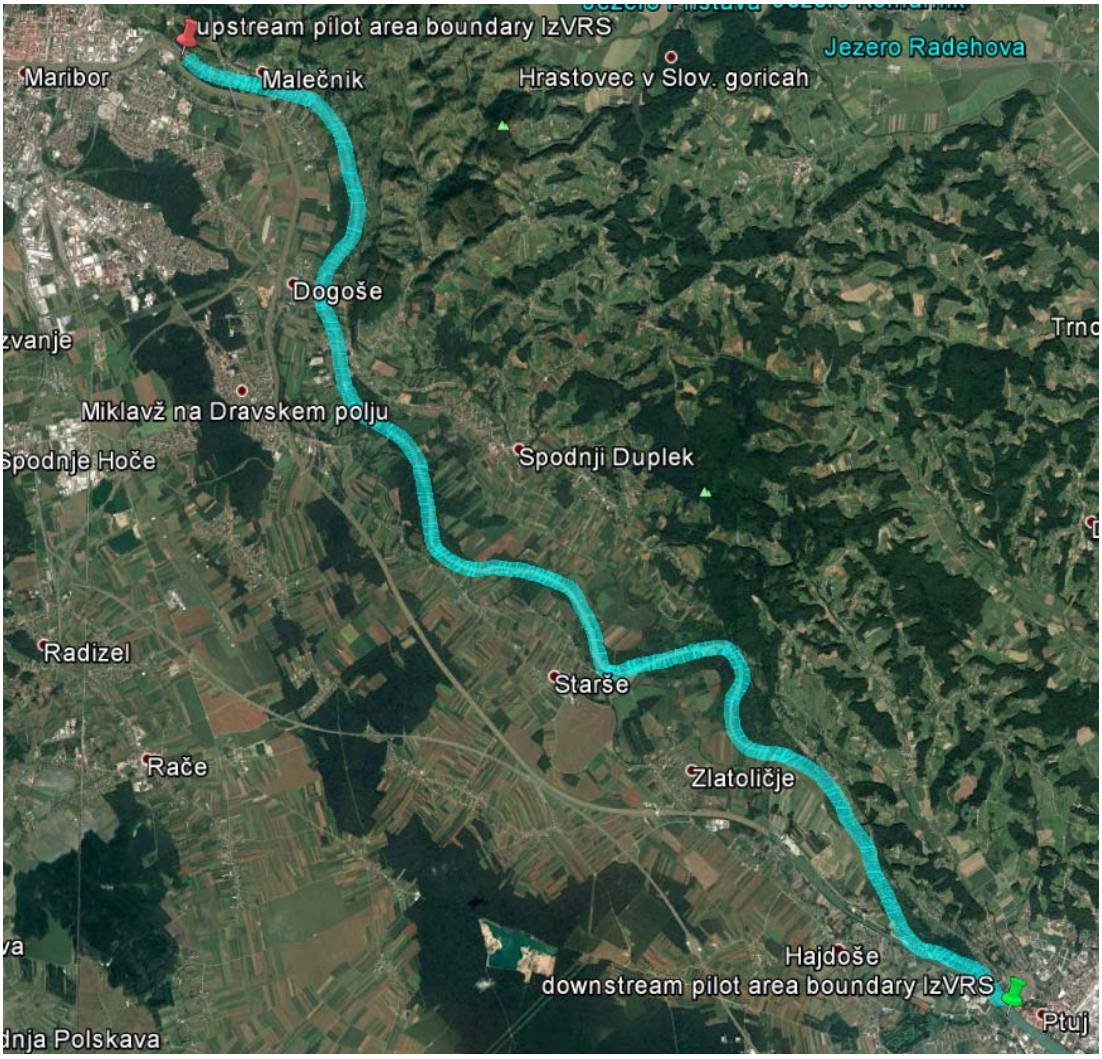

Figure 2. Pilot area reach (Maribor/Melje dam – Ptujsko lake inlet)

Pilot study area reach upstream boundary point is just downstream of Melje dam, where Drava River channel divides into two reaches – one, artificial derivation channel, leading to HPP Zlatoličje powerplant (installed flow 530 m3/s) and other, natural Drava river channel (bypassed reach) running at the foothills of Slovenske Gorice. This reach has a predefined environmental flow of 10 m^3/s in the winter months (from November to February) and 20 m^3/s in the warmer season (from March to October). These two channels meet again just upstream of Ptujsko lake inlet.

Figure 3. Section of pilot area reach near Malečnik (downstream of Melje dam)

2. 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 (extensive suspended deposits in the areas of the reduced flow),
- 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,
- Cropland development is exposing topsoil to the rainfall erosion and thus causing soil washing off the fields into river.

Hydromorphological restoration works in the pilot area are mostly due to improving flood protection in the area, since the area has been regularly flooded in the last 15 years. Restoration works however are limited with the introduction of the Natura 2000 nature conservation legislative system. Following is the table of the main restoration works at the study site.

Table 2. Locations and types of restoration works at the pilot/study site Drava (SI)

Site	Location		Restoration works	Period
	Lat [°]	Lon [°]		
Gravel bar 1	46,510	15,717	Lowering and merging of two gravel bars to slow down vegetation encroachment, selective vegetation removal (bushes, shrubs, etc.) to increase hydraulic capacity	2003 , 2009, 2012
Gravel bar 3	46,516	15,715	Vegetation removal, tree cutting to increase river cross section/hydraulic capacity, gravel bar upper layer restoration. In 2012 gravel bar narrowing 711m long x 21m wide; for the purpose of reducing the hydraulic roughness of the channel	2002, 2007-2008, 2010 - 2012
Gravel bar 4	46,524	15,712	Two-phase gravel bar restoration, selective vegetation removal, upper gravel bar layer removal, selective tree removal, trench creation for the purpose to store removed gravel-upper layer mix	2001, 2007-2008, 2010, 2012
Gravel bar 6	46,534	15,717	Floods in November 2012 caused extended sediment depositions, which filled up oxbow lakes and consequently caused decreasing of river cross section capacity. Sediment deposits in vclume of 10.700 m^3 were removed and new river branch was formed.	2013
Gravel bar 9	46,551	15,710	Lowering (levelling) of gravel bar (in 2002 and 2003), nearby meander sediment reinjection, vegetation removal (smaller trees, shrubs, etc.), except for the central area of the gravel bar, upper earth layer removal to slow down vegetation encroachment. In 2011 and 2012, elevating the gravel bar level by reducing the total area of the gravel bar. Maintenance works to maintain hydraulic capacity after 2012 floods.	2002-2003, 2009, 2011-2013
Gravel bar 10	46,554	15,696	Partly and selective removal of vegetation, excavation of filled meander near the bank; deposited sediment removal near the centreline of the Drava River, part of the removed sediment was used to elevate part of the gravel bar near the left bank, additional lowering of gravel bar after floods in November 2012 – hydraulic capacity increase/flood protection level maintenance	2008-2010, 2013
Gravel bar near the highway bridge columns	46,558	15,679	To mitigate floods because of the narrowing of river cross section in this area due to sediment depositions after the highway bridge construction, the following restoration works were done – sediment deposit and vegetation removal between cross section 5E and 7 (see figure), new artificial meander between cross section 6D and 7, bridge columns protection with quarry stone and vegetation removal with gravel bar lowering between cross sections 5D and 7E and smaller branch construction between cross sections 4E and 5D on the right bank. On the left bank some riprap protection and gravel bar lowering between cross sections 3 and 5E together with 7B and 8A.	2008-2011
Groynes construction	46,468	15,777	To mitigate further bank and riverbed erosion, 4 groynes, 10-14 m long and inclined 15° to the axis of bypassed reach were constructed. Groynes were made of individual gabions, filled with quarry stones. Additional 4 groynes were constructed in 2013, each 12 m long and inclined 15° to the axis of bypassed reach. Total 8 groynes construction.	2012-2013
Gravel bar reconstruction	46,559	15,676	Newly formed gravel bar (after floods in 2012) reconstruction to mitigate the occurrence of depression areas within the gravel bar	2014

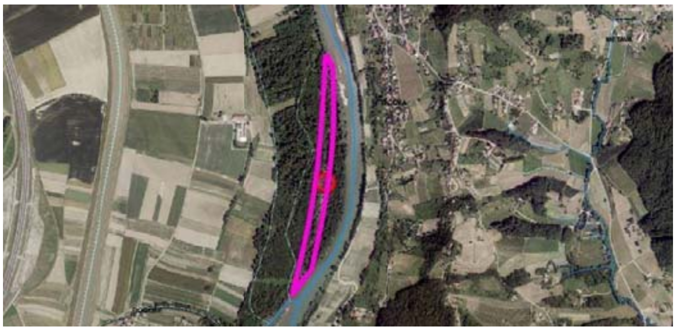
Figure 4. New branch at gravel bar 6 formation

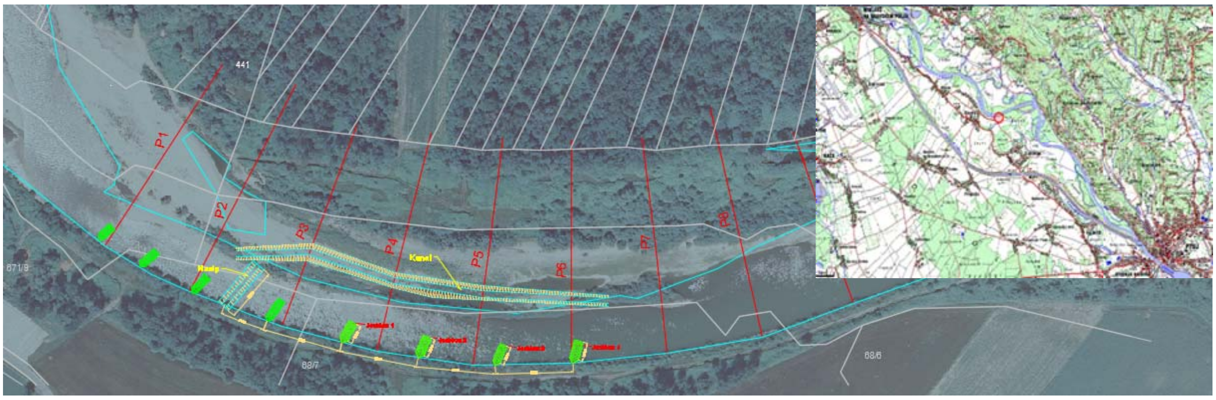
Figure 5. Groyne construction location (green colour)

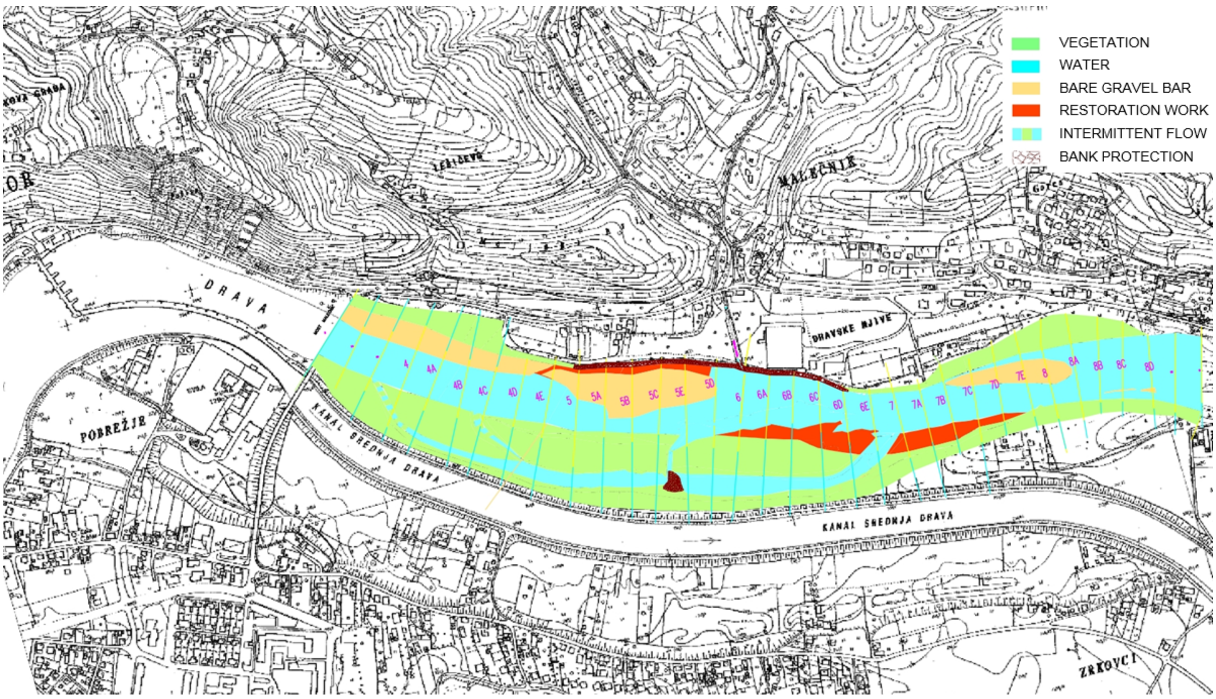

Figure 6. Restoration works at the gravel bar formation near the highway bridge columns (Malečnik)

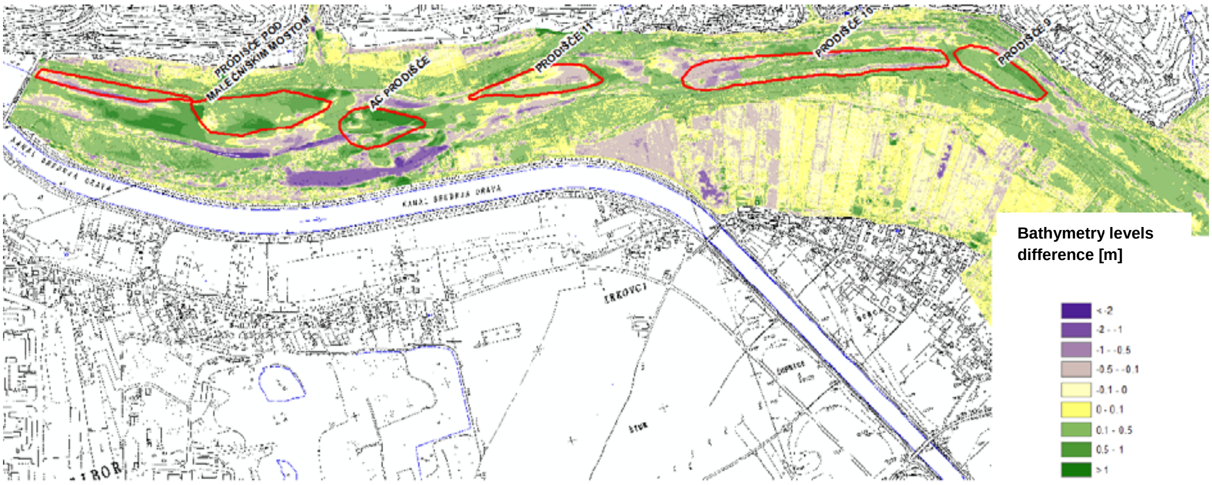

Figure 7. Sediment erosion/deposits after floods in 2012 (red-lined gravel bars) (source: VGB Mb, 2013)

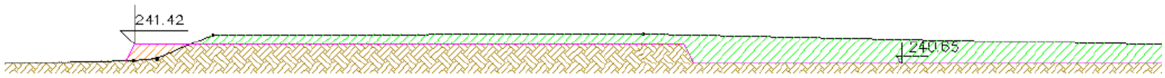

Figure 8. Sediment depositions removal on gravel bar 11 (source: VGB Mb, 2013)

Additionally to the aforementioned restoration works per location, riverbed maintenance works are done regularly due to the depositions of suspended sediment in the riverbed after occurrence of high discharges (ie. 1.000 m^3/s or above). If not promptly removed, hard compact consolidated clay/silt depositions form (affecting hydraulic capacity, habitats due to decreased oxygen levels, etc.), which can be adequately removed only mechanically.

Figure 9. Restoration works (autumn 2012) – gravel bar 1 and 3 (star marked) (source: VGB Mb 2013)

The majority of restoration works were in Malečnik area, i.e. in the upper part of the study area. The time-lapse of the works done since the year 2001 is presented below. Main reason for these works is riverbed and riparian maintenance to enhance flood protection , especially since the 2012 major floods.

The bypassed, regulated reach that is the focus of this pilot study analysis has predefined minimal, regulated (environmental) flows, which alter hydraulic and consequently hydromorphological conditions. Hence, the main objectives are to optimize the level of availability of ecosystem services while maintaining good hydromorphological conditions. Within this pilot area the main identified goals (ordered by the level of importance) to reach these objectives are decreasing of channel clogging and improving flood protection, increasing substrate heterogeneity of the channel and development of new macroforms.

Figure 10. Time-lapse (2001 – 2016) of restoration works in the upper part of Drava River pilot area (Background images source: Google Earth)

3. Monitoring activities

3.1 General objectives of the monitoring program

A bypassed regulated reach with environmental flow of 10 m^3/s in dry season and 20 m^3/s in rainy season represents study area on Drava River. At normal hydrological conditions, water is diverted through artificial open channel to HPP Zlatoličje powerhouse, with obligatory 10 (20) m^3/s derived via Melje run-of-the-river dam to the bypassed regulated Drava River reach.

Within this study area, we plan to connect and identify common strategies and synergies with already undertaken activities on this river reach. Besides obligatory (periodical) maintenance works (gravel bars, river/riparian vegetation management), there are also opportunities by connecting to LiveDrava LIFE+ project (2012-2017, http://livedrava.ptice.si) – riparian ecosystem restoration of the lower Drava River in Slovenia and some other sediment transport management related activities/other river restoration plans.

Main objective of our planned monitoring is to obtain crucial data by precise field surveys to enhance the existing survey data (external expertise) and executing geological drill holes to obtain lacking riverbed samples for sediment transport modelling. We will obtain other necessary data through scheduled monitoring of national hydrological service, dam management services and through aforementioned active projects. Results of modelling will then be the basis to identify the effect of hydromorphology on ecosystem services and optimize their relation.

3.2 Physical monitoring

Physical monitoring on the Drava study area will consist of the following:

- Geological riverbed drill holes to obtain samples (one – time),
- Gravel bar sampling (1-2 times),
- 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,
- Suspended sediment measurements; 2-3 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 m^3/s and above). This is to determine the effect of various scenarios (e-flow increase, etc.) on fine/suspended sediment remobilization in the channel.

We present proposed drill holes locations on the following figures; however, the precise location is still subject to more thorough terrain analyses. Additionally, we chose areas of interest (AOI) – potential restoration locations within the study area at which detailed sediment erosion/deposits dynamics will be thoroughly analysed (sediment transport modelling together with resulting river hydraulics).

River sediment transport/dynamics will be analysed according to corresponding ecosystem services, i.e.:

- sediment transport modelling based on extreme hydrologic conditions and influence on flood protection and vice-versa,
- sediment transport modelling based on low flows and hydromorphologic influence on selected (riparian) areas,
- proposed scenarios of dynamically regulated environmental flow and its influence on hydromorphologic conditions on pre-selected areas of interest within the study area,
- habitat modelling, ie. modelling in an upper 10 km of the bypassed reach (heading downstream of Melje dam) of representative fish species using hydrodynamic modelling and fish data sampling to simulate habitat suitability in case of altered flow (focus on e-flow) in the channel.

Based on this, interim results in the following form will serve as a supporting data for the modelling phase:

- sediment deposits/erosion locations and levels by 3D comparison of available terrain/bathymetry,
- generated grain-size curves from drill holes and gravel bar sampling,
- 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:

    - Jet tests to assess the erodibility of fine-grained sediment with respect to shear stresses of the flow;
    - Bore hole shear tests to assess shear parameters, determining the stability of the bank with respect to bank collapse;
    - Determination of bulk density using cylinder samples;
    - Grain size analyses;
    - Photogrammetric survey of the tested bank will additionally allow assessing the bank roughness to determine the portion of shear stress which effectively acts as an erosive shear stress on the bank surface, and will help characterizing the bank geometry.

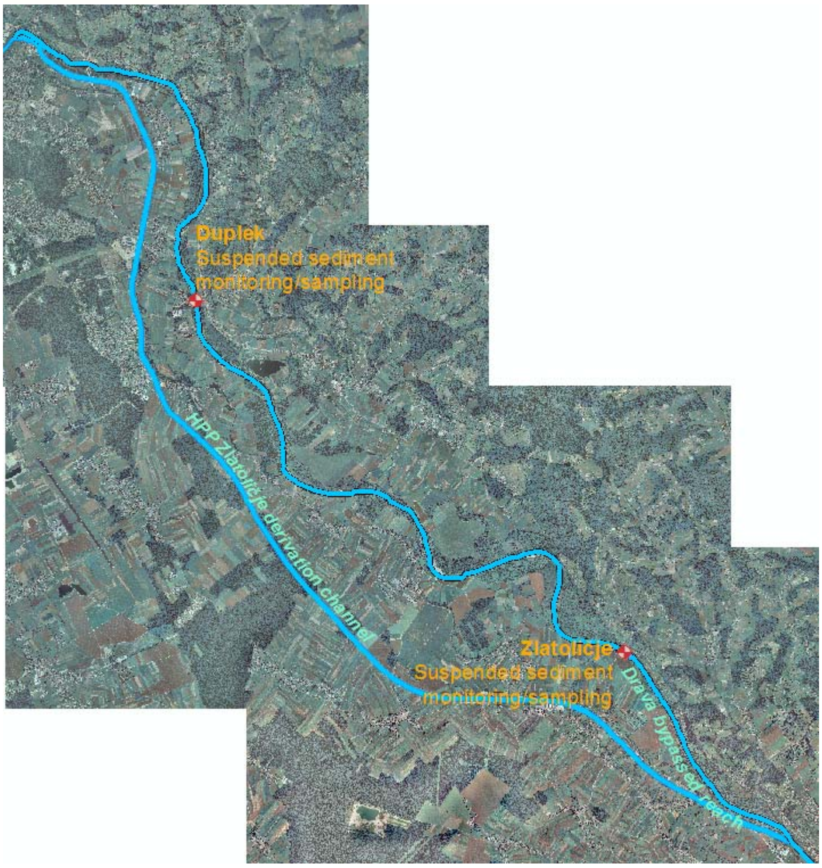

Figure 11. Locations of suspended sediment monitoring/sampling

Measurement frequency of sediment concentration monitoring is foreseen as 10 times in 2 different locations (see previous image) in the time of winter hydrologic conditions and similarly 10 times at 2 different locations along the bypassed reach in summer hydrologic conditions. There is also plan to measure sediment concentration in the case of discharges exceeding 700 m^3/s (1-2 times, if such event should occur); bank erosion monitoring will be as a one-time event only.

We identified three areas of interest within this study reach to see the effect of applied hydrologic scenarios to the model (increased e-flow, etc.):

- AOI1 - habitat modelling section of approx. 10 km length,
- AOI2 - bridge column scour development will be analysed (sediment around the bridge columns has been eroded to the foundations through the years);
- AOI3 – sediment deposition/erosion dynamics under the bridge and in the local areas near the bridge columns (scour) will be analysed.

Model, based on applied scenarios (altered/gradually elevated e-flow, etc.) will be run separately for habitat modelling since the shorter section within the bypassed reach requires less computational efforts. To analyse the effect of bridge column scouring as a consequence of aforementioned applied hydrologic scenarios, sediment transport model will be run along the whole reach and simultaneously, the morphologic changes (due to riverbed works as a part of riverbed restoration) along the bypassed reach will be analysed.

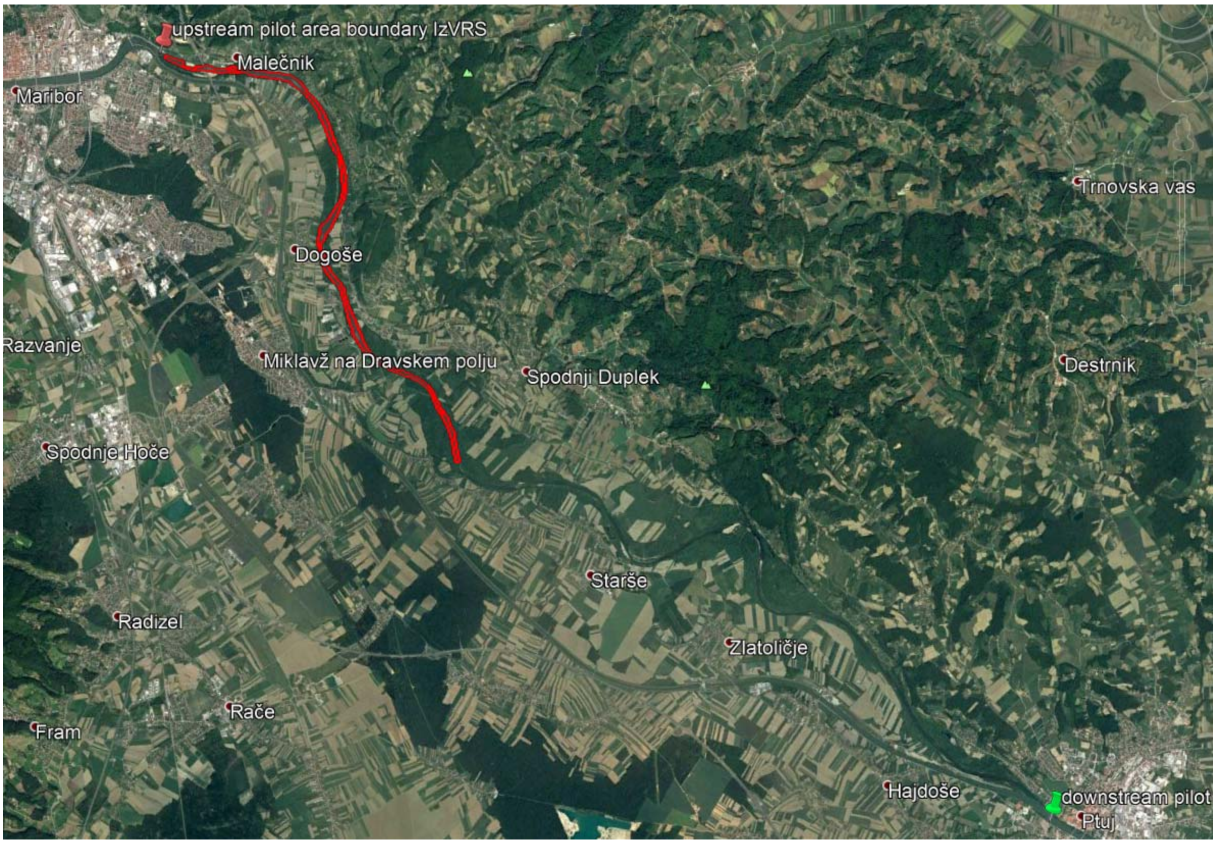

Figure 12. Areas of interest 1 – habitat modelling section; upper pilot area, length approx. 10 km

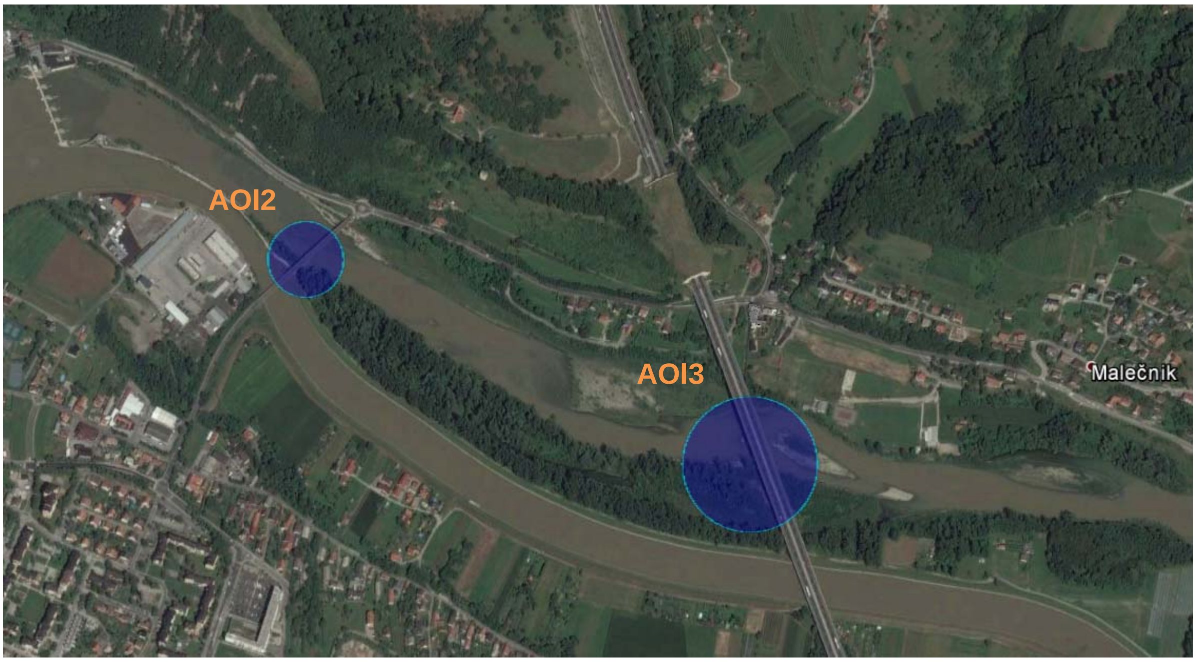

Figure 13. Areas of interest 2 and 3 – bridge column scour analysis locations

Figure 14. Area of interest 2 – bridge column scour locations (arrows)

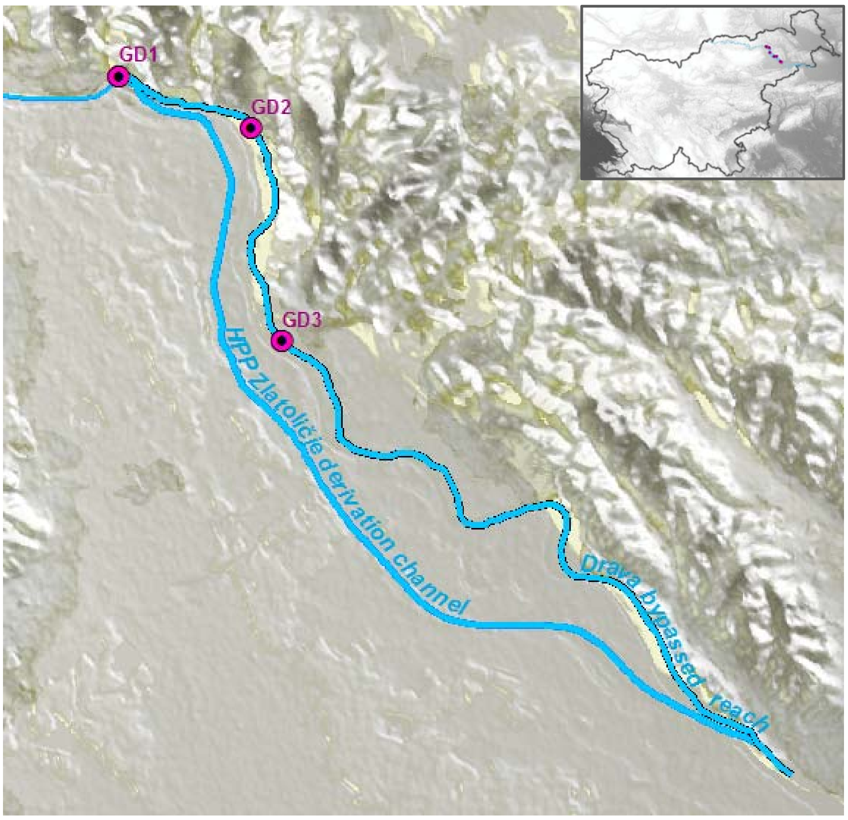

Figure 15. Proposed geological drill hole and area of interest locations in the study area

3.3 Ecological monitoring

Ecological monitoring on the study site consists of two parts:

- Official regular ecological monitoring (water quality monitoring) run by the Environmental Agency of the Ministry of the Environment,
- Ecological monitoring based on the proposed modelling scenarios (e.g. habitat modelling, biota sampling).

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.

Figure 12 shows the location of hydrological monitoring stations (blue) and water quality monitoring stations (green) run by Slovenian environment agency (ARSO).

Hydrological monitoring includes measuring:
- Water table,
- Flow velocity,
- Water temperature,
- Concentration of suspended material/turbidity,
- Geometry measurement of section.

Water quality monitoring includes measuring for defining:
- Chemical status,
- Ecological status.

Both statuses are depending on specific pollutants characterised in pilot area.
Obtained data will be used as an input for habitat modelling. Within habitat modelling, fish fauna monitoring is expected (including electric fishing) and some benthic invertebrate sampling (basis to estimate hydromorphological alteration).

Table 3. Location and measurement type of monitoring on Drava 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

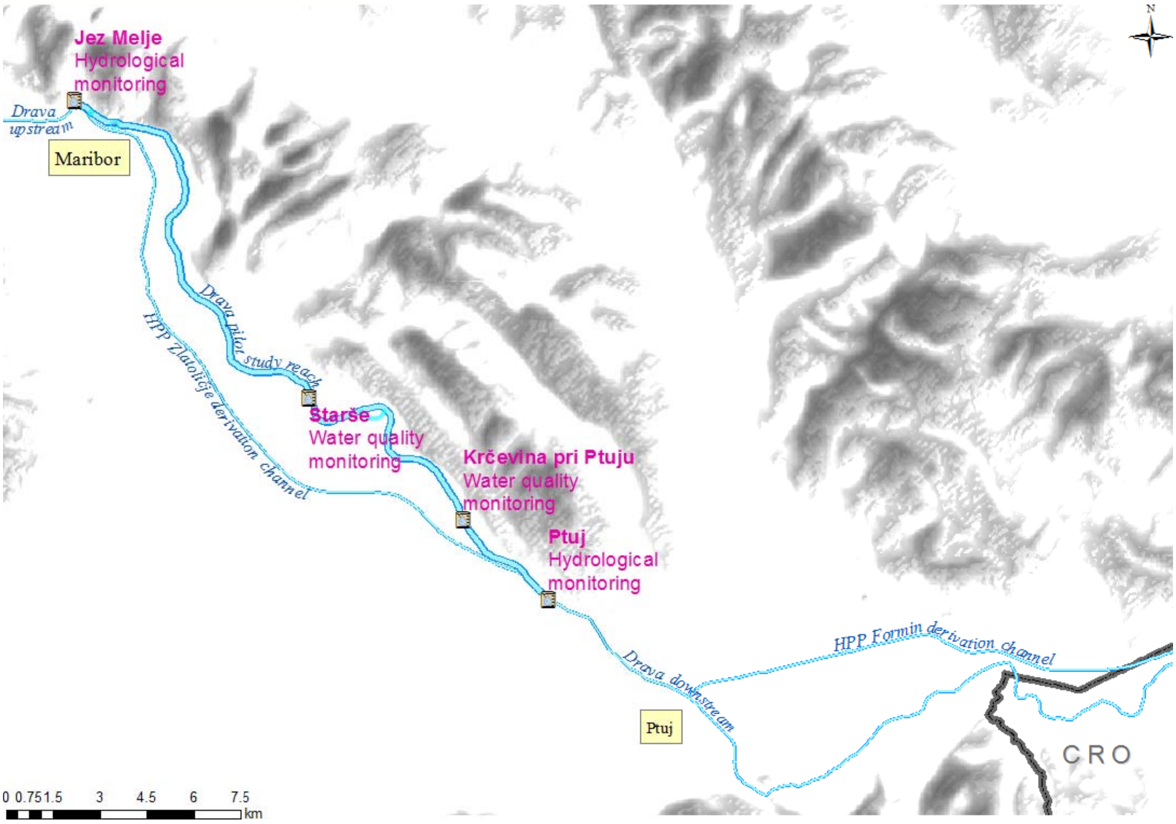

Figure 16. National monitoring network on Drava case study area

Habitat modelling

Habitat modelling will be determining the suitability of habitat based on a small number of selected environmental factors whose interactions largely determine the properties of the habitat. It will compare 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 we will use two major groups of the input data: numerical data (in this case hydraulic data: the depth of water and the speed of the water flow), and the descriptive information together with the indexed data (particle size of the substrate and the type of hiding areas).