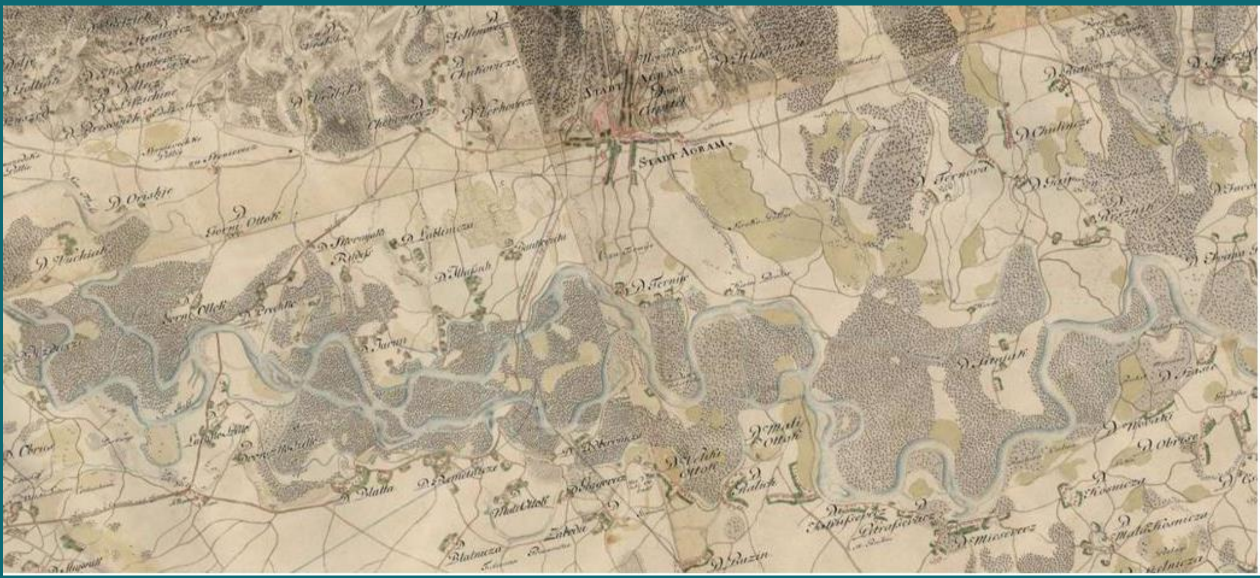

Sava River restoration from Brežice to Rugvica - feasibility study

River restoration concept based on calculations of optimal river width

November 2021

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Nußdorf-Debant, November 2021

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1 Summary

The Sava White Book (Schwarz, 2016) describes threats and restoration potentials for the river Sava. Based on the facts and information listed in the Sava White Book, the Austrian company “REVITAL Integrative Naturraumplanung” prepared this feasibility study, on behalf of EuroNatur - European Nature Heritage Foundation. Riverbed incision is a huge problem, especially in the river stretch around Zagreb. This feasibility study describes possible causes of the depression and near natural measures to stop riverbed deepening.

The river Sava is a typical alluvial river. Without regulations of the riverbed, the river Sava would be in a transition zone between a braided multi-channel river system (upstream of Zagreb) to a meandering river (downstream of Zagreb). Due to human influence, morphology and the geometry of the river and its riverbed have changed in the last centuries and decades.

From the Slovenian border to downstream of Zagreb the river Sava is completely channelized. Around the city of Zagreb, the channel has the form of a double trapezoidal profile. The width of the riverbed is about 100 m. Continuous dikes and wide river forelands are typical for this river stretch. The distance between the dikes is about 300 m.

Downstream Zagreb, from Hrušćica to Rugvica (rkm 675) there is the last remaining braided and anabranching stretch of the river Sava in the project area, but it is also severely suffering from the bedload deficit.

Canalization and river regulation lead to poor or very poor hydro morphological status of the river Sava. The hydro morphological condition within the project area ranges from slightly modified (downstream of Zagreb) to severely modified in the river stretch through the City of Zagreb.

Another factor for riverbed incision is the lack of sediment coming downstream, caused by dams of Hydro Power Plants upstream the project area.

This feasibility study describes one possibility to stabilize the riverbed in a nature friendly way.

In a first step the optimal river width to stop riverbed incision was calculated based on different variables like channel geometry, discharge, mean slope and granulometry.

In a second step the project area was divided in five sections, to which similar measures can be assigned. In addition, two intervention areas to stabiles the riverbed with technical measures were defined.

The feasibility study shows that it is possible to stop riverbed incision with some initial measures like:

- building “initial channels”
- restoring soft banks
- widening the river
- flattening or lowering areas
- reinforce and reset bank protection

After implementing these measures integrative goals like riverbed stabilization, increased discharge capacity, improvement of the ecological situation and discard capacity as well as new recreational sites, can be reached.

2 Introduction

2.1 Project area

The project area includes the Sava and its surrounding area in the section between Rugvica (Croatia) rkm 673,8 and Brežice (Slovenia) rkm 738,0 (Figure 1). The river section under consideration is around 53 river kilometres long. In the middle of the project area is Zagreb, the capital city of Croatia.

The project area is extended by a small area around the Sava-Odra derivation channel, that is an important flood protection measure for the city of Zagreb.

Figure 1: Project area, river Sava from Rugvica (Croatia) rkm 673,8 to Brežice (Slovenia) rkm 738,0 and its surrounding area.

2.2 Problem definition

2.2.1 Current situation of rivers in Europe

In the 19th and 20th century, when the demands for cultivatable land, infrastructure and settlements increased and flood protection gained importance, many European rivers underwent systematic regulations. The channelisation works straightened the river course and constrained the flow into a narrow channel between protected riverbanks (Habersack & Piegay, 2007).

Accordingly, the capacity of sediment transporting was strongly decreased by river regulations, and hence caused massive riverbed incisions.

The incision was accelerated by decreased sediment supply from upstream. The missing sediment is the result of barriers like hydro power plants. The technical and ecological consequences of river regulations were noticed in the late 20th century, as they are:

- decrease of habitat diversity and availability and hence a loss of biodiversity and biomass,
- separation of the riparian floodplain from the river / water body by dikes,
- drop of the groundwater level,
- aggravation of flood risk downstream due to less dampening highwater peaks,
- scouring of bridge piers and bank protections, etc.

These consequences of river regulations necessitate the implementation of countermeasures to improve the existing situation and prevent further negative consequences (Klösch et al. 2019).

2.2.2 Current situation of river Sava in the project area

The river Sava, with a length of 926 km and a catchment area of over 97,800 km², the largest tributary of the Danube by discharge, did not escape this negative development either.

The middle and lower Sava is internationally recognised for its huge hardwood forests, the large near-natural flood retention system around the famous Lonjsko Polje Nature Park in Croatia. The river attracted international attention due to a historic flood in 2014. The alpine upper Sava in Slovenia crosses several breakthroughs stretches and small basins, and today is partially impounded by hydropower dams. Below Zagreb, the Sava valley is broad, and the river continues with a small slope all the way to the confluence with the Danube in Belgrade. (Sava White Book, 2016).

The approximately 53 km long Sava stretch from Brežice (rkm 738, Slovenian) to Rugvica (rkm 673,8 Croatia) is considered in more detail in this feasibility study.

2.2.2.1 River regulation

First major Sava river regulations started in 1899 and lasted until 1941. Historical flood in 1964 initiated additional regulations that were implemented in 60-ties and 70-ties of 20th century. The planned flood-protection system was never completely finalized. Upper middle Sava was regulated upstream Krško but with the construction of Hydropower plant (HPP) Brežice this section has been completely flooded by the hydropower reservoir since 2018.

The section downstream Brežice to Podsused is regulated but regaining meandering power. Active and former floodplain areas are partly protected as a special ornithological reserve and a Natura 2000 site, which offers some space for reconnection with Sava river.

Through the city of Zagreb, the Sava river is completely channelized in the form of a double trapezoidal profile. Continuous dikes and wide river forelands accompany the river. The distance between the dikes is about 300 m (Figure 2). However, in the river surroundings some floodplain areas still exist, which offer space for reconnection with the river Sava. A derivation channel Sava-Odra was built in late 60-ties for flood protection, starts in Zagreb around the Lučko area.

Downstream Zagreb, from Hrušćica to Rugvica (rkm 675) there is the last remaining braided and branched stretch of the Sava River in the project area (Figure 4). It is protected as a Natura 2000 site.

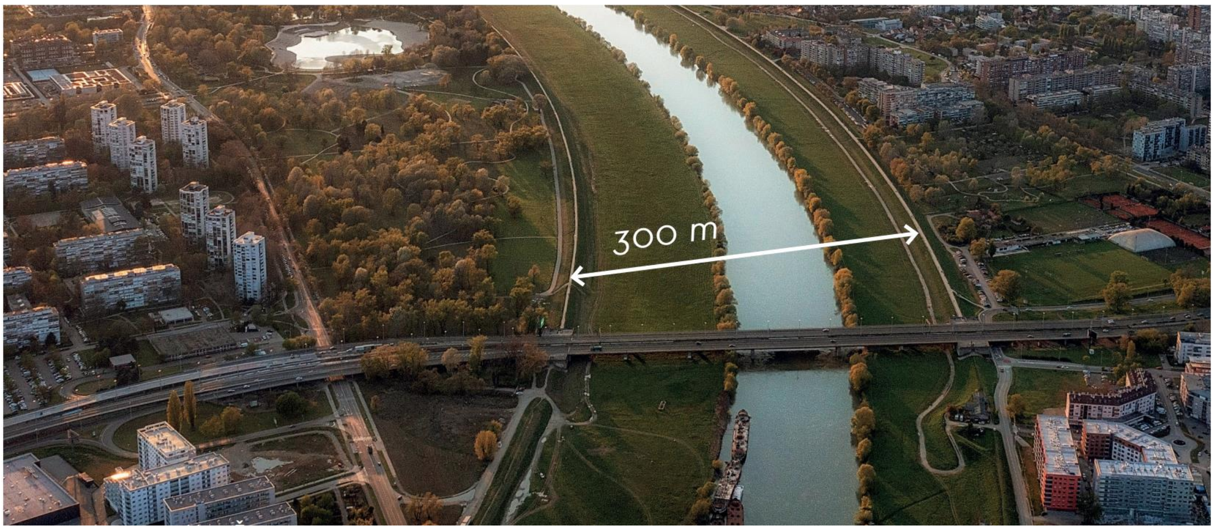


Figure 2: Current situation of Sava river in Zagreb (photo by: Mario Žilec).

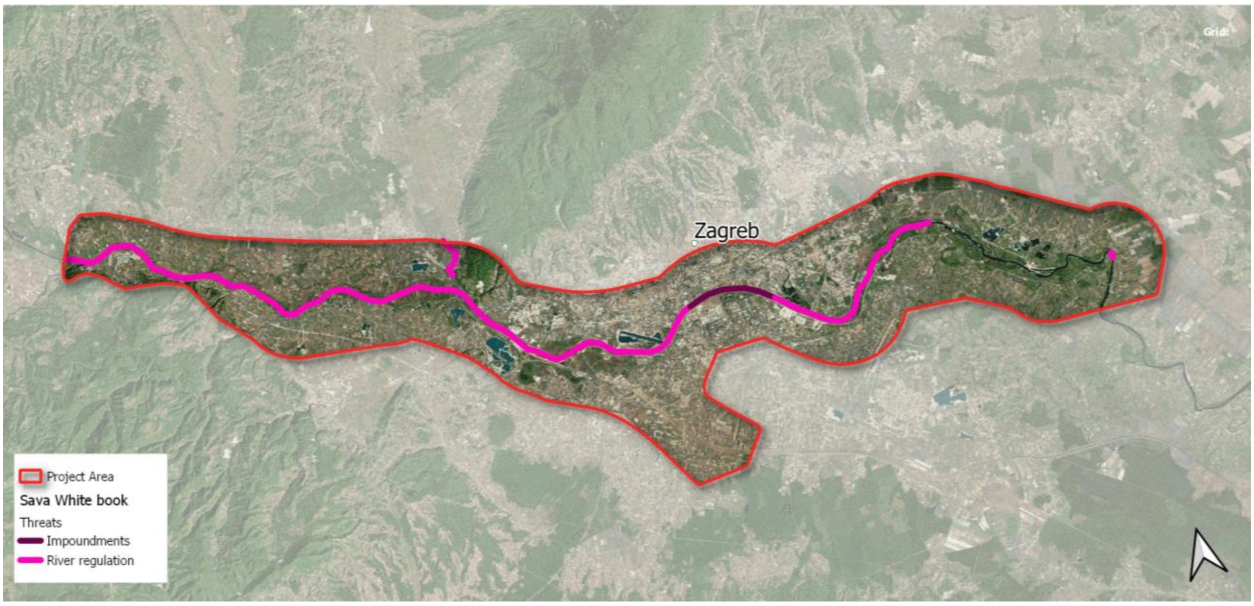


Figure 3: Current alterations and threats (impoundments, river regulation) along the Sava around Zagreb (Source: Sava White Book / SWB, 2016).

Figure 4: Historical situation of Upper middle Sava near Zagreb. Example for transition from branching to meander types (First military survey of Habsburg monarchy (1783–1784))

2.2.2.2 Hydromorphology

Hydromorphological conditions within the project area are diverse. Whereas the stretch throughout Zagreb city is extensively modified (Figure 6), in some areas even severely modified, other stretches are moderately but also slightly modified, especially in the area Hrušćica to Rugvica in the east of Zagreb (Figure 5).

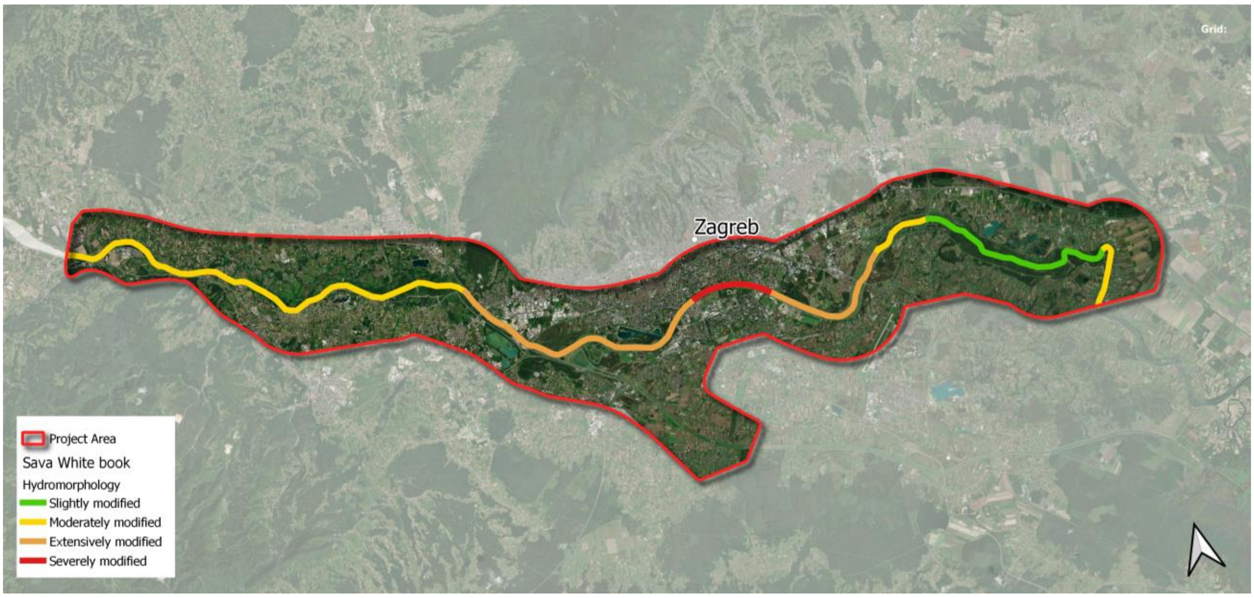


Figure 5: Hydromorphological assessment of the Sava around Zagreb (Source: SWB, 2016).

Figure 6: The Sava in Zagreb, strongly altered, with trapezoid cross section, detached floodplains and ramp for retaining cooling water, Class 4 (extensively modified) (Source: Bing Virtual Earth).

2.2.2.3 Sediment balance and riverbed stability

A key element of the natural dynamic river ecosystem of the river Sava is sediment transport and river bed stability. Currently there is a huge lack of sediment due to HPP dams in the upstream of Brežice.

Normally gravel and sand is transported constantly along the river. In order to transport material along the river, the water loses its power. In case there is no material the water has no possibility to lose power, this leads to river bed incision and fast currents

Regular water level measurements at the Sava gauges drew attention to the riverbed deepening due to river regulations and HPP construction, which is still ongoing.

Geodetic surveys of the Sava riverbed in the section from rkm 673.00 to rkm 728.52 km were done in the period from 1985 to 2003. The survey of the profiles at water gauging stations show the following picture:

- In the section from Jesenice to gauging station Zagreb (rkm 702), the riverbed deepened by about 2,5 m in the period 1985-2009 (Figure 7).
- In the section from gauging station Zagreb to the riverbed sill at TE-TO Zagreb (rkm 697.00) there are no significant changes in the riverbed height due to the influence of the sill.
- Downstream from the sill at rkm 697.00, the riverbed deepens significantly, due to the influence of the sill and the increased removal of gravel.
- In the section of gauging station Rugvica (rkm 673,8), there is deposition of bedload and a rise in the riverbed of the Sava.

(Source: *PROJEKT DANUBE SEDIMENT - Okvirna procjena sedimenta rijeke Dunav i većih pritoka, p. 91)*

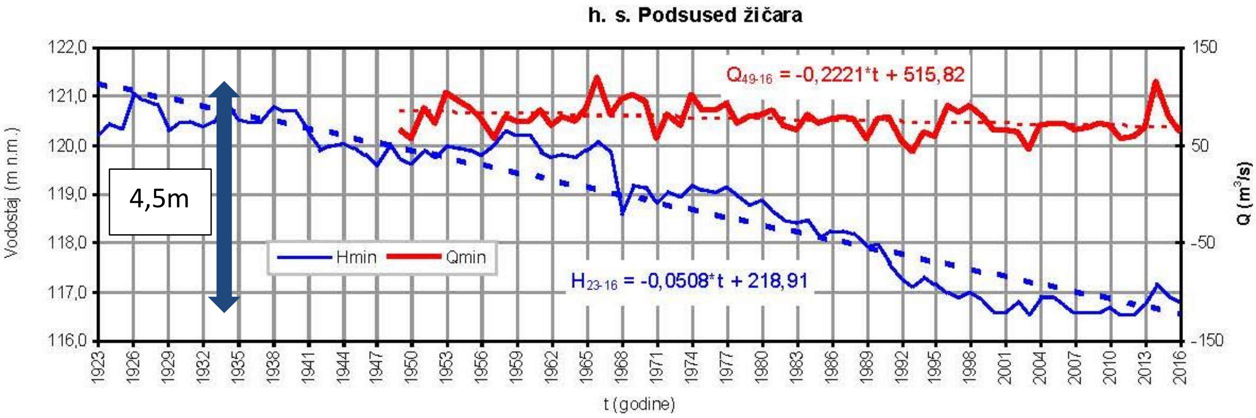


Figure 7: Comparison of minimum annual water levels and flows in the period 1923-2016 at the Podsused gauge shows that the river bed has deepened by almost 4.5 m in the last 100 years. (Source: PROJEKT DANUBE SEDIMENT - Okvirna procjena sedimenta rijeke Dunav i većih pritoka, p. 92, p. 102)

Dams and reservoirs, that are built upstream, cause these effects for riverbed development. In addition to a dozen dams and barriers already built in Slovenia, HPP Krško was completed in 2013 and HPP Brežice in 2017 on the lower reaches of the Sava River in Slovenia. Compared to the period before their construction, these facilities caused a significant reduction in sediment transport and thus significant morphological changes in the riverbed, i.e., strongly erosive processes in the Sava riverbed and lowering of the bottom level with simultaneous deposition of fine sediment (sand) and silt on the banks, as observed in Rugvica. (Source: PROJEKT DANUBE SEDIMENT - Okvirna procjena sedimenta rijeke Dunav i većih pritoka, p. 144)

All this results in an increasingly riverbed incision. Local erosion processes and deepening of the riverbed are very dangerous phenomena that can endanger the stability of flood protection structures.

2.2.2.4 Land structure

One part of the Sava White Book is the analysis and description of the land structure along the whole river Sava. Table 1 gives an overview of the land structure within the morphological floodplain (the morphological floodplain is defined as maximum area originally influenced by floods) and the active floodplain.

The difference between the land structure within the morphological floodplain and the active floodplain is serious regarding structures that need a connection to the water body and regular floods. Especially land structures like oxbows, softwood and hardwood alluvial forests, lowland oak forests or floodplain swamps are not flooded in a larger scale within the active floodplain anymore. On the other hand, wet grassland takes nearly the same area within active and morphological floodplain.

Table 1: Overview of the land structure within the project area, the morphological floodplain and the active floodplain. The marked habitats suffer particularly from the lack of flooding by the Sava.

Land structure	Land structure within the project area / morphological floodplain [km²]	Land structure within the active floodplain [km²]
101 River	6,15	6,15
102 Impoundment / Canal	0,23	0,13
103 Lake	0,00	0,00
104 Oxbow	**0,15**	**0,03**
105 Filled Gravel Sand Pit	4,22	0,56
106 Fishpond	0,03	0,00
107 Ash Dump Pond	0,00	0,00
201 Rock Bars	0,00	0,00
202 Gravel Bars	0,24	0,24
203 Sand Bars	0,03	0,03
204 Mudd Bars	0,01	0,01
205 Pioneer Vegetation on Banks	0,11	0,11
301 Softwood	**20,02**	**11,81**
302 Hardwood	**7,60**	**3,68**
303 Lowland Oak Forest	**4,52**	**0,00**
304 Poplar Plantations	0,35	0,01
305 Clear-cuts / Amorpha stands	0,22	0,00
306 Other Forests	1,72	0,09
401 Floodplain Swamps	**0,33**	**0,05**
402 Wet Grasslands	**14,26**	**12,64**
403 Other Grassland	32,02	6,61
404 Orchards / gardens	4,45	0,02
501 Small Sectioned Agriculture	85,52	10,51
502 Large Sectioned Agriculture	7,96	0,10
601 Settlement	18,76	0,09
602 City Agglomeration Commercial	23,72	0,00
603 Harbour Industrial	0,00	0,00
604 Road Traffic Lines	6,84	0,22
605 Railway Lines	0,88	0,01
606 Recreation Areas	2,49	0,00
701 Flood Dikes	4,17	2,21

702 Groyne Traverse Riprap	0,01	0,01
703 Dam / Weir / Sluice	0,00	0,00
704 Concrete Bank	0,00	0,00
705 Gravel and Sand Pit / Deposit Dump site	3,83	0,39

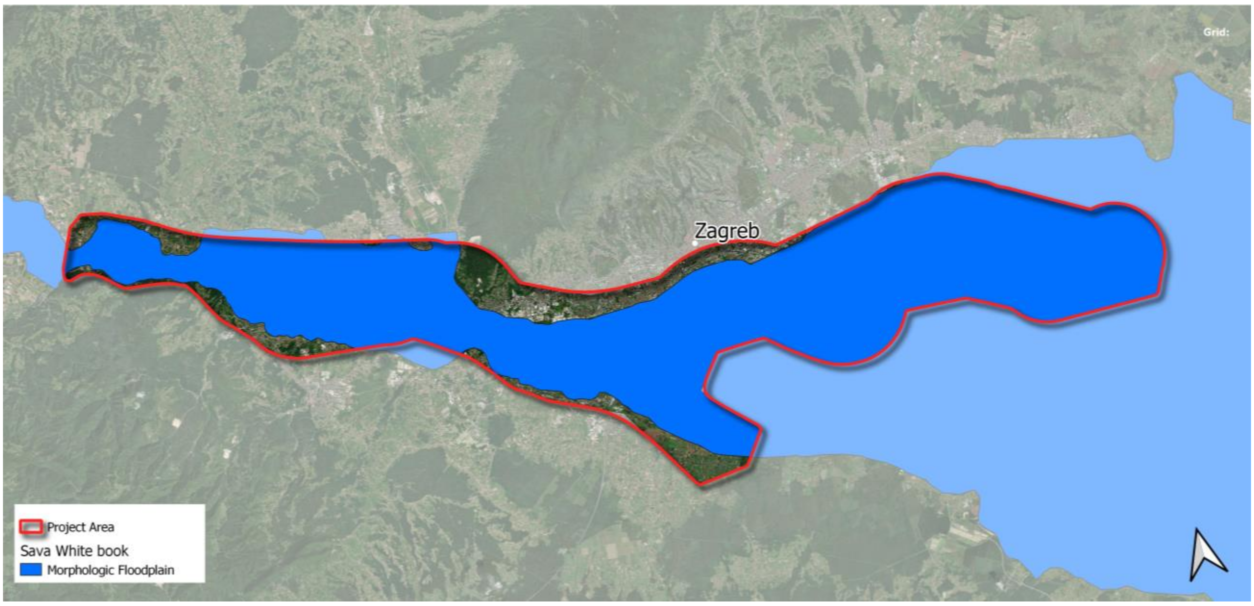


Figure 8: Morphological floodplain (The morphological floodplain is defined as maximum area originally influenced by floods) of the river Sava in the project area (Source: SWB, 2016).

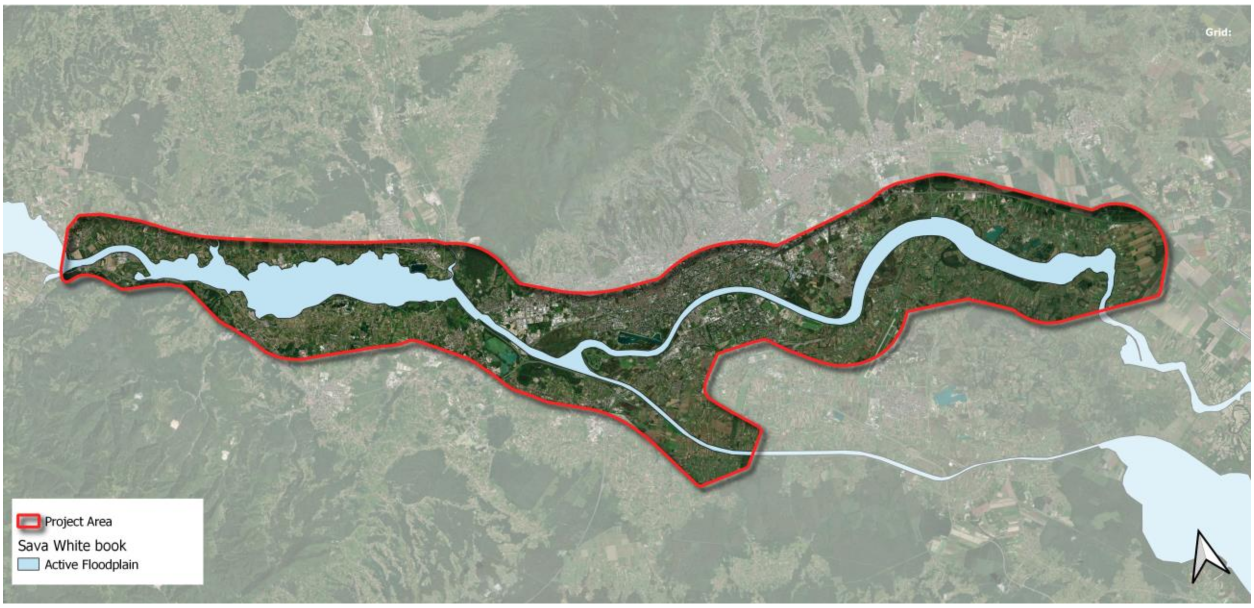


Figure 9: Active Floodplain of the river Sava in the project area (Source: SWB, 2016).

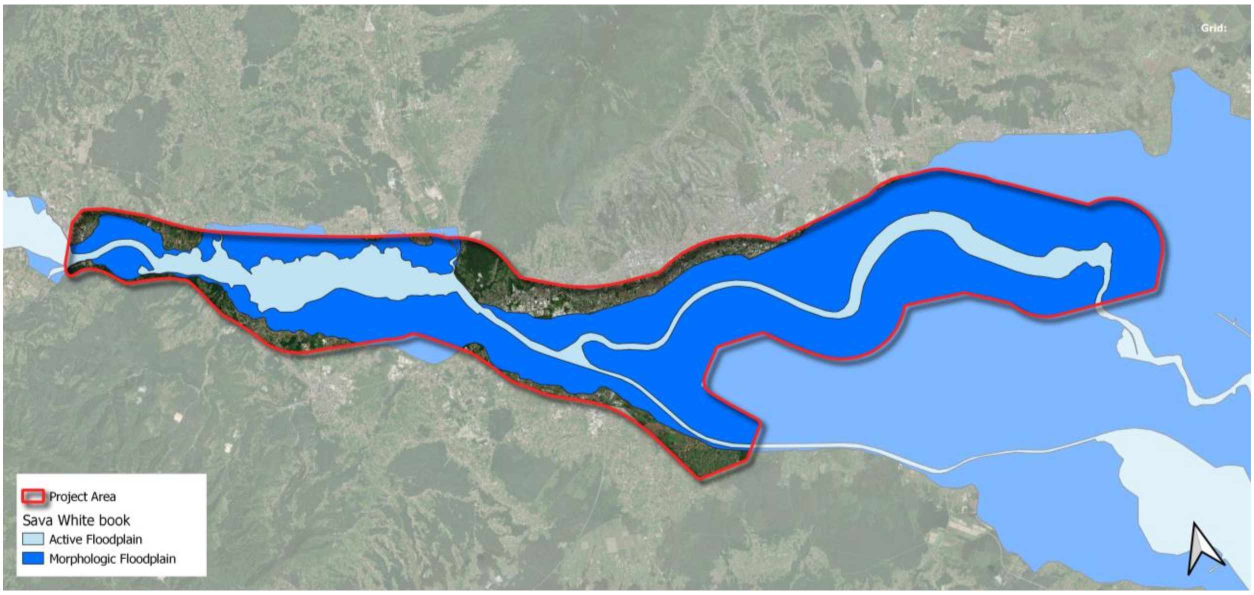


Figure 10: Overview of the morphological and active Floodplain of the river Sava in the project area (Source: SWB, 2016).

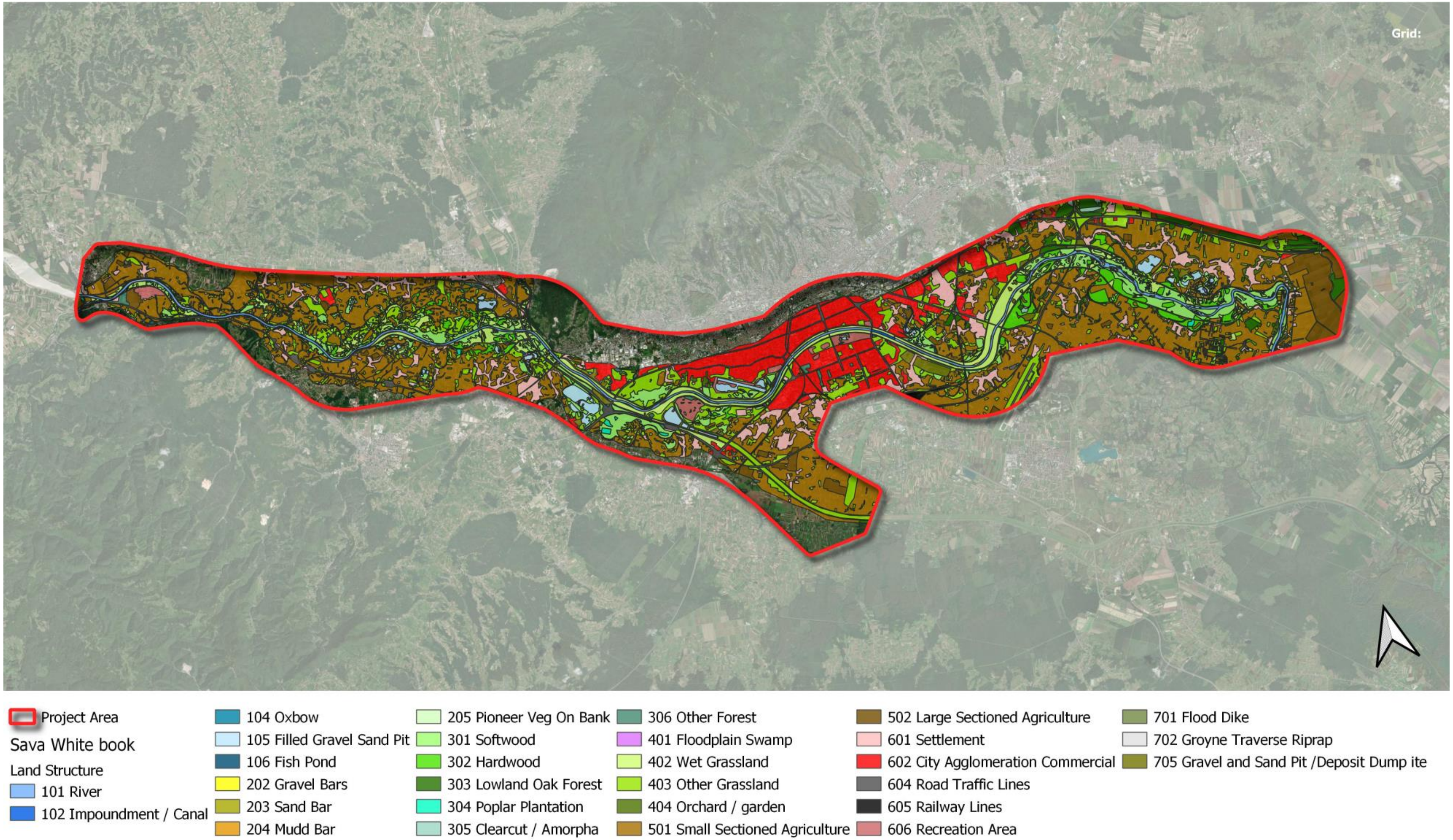


Figure 11: Land structure types in the project area (Source: SWB, 2016).

2.2.2.5 Biodiversity

Downstream of Zagreb the river is rich on gravel or sediment bars and islands and host further downstream meander bends with steep banks that are home to several flagship bird species. Figure 12 shows the distribution of characteristic species in this section.

Gravel bars and islands downstream to Rugvica (660 rkm) support breeding of up to 150 pairs of common terns (*Sterna hirundo*). They also represent the only breeding site along the whole Sava for the threatened little tern (*Sterna albifrons*), which has a population of up to 20 pairs (detection status 2012, later no detection), as well as for the little ringed plovers (*Charadrius dubius*) with up to 14 pairs. A few pairs of common sandpiper (*Actitis hypoleucos*) can also be found there.

The first steep banks, resulting from dynamic hydromorphological processes, appear downstream of the Slovenian-Croatian border. Freshly eroded steep banks provide home for another indicator species, the sand martin (*Riparia riparia*). The total breeding population along the Sava is estimated at 3,000 pairs, the section upstream of the Una confluence hosts two thirds of the total breeding population. Particularly important sites are located downstream of Zagreb and upstream of Sisak, with colonies holding up to 270 pairs. Another charismatic species that lives in steep sand banks is a solitary nesting kingfisher (*Alcedo atthis*). (Source: SWB 2016, p. 21)

The Natura 2000 area Special Protection Area (SPA) *“Sava kod Hrušćice sa šljunčarom Rakitje”* with its 1,453 ha is listed as an internationally important natural site for birds along the Sava (Source: SWB 2016, p. 23)

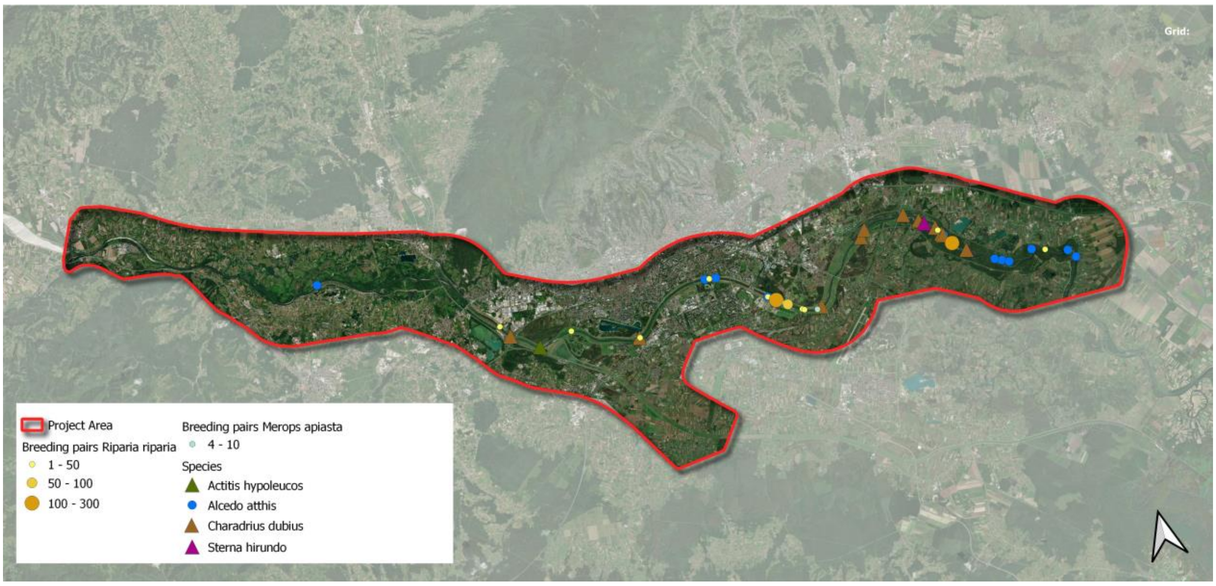


Figure 12: Distribution of selected indicator species of breeding birds along Sava in the project area (Source: SWB 2016, p. 24).

2.2.2.6 Protected areas

Within the project area most of the Sava River and its remaining floodplain is protected as Natura 2000 site under Birds and Habitat directive (Figure 13):

Birds directive:

- Sava kod Hrušćice sa šljunčarom Rakitje
- Krakovski gozd - Šentjernejsko polje

Habitat directive

- Spodnja Sava
- Krka s pritoki
- Sotla s pritoki
- Vrbina
- Sava uzvodno od Zagreba
- Medvednica
- Sutla
- Potok Dolje
- Sava nizvodno od Hrušćice

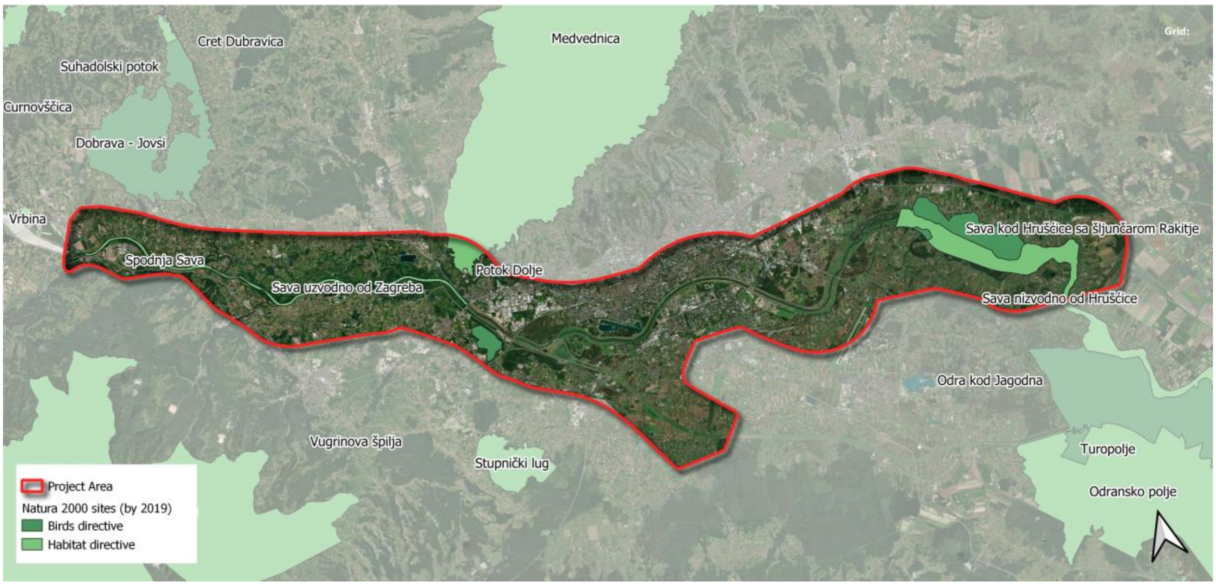


Figure 13: Natura 2000 (GIS dataset from end 2019) sites areas around the project area. (Source: Open Geoportal EU)

Particularly important are Sava river stretches: Spodnja Sava (SI), Sava uzvodno od Zagreba (HR) and Sava nizvodno od Hrušćice (HR) that are covering free-flowing river areas suggested for restoration.

Additionally, upstream Zagreb one Special ornithological reserve, covering Sava former floodplain is designated: Sava – Strmec (269,92 ha). Within Zagreb reach Savica protected landscape (79,54 ha) covers the former Sava branch on its left bank.

2.3 Consequences and challenges

Within the project area anthropogenic activities like riverbed regulation with dikes and embankments, gravel and sand extraction from the riverbed or trapped by hydro power plants upstream, caused enormous riverbed incision up to 4 m in the last decades. Consequently, various impacts on the flood protection as well as on the river and alluvial forest ecosystem can be observed:

- risk of instable fundaments of bridges and riverbank protections within Zagreb and thus uncontrolled morphological processes during a flood (risk of dike breach)
- declining ground water level with consequences on drinking water supply, agriculture and forestry use
- loss of biodiversity due to lost connection between river and floodplains
- higher risk for flooding downstream due to less water retention upstream
- loss of river-related recreational areas that will increase in importance specifically due to climate change

Unfortunately, like so many other European rivers, the Sava within the project area faces enormous challenges (see also Figure 14):

- Stopping riverbed incision in an environmentally friendly way: this is crucial to maintain flood protection, to stabilize the groundwater level, to ensure the drinking water supply, enable agricultural use and preserve alluvial forests in the surrounding area
- Improving the ecological condition of water bodies (e.g., hydromorphology) according to defined goals of the European Union
- Pressure due to increasing recreational use
- Finding sustainable solutions that require low maintenance effort
- Finding solutions and commitments especially for flood risk reduction and sediment management, which are broadly supported. Considering that, all changes to the river in the upper stretches have implication for the lower course

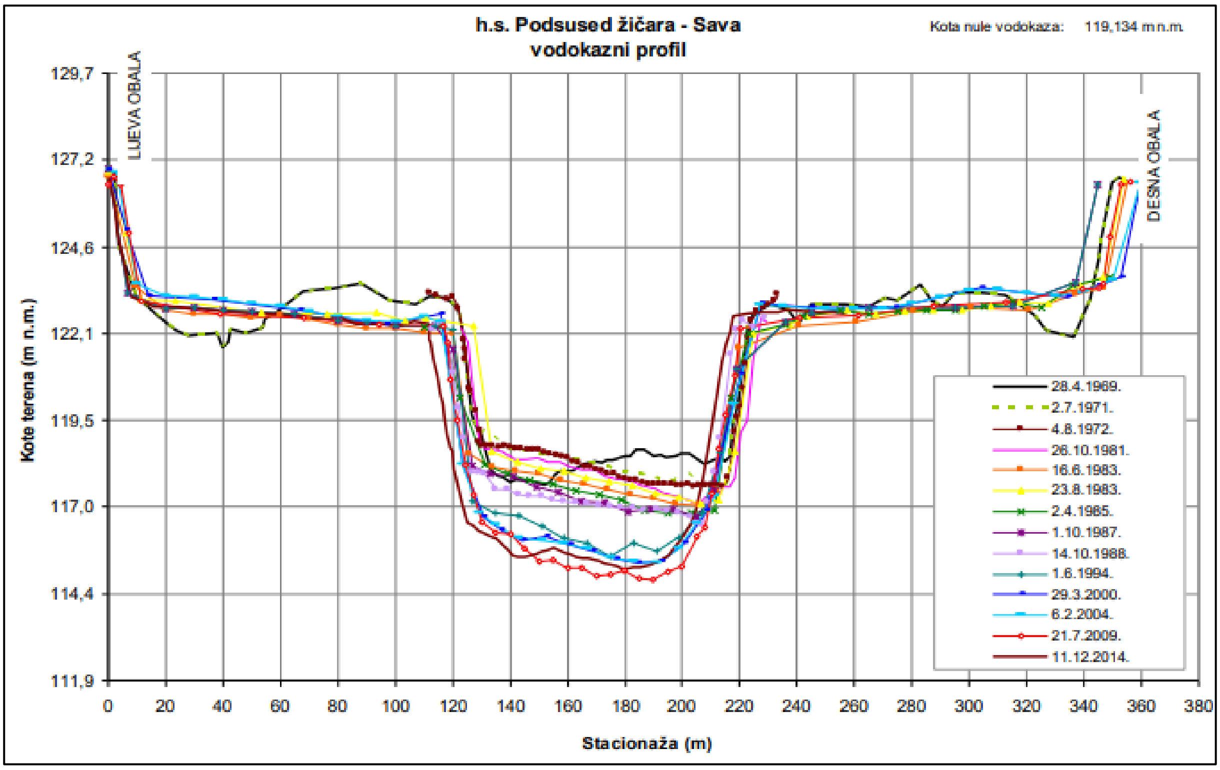


Figure 14: Riverbed incision of the river Sava, Podsused Zicara from 1969 up to 1987 (source: [3] Projekt Danube Sediment p. 92)

2.4 Main goal of this study

This feasibility study for the river Sava focuses on developing a concept to stop riverbed incision in and around Zagreb by sustainable river restoration measures like riverbed widening based on optimal river width or sediment management creating multi-purpose positive effects.

The optimal river width will be calculated for the two potential river restoration sites no. 5 (Sava from Podgračeno to just upstream of Zagreb) and no. 6 (Ivanja Reka, Sava downstream of Zagreb) that are defined in the Sava White Book Study (p. 101). Both are part of the Croatian section of the river Sava.

These two sites will be investigated in detail to get the required optimal corridor width. The results will then be transferred to the entire river stretch.

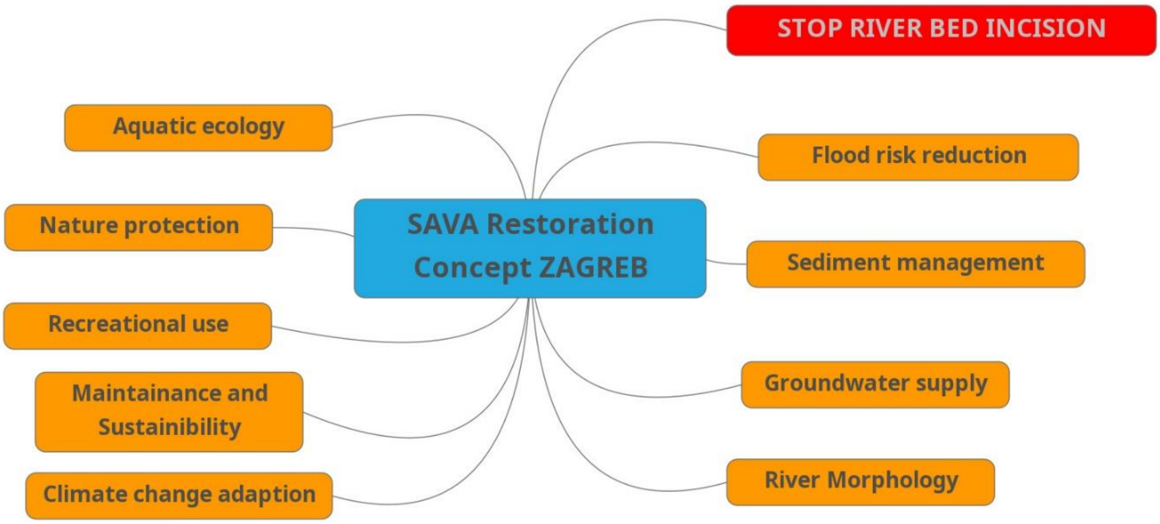


Figure 15: The Sava restoration concept faces numerous challenges.

3 Methodology

3.1 Used data

For developing this study, the following data was used:

Publicly available data:

- Open Street map data from Slovenia and Croatia (Roads, building, WMS service for background map)
- Google satellite Maps for background information (WMS)
- Natura 2000 sites
  (open geodata portal EU, https://data.europa.eu/euodp/de/data/dataset/DAT-68-en)

Sava white book data:

- Land structure
- Hydro morphology
- Floodplain delineation
- Data about threats
- Restoration sites

Datasets that were provided by Hrvatske vode - legal entity for water management in Croatia:

- Survey of Gauging Stations
- Survey of the Cross sections (2004, 1994)
- Lidar data (part of the project area)
- Hydrological Data
- Grain size distribution

Please see chapter 7 for more information about the used Studies and literature.

3.2 Development process

Due to the situation related to COVID-19 pandemic in 2020 and 2021 there was no possibility for personal meetings. Meetings and coordination were done via email, skype or zoom. One person from REVITAL had the possibility for a short field trip and visited the project area in May 2021.

Dates of the online meetings with externals:

- 18.05.2020 start workshop
- 25.05.2020 Sava Parks Network meeting
- 29.09.2020 first stakeholder meeting
- 19.11.2020 second stakeholder meeting
- 11.11.2020 third stakeholder meeting
- 07.12.2020 Sava Parks Network meeting
- 05.03.2021 fourth stakeholder meeting
- 20.09.-21.09.2021 field trip on rivers Drava and Sava
- 23.09.2021 Sava Parks Network meeting, final presentation

3.3 Calculation of the framework conditions for riverbed stabilisation

The current incision of the riverbed of the river Sava is caused by numerous factors. The most important factors are the regulation measures which were implemented over the last 100 years as well as the lack of sediment due to hydroelectrical power plants which were built further upstream of Zagreb.

The goal of the present study is to reduce the erosion potential of the river Sava in the project area by widening the riverbed and providing sediment to the river system.

Therefore, river stretches, where incision is a major problem were identified. The current morphology type of the river stretches was defined using aerial photos and different approaches of morphological prediction. For these river sections the natural (historic) morphology type and the corresponding river geometry was defined using historic maps of the river Sava as well as applying different approaches for morphological prediction.

Based on this analysis, a target morphology for each of the river stretches was defined. The results were compared with river stretches further downstream of Zagreb which currently are in a more natural state.

The result of the processing was a required optimal corridor width – accompanied by additional measures like sediment input - which is necessary to make possible a long-term stable morphology of the river Sava.

3.3.1 Preparation of existing data and data analysis

Based on the data provided, the actual situation was analysed for the project area.

- Areal image interpretation
  - Actual geometry (width) of the river Sava
  - Morphological structures in the river Sava in the current state
  - Historical morphology of the river Sava
- Evaluation of hydraulic and sediment parameters of the current state
  - Characteristic hydrological data
  - Longitudinal gradient
  - River geometry (cross sections), calculation of relevant flow depths
  - Grain size distributions – analysis of existing data
  - Sediment transport capacity and annual sediment transport

3.3.2 Determination of framework conditions for the river Sava restoration

Based on the analysis of existing data (geometry, hydrology, sediment data etc.) the framework conditions and relevant parameters for river restoration – considering the main objective of riverbed stabilization - were determined.

Different approaches and methods were applied to define the historical and the current morphology type of Sava as well as to calculate the natural river width of Sava in the different river sections. The applied approaches to estimate natural river width and morphology type are explained in detail in chapter 4.2.

Based on the results of the calculations, an optimal corridor width for each of the investigated river stretches was defined.

In a first step hydraulic 1D-calculations for the current river geometry were performed for different discharges. The results of the performed calculations were flow depths and sediment transport capacities for the relevant water discharges.

In a second step the river widening (optimal corridor) was applied to the hydraulic model and parameters like flow depth and sediment transport capacity were recalculated.

The results of the calculations for the current state and the target state were compared. Comparing the sediment transport capacity of the current and the target state predictions of possible stabilizations of the riverbed due to the implemented measures can be made.

The calculations of the current and future transport capacities of the river Sava in the project area also gives an idea of the required sediment input.

The result of this analysis was a set of parameters on which further measures could be designed to achieve a morphologically stable system (manly river geometry, sediment input).

3.4 Concept for river restoration project and feasibility study

Based on the gained information about the optimal river width for riverbed stabilisation a concept for river restoration of the river stretch near Zagreb was set up.

Figure16: River stretch near Zagreb, river Sava (Source: Google Earth, 2021).

3.4.1 Concept for river restoration project

A first draft of the concept for river restoration (site plan and first sketches of measures) was worked out based on the results of the framework conditions determined as described in chapter 3.3 (river width, bed load input…).

The concept includes suggestions for measures like initial channels, new bank protection, lowering the surface or building new ramps for reactivating the derivation channel Sava-Odra.

Based on the information gained during the virtual workshops and meetings and the impressions gained during the field trip the river restoration concept was worked out.

Possible measures like initial channels or lowering the surface are located on a map and described in this report.

4 Current State

4.1 Hydrology

4.1.1 Gauging Stations

Within the area of interest data from four gauging station (that where relevant for the feasibility study) on River Sava were used in this study. For the gauging stations Podsused-Zičara, Zagreb and Rugvica there exist regular measurements of water levels, discharges and surveys of the riverbed from the 1960`s up to now. For the Stations Posused-Zičara and Rugvica grain size distributions and amount of sediment transport have been observed (one time only).

Table 2: Gauging stations of the river Sava that were used for the feasibility study.

Gauging Station	rkm
Jesenice	728,00
Podsused-Zičara	714,00
Zagreb	702,72
Rugvica	673,80

In the following chapters the data from the Croatian gauging stations are described in more detail.

Figure17: Overview of gauging stations on River Sava that were taken into account.

4.1.1.1 Gauging station Podsused – Sava

The gauging station Podsused-Zičara is located upstream of Zagreb at rkm 714,0. Regular measurements of water levels and discharge are carried out, since 1969 up to now regular surveys of the riverbed are made.

The survey of the riverbed shows an incision up to 2,5m from 1969 to 2014.

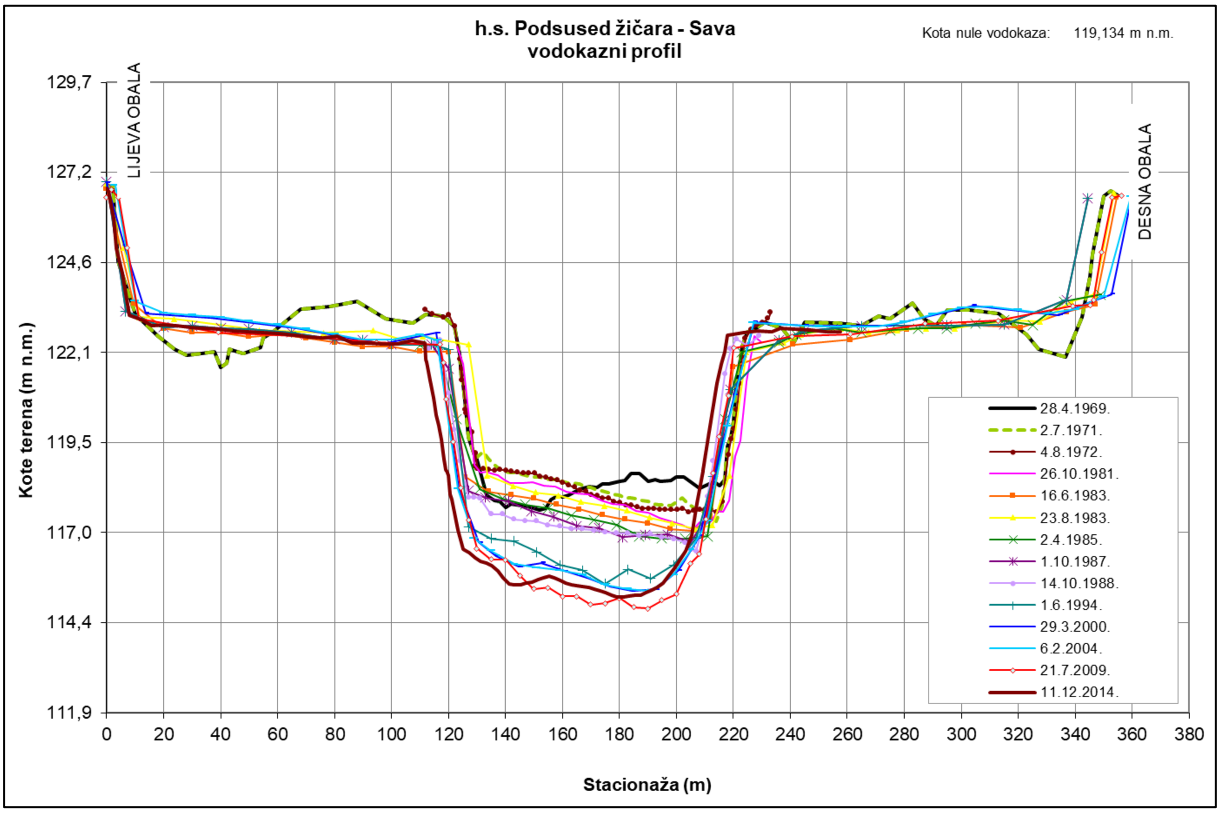


Figure 18: Changes in the river profile at Podsused in the period from 1969 to 2014. (Source: [3] Projekt Danube Sediment p. 92)

Additional, detailed investigations on grainsize distribution of the suspended load as well as on bedload material were made for the gauging station Podsused-Zičara.

Mean discharge at the gauging station Podsused is about 303 m³/s, the mean annual flood discharge is about 1819 m³/s.

The following figure shows the flow duration curve for Podsused-Zičara from the year 2013.

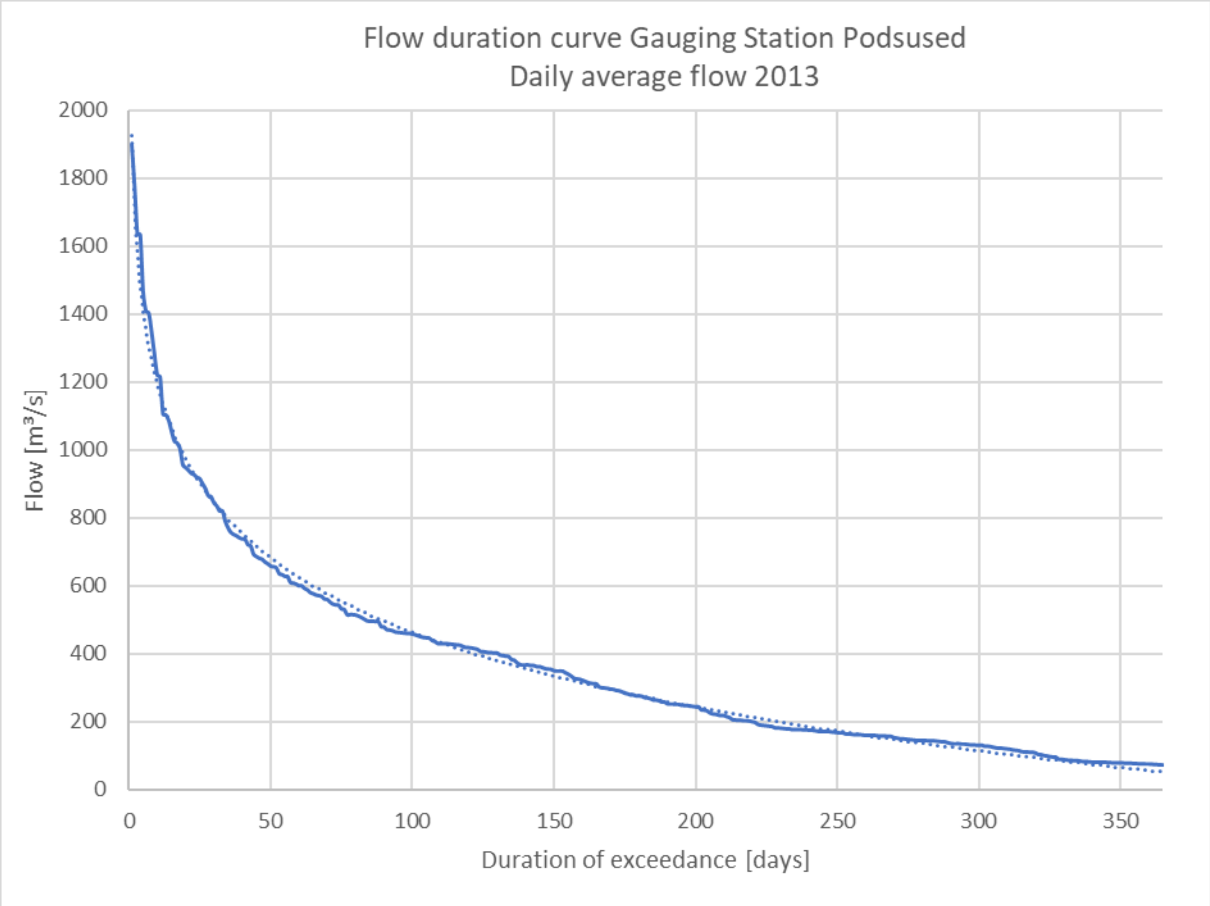


Figure 19: Flow duration curve at the gauging station Podsused from the year 2013 (Source: [1] HRVATSKE VODE (2015))

4.1.1.2 Gauging station Zagreb – Sava

The gauging station Zagreb is in the City of Zagreb at rkm 702,72. Regular measurements of water levels and discharge are carried out, since 1966 up to now regular surveys of the riverbed are made.

The riverbed surveys show an incision up to 3,0 m from 1966 to 2009.

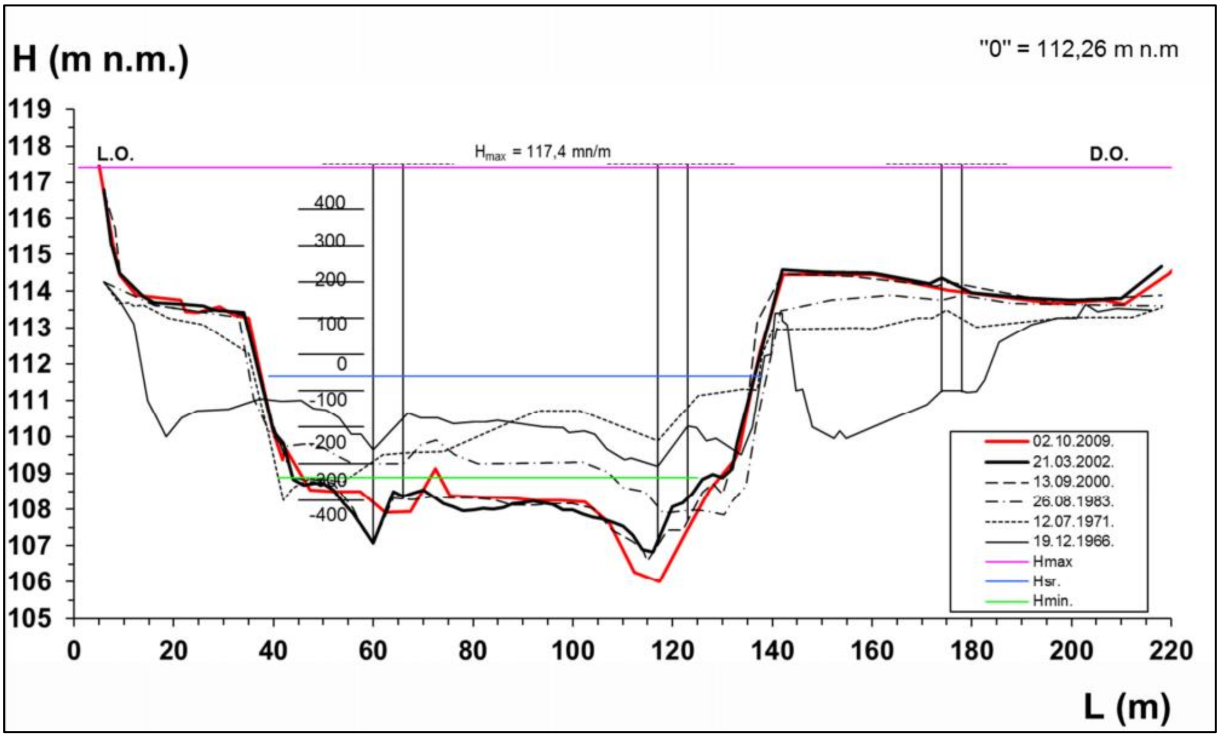


Figure 20: Changes in the river profile at gauging station Zagreb in the period from 1966 to 2009 (source: [7] ISRBC 2013).

The mean discharge at the gauging station Zagreb in the period 1984-2011 was about 278 m³/s, the highest discharge was in 2010 with about 2851 m³/s.

The following figure shows the flow duration curve for the gauging station Zagreb for the period 1984 up to 2011.

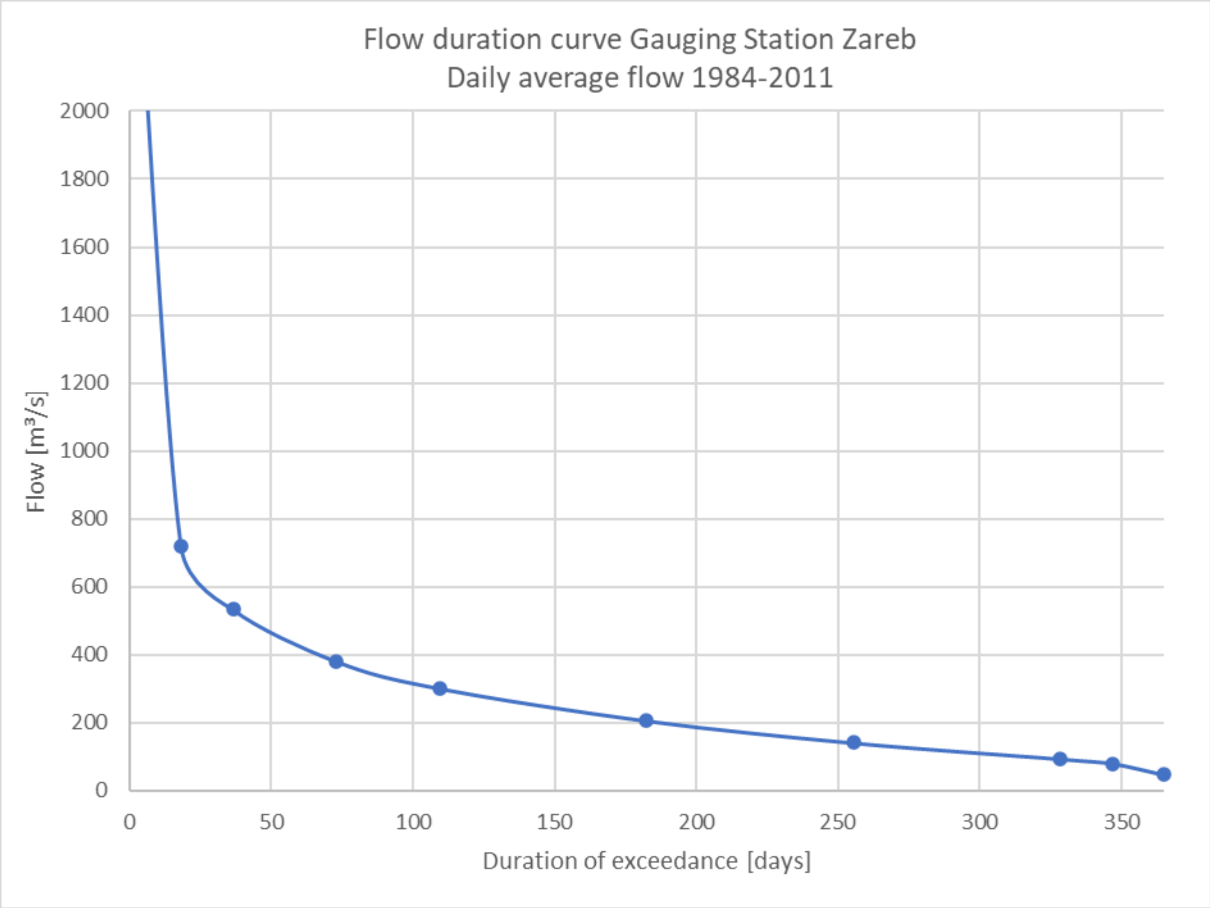


Figure 21: Flow duration curve at Station Zagreb for 2013 ([2] HRVATSKE VODE (2015))

4.1.1.3 Gauging station Rugvica – Sava

The gauging station Rugvica is located downstream of Zagreb at rkm 693,69. Regular measurements of water levels and discharge are carried out, since 2000 up to now regular surveys of the riverbed are made.

The riverbed survey shows an incision of the riverbed; however, this is significantly lower than upstream due to short time span period.

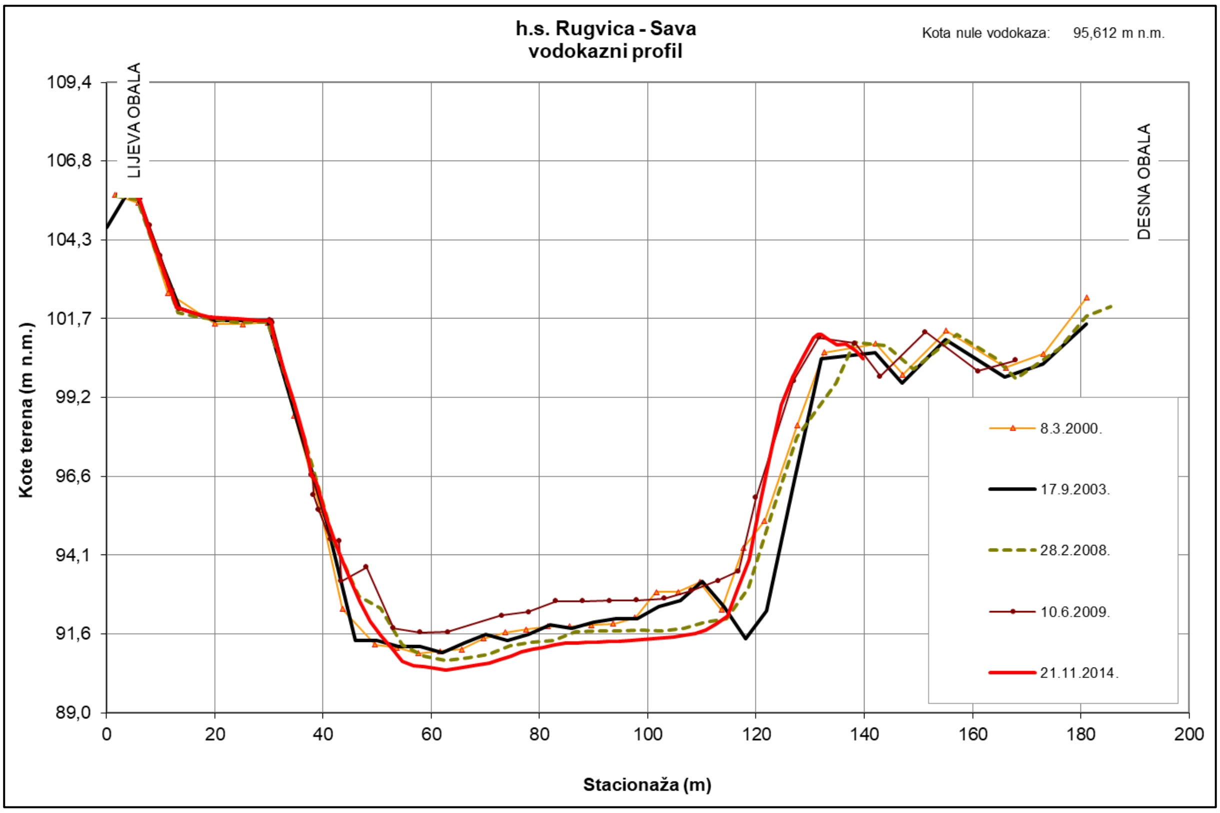


Figure 22: Changes in the river profile at the gauging station Rugvica in the period from 1966 to 2009 (Source: [3] HRVATSKE VODE (2019):

On the gauging station Rugvica detailed investigations on grainsize distribution of the suspended load as well as on bedload material were made.

Mean discharge at the gauging station Rugvica in the period 1981-2011 was about 304 m^3/s, the mean annual flood discharge is about 1504 m^3/s.

The following figure shows the flow duration curve for the gauging station Rugvica for the period 1981-2011 and for the year 2013.

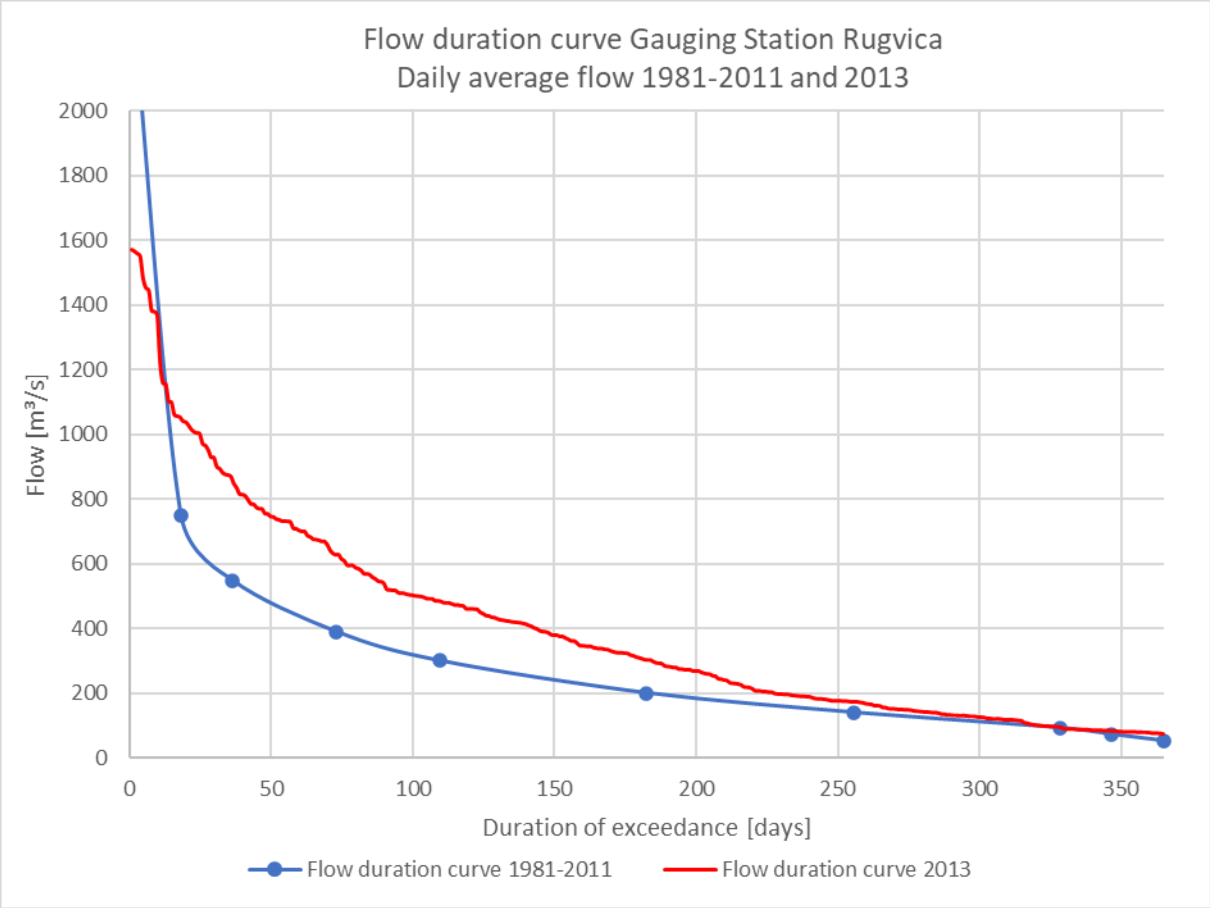


Figure 23: Flow duration curve at gauging station Rugvica for 1981-2011 and 2013 (Source: [4] HRVATSKE VODE (2015)):

4.2 River geometry

The river Sava is a typical alluvial river. It is flowing mostly on its own alluvial deposits. Without regulations of the riverbed, the river Sava would be a large meandering river, especially within the project area. Due to human influence, morphology and the geometry of the riverbed have changed in the last centuries and decades.

The sections around the gauging station Podsused are regulated but regaining meandering power. The width of the riverbed is about 100 m.

In Zagreb, the river Sava is completely channelized in the form of a double trapezoidal profile. The width of the riverbed is about 100 m. Continuous dikes and wide river forelands are typical for this river stretch. The distance between the dikes is about 300 m.

Downstream Zagreb, from Hrušćica to Rugvica (rkm 675) there is the last remaining braided and anabranching stretch of the river Sava in the project area.

Geometry data for the investigated section of the river Sava was provided by Croatian Waters. There are existing river surveys of profiles from the confluence of the rivers Sava and Danube, up to the Croatian/Slovenian border at rkm 730,00.

Croatian Waters also provided LIDAR data for the area around and upstream of the city of Zagreb.

4.2.1 Longitudinal Profiles

Based on the survey data or the riverbed, a longitudinal profile was generated between rkm 670,00 and 730,00. Along the city of Zagreb, a longitudinal profile of the water levels was generated based on the provided LIDAR data.

Upstream of the city of Zagreb, around the gauging station Podsused, the mean slope of river Sava is between 1-1,5 ‰. In the river stretch around Zagreb the mean channel slope lowers down to 0,7 - 1,0 ‰. Downstream of the existing weir at rkm 697,50 the mean slope lowers constantly to 0,5 ‰ and keeps this slope till the gauging station Rugvica. Near Rugvica the Sava River morphology changes from a gravel-bed river at the upper Sava river to a sand-bed river at the middle Sava (Figure 24).

A comparison of different longitudinal profiles of the last decades (1987, 1995 and 2004) show the incision of the river Sava between Podsused and Rugvica. Upstream of the city of Zagreb the main incision occurred from rkm 703,0 -714,0, in the period between 1987 and 1995.

Further downstream the construction of the weir at rkm 697,50 led to an incision of the riverbed up to a maximum of 4 m (Figure 25).

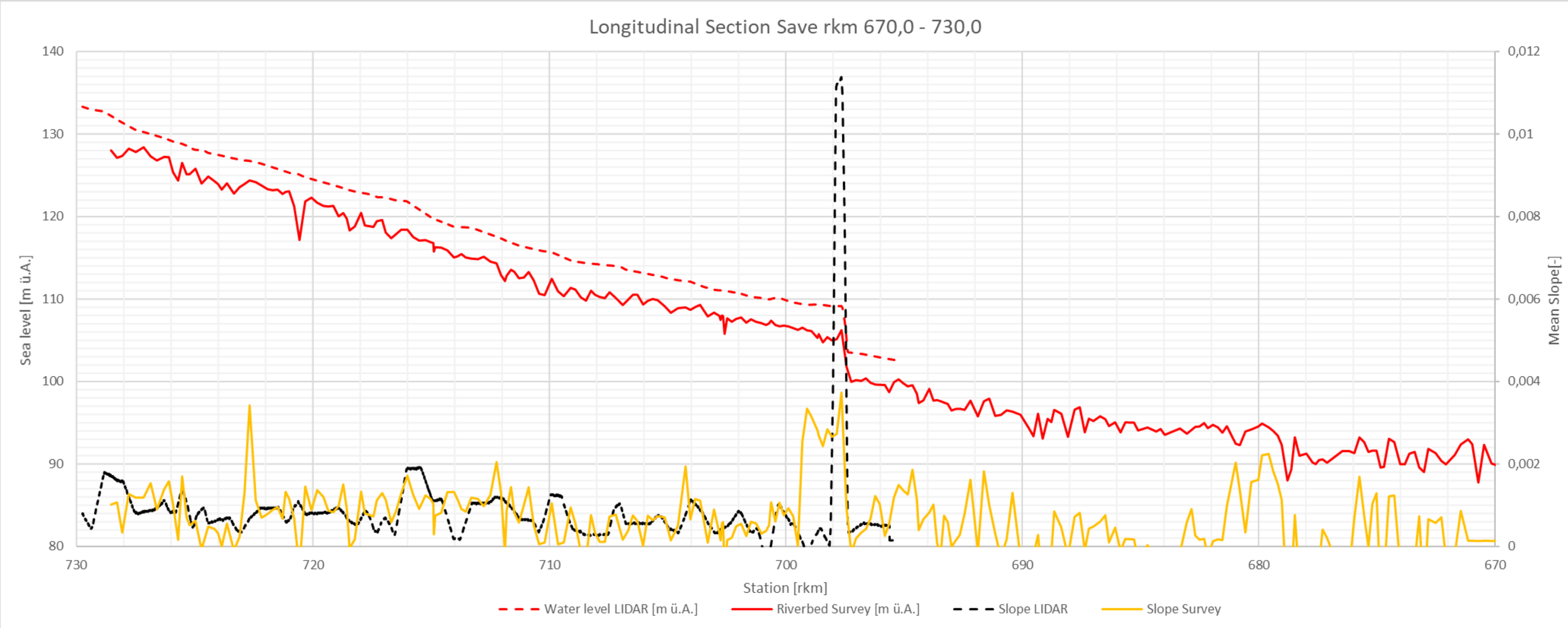


Figure 24: Longitudinal Profile of Sava-river between rkm 670,00 and 730,00; (Source: Survey and LIDAR data provided by Croatian Waters)

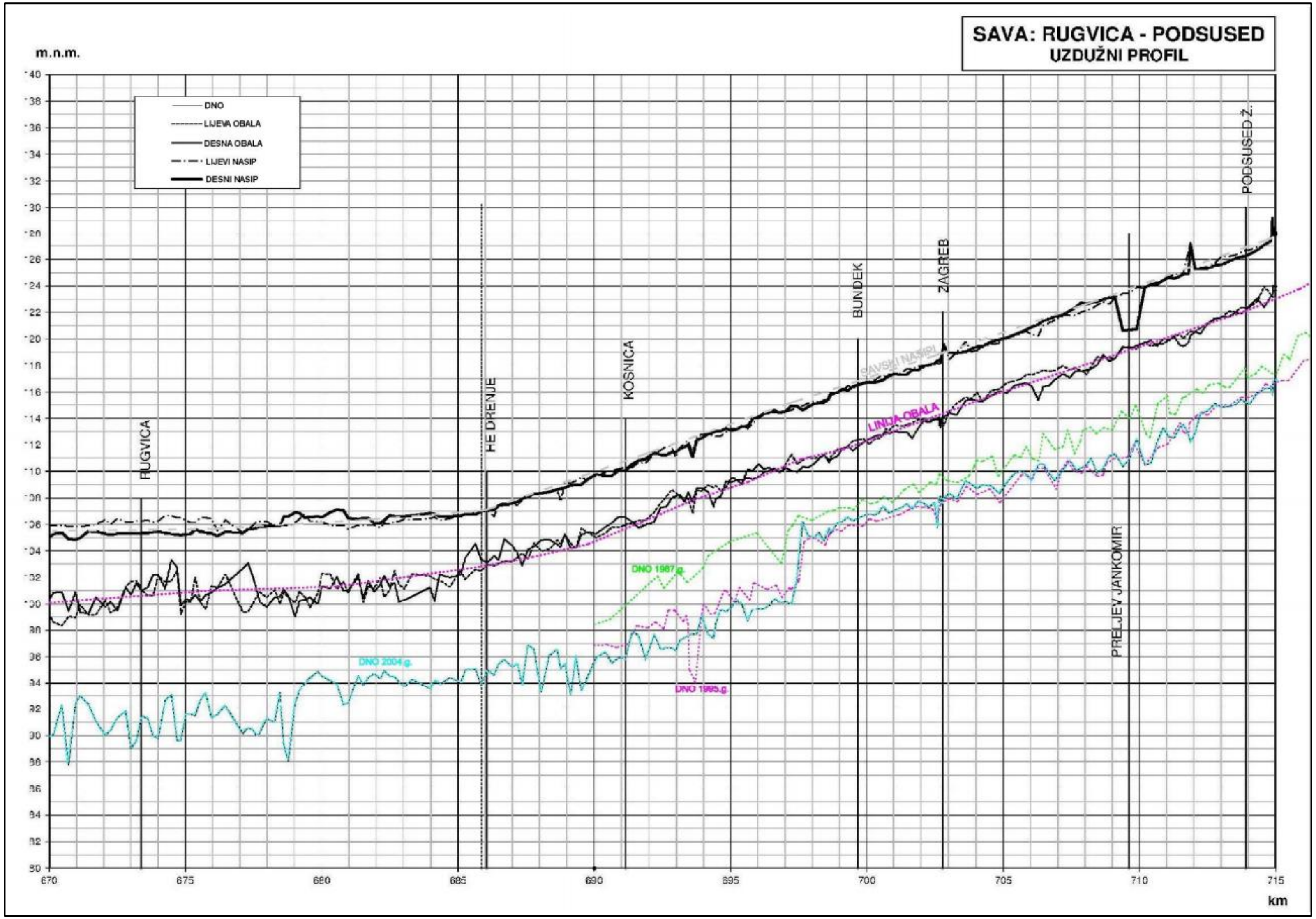


Figure 25: Comparison or longitudinal profiles of Sava River; Surveys 1987 (green), 1995 (magenta) and 2004 (cyan) (Source: [5] HRVATSKE VODE (2015))

4.2.2 River sections examined in detail

Based on the mean slope, the profile width and the hydro morphology, six representative river sections were defined between rkm 730,00 and 680,00. Within each of these sections the characteristics of the river Sava remain the same.

Section 1: rkm 728-716 (Sava upstream from Podsused)

The mean slope is about 1 ‰, mean channel width is about 100 m. The mean annual flood discharge was estimated with around 1819 m³/s. The river section is regulated but on the aerial photo alternating gravel bars can be measured. This indicates that there is still certain natural relocation of sediment and bedload material. The mean diameter of the bedload material is around 30 mm.

Figure 26: Alternating gravel bars in section 1 (Source: REVITAL)

On the aerial photo alternating gravel bars can be observed. This indicates that, depending on the longitudinal slope and grain size distribution, a channel width of around 100m leads to the formation of alternating bars. The morphological conditions in section 1 are in a transition between a plane river bed and alternating bars. This coincides with morphology obtain in the DaSilva- diagram, shown in chapter 4.2.4.2.

Section 2: rkm 716-713 (Sava at Podsused)

The mean slope is around 1,2 ‰, the mean channel width is 95 m. The channel is regulated in a double trapezoidal profile. Continuous flood protection dikes were built on both sides of the river. The distance between the dikes is about 300 – 400 m. The mean depth of the primary channel is about 6,8 m.

Figure 27: Plane riverbed in section 2 (Source: REVITAL)

The river channel is slightly narrower and longitudinal slope is slightly higher than in section 1. Almost no gravel bars can be observed in section 2. The Sava flows in a plane riverbed, incision of the riverbed can be observed. Due to the high transport capacity deposition of bedload material is limited.

At rkm 714,0 there is the Gauging station Podsused.

Section 3: rkm 713–709 (Sava at Jankomir)

The mean slope is around 1,0 ‰, the mean channel width is 105 m. The channel is regulated in a double trapezoidal profile. The distance between the dikes is about 300 m. The mean depth of the primary channel is about 7,4 m. The Sava flows in a plane riverbed, incision of the riverbed can be measured.

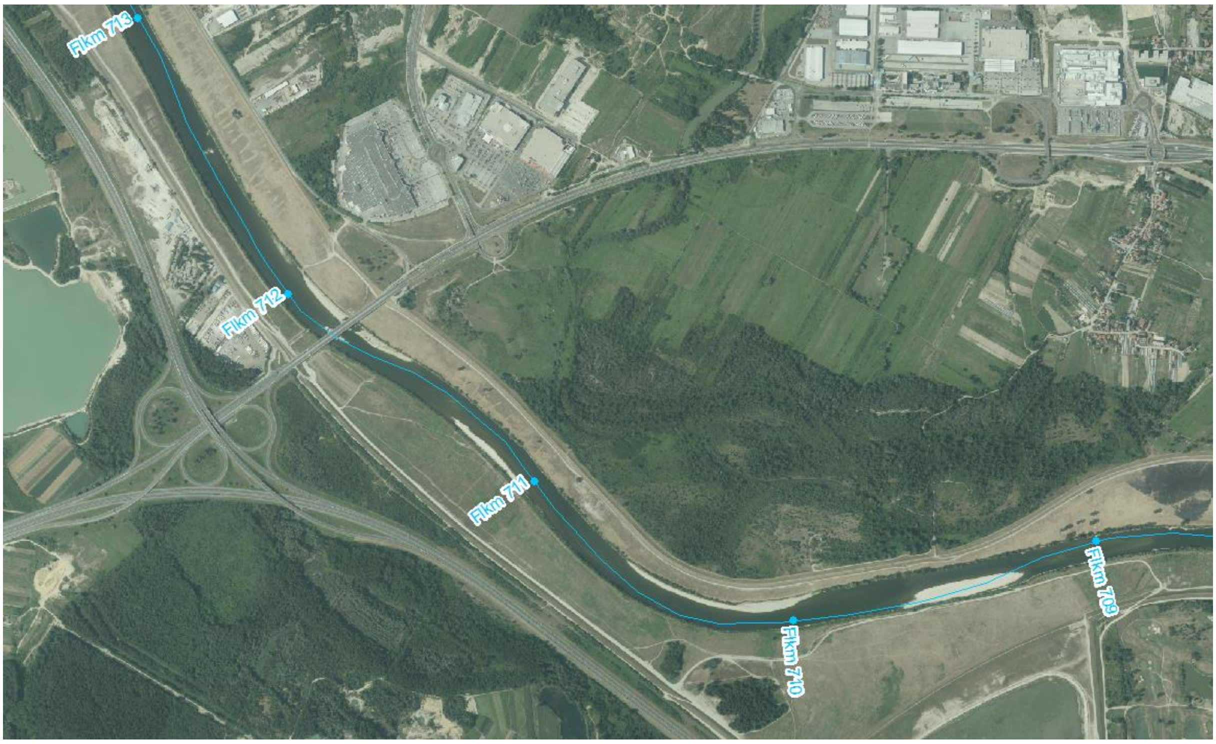


Figure 28: Plane riverbed and small gravel bars in section 3 (Source: REVITAL)

At rkm 709,5 on orographically right side of the river Sava there is an existing Sava-Odra bypass channel for flood protection of the city of Zagreb. Between rkm 709 and 712 the river channel is slightly wider than upstream. This slight widening already causes the formation of alternating gravel bars as it can be observed on the aerial photo.

Section 4: rkm 709–697, (Sava stretch though the city of Zagreb)

The mean slope is around 0,7 ‰, the mean channel width varies from 95 m up to 110 m. The channel is regulated in a double trapezoidal profile. The distance between the dikes is about 300 m. The mean depth of the primary channel is about 7,45 m.

Between rkm 697 and 703 the channel width is about 95m. As it can be seen at the arial photo, the river Sava flows in a plane bed.

Upstream of rkm 703 the channel gets slightly wider. This already leads to the formation of alternating bars.

Figure 29: Plane riverbed and small gravel bars in section 4 (Source: REVITAL)

Section 5: rkm 697– 690, (Sava downstream of the existing TE-TO Zagreb weir at rkm 697,5)

The mean slope is around 1,0 ‰, the mean channel width is between 100 and 120m. The channel is regulated in a double trapezoidal profile. The distance between the flood protection dikes reaches from about 300 m up to 750 m. The mean depth of the primary channel is about 7,80 m. Downstream of the existing weir incision of the riverbed up to 4 m can be measured.

Figure 30: Plane riverbed and small gravel bars in section 5 (Source: REVITAL)

Alternating gravel bars can be observed downstream of rkm 694. The bigger distance of the outer dikes allows bigger widening of the river channel than in the stretches upstream.

Section 6: rkm 690 – 678 (Sava at Ivanja Reka)

The morphology of river Sava corresponds almost to the natural state. The stretch is braided and anabranching. Nevertheless, the lack of sediment input due to the upstream dams leads to an incision of the main channel. Flow through the secondary channels gets even less frequent due to sedimentation of suspended material.

This section of the river Sava was chosen as a reference section to re-establish the natural morphology of the upstream sections. In section 6 the grain size distribution changes significantly from 30 mm upstream to about 6 mm. The characteristic of the river Sava changes from a gravel-bed river to a sand-bed river in this section.

Figure 31: Braided riverbed with secondary channels and gravel bars in section 6 (Source: REVITAL)

Table 3: Summary of the characteristics of the 6 investigated river sections.

River section	rkm Start	rkm End	Mean slope [‰]	Profile	D_m [mm]	MHQ [m³/s]	Primary channel width [m]	Depth H [m]
1	728	716	1	719,355	30,21	1819	100	6,62
2	716	713	1,2	714,31	30,21	1819	95	6,8
3	713	709	1	711,288	30,21	1819	105	7,38
4	709	698	0,7	706,035	30,21	1504	95 - 110	7,45
5	697	690	1	695,03	30,21	1504	140	7,8
6	690	678	0,5	681,717	5,83	1504	520	2,7

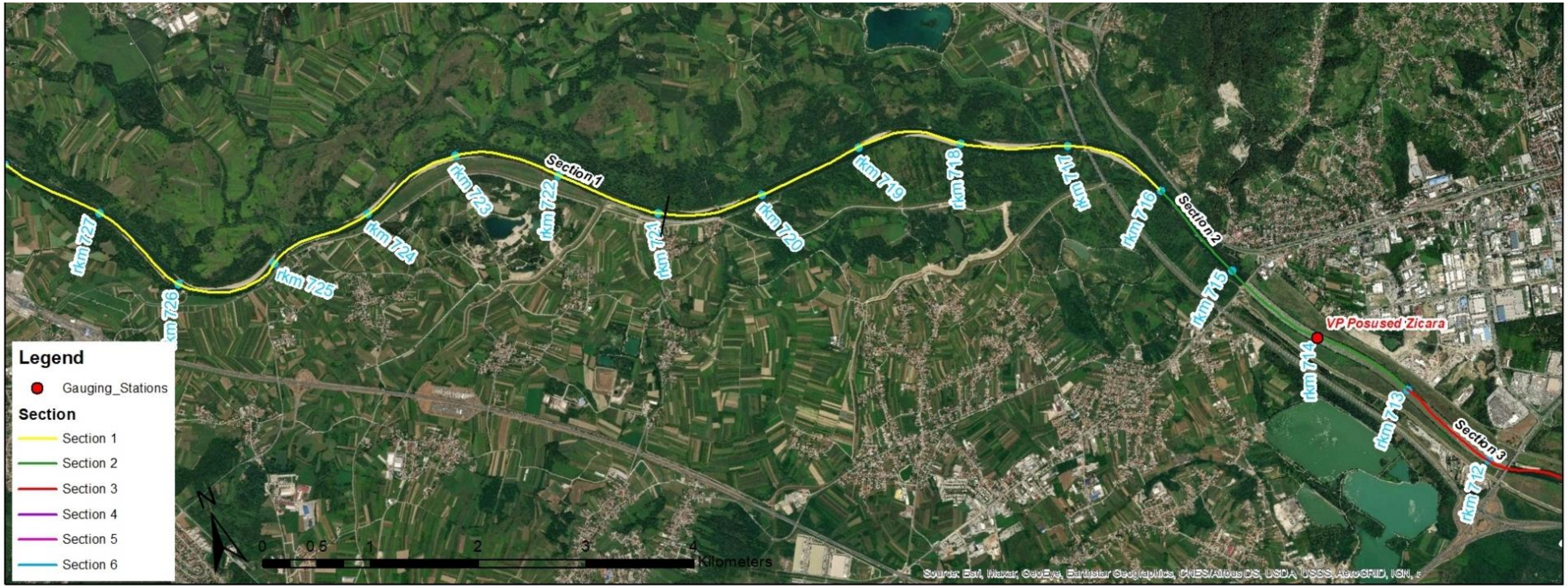


Figure 32: Detailed map of the river sections 1 and 2 (Source: REVITAL)

Figure 33: Detailed map of the river sections 3 and 4 (Source: REVITAL)

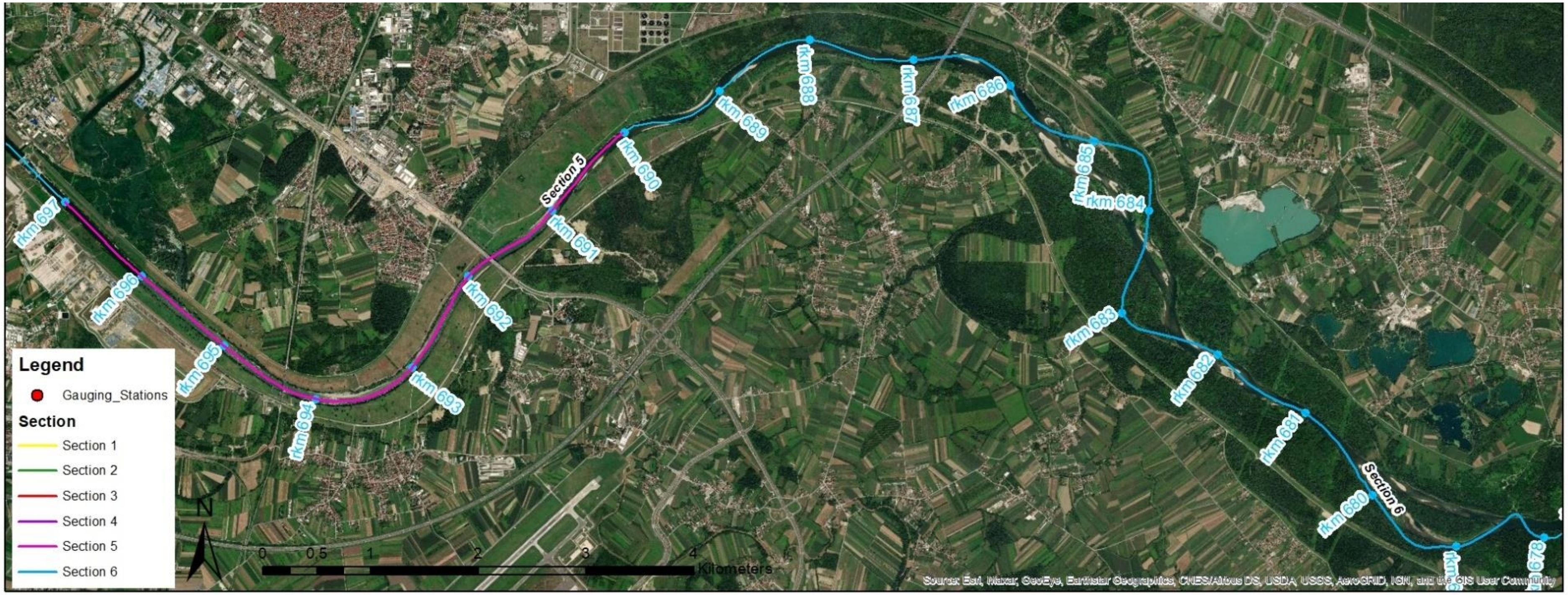


Figure 34: Detailed map of the river sections 5 and 6 (Source: REVITAL)

4.2.3 Characteristic Profiles

For each of the 6 river sections, defined in chapter 4.2.2, a characteristic cross profile was defined.

The first step was to determine the current morphology of the river sections. This was done with the “(B/h;h/D)-plan” of Da Silva (1991). The “(B/h;h/D)-plan” of [8] Da Silva (1991) uses the channel width, channel depth and grain size.

In a second step a possible widening of the channel was investigated. In section 1 the channel should be wide enough to establish a braided morphology.

In the actual state the main channel width of the river Sava is about 90 to 140m in sections 1 to 5 (Table 3).

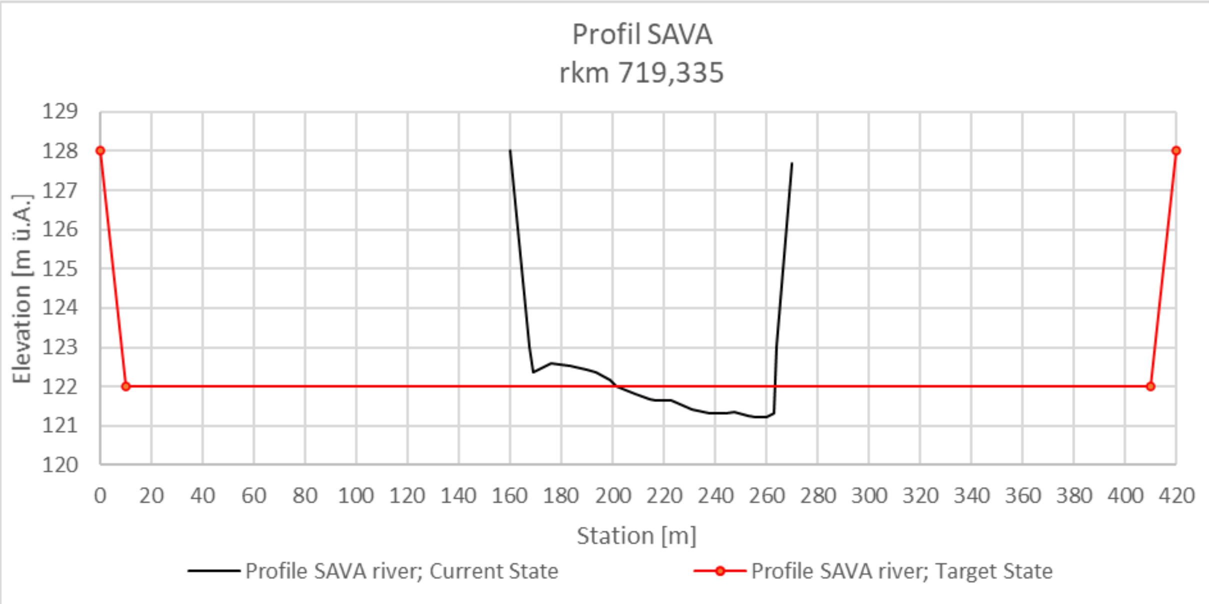


Figure 35: Profile with river widening potential of the river Sava at rkm 719,335, river section 1.

The widening in the sections 2 till 5 is limited by the outer flood protection dikes. The maximum channel width between the dikes is about 250-350 m. It is not possible to use the maximum space between the dams, the remaining part is used to protect the existing dikes.

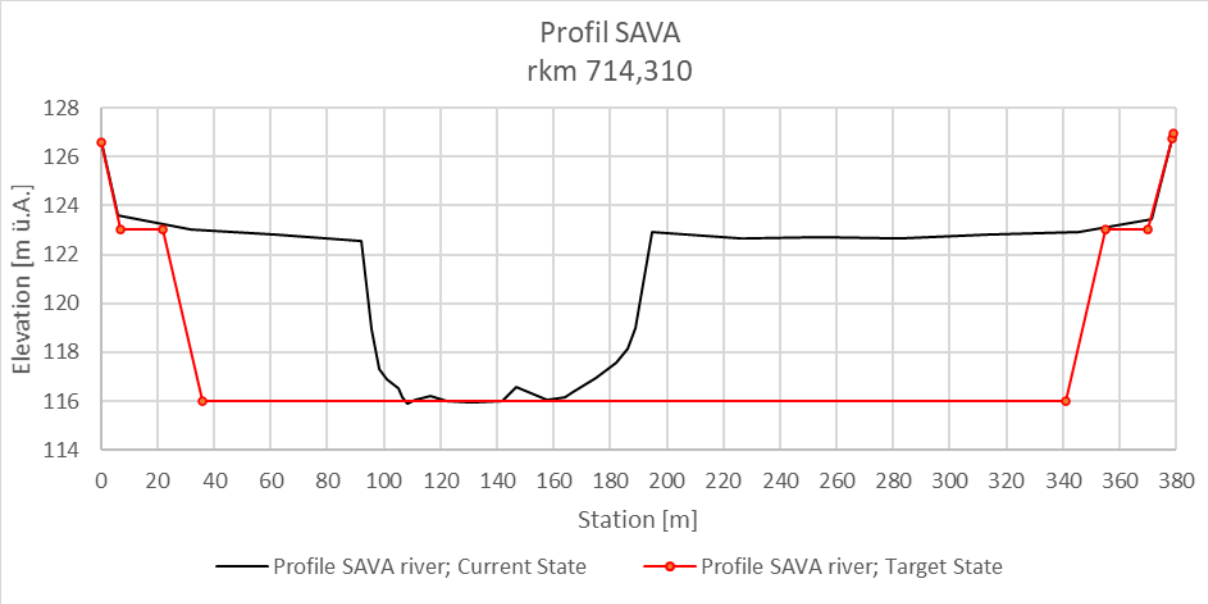


Figure 36: Profile with river widening potential of the river Sava at rkm 714,310, river section 2.

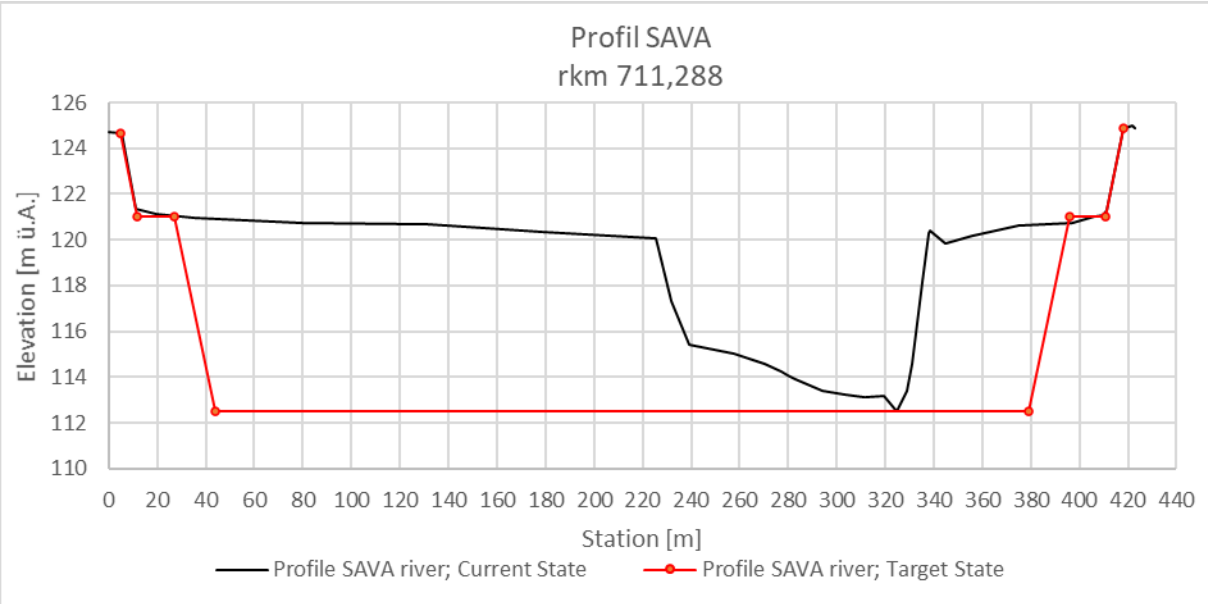


Figure 37: Profile with river widening potential of the river Sava at rkm 711,288, river section 3.

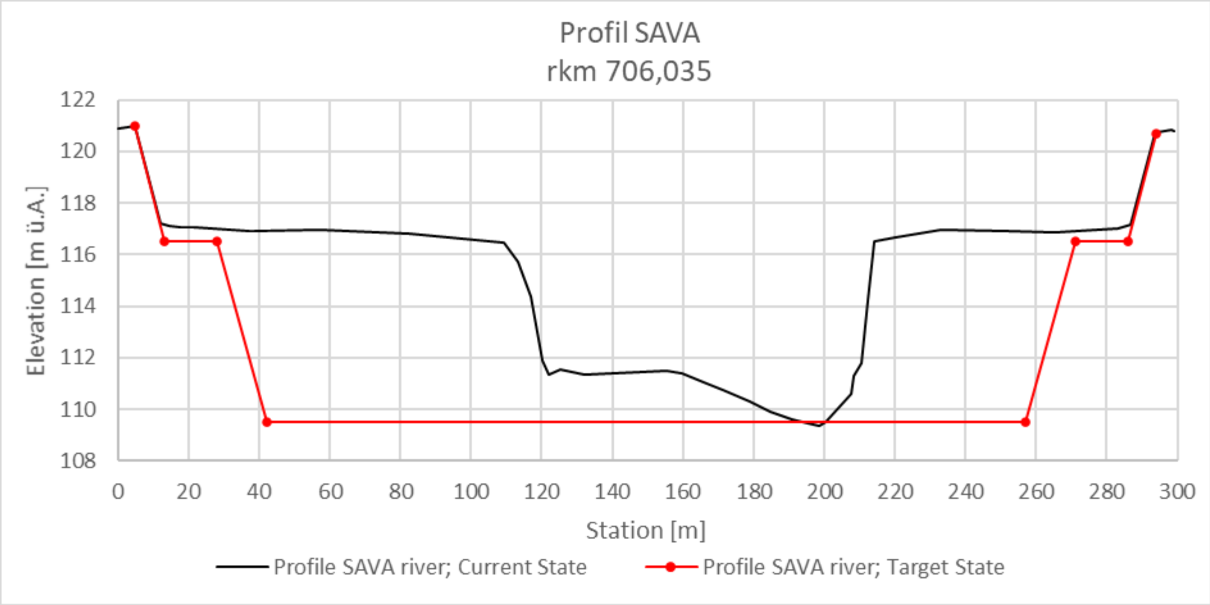


Figure 38: Profile with river widening potential of the Sava at rkm 706,035, river section 4.

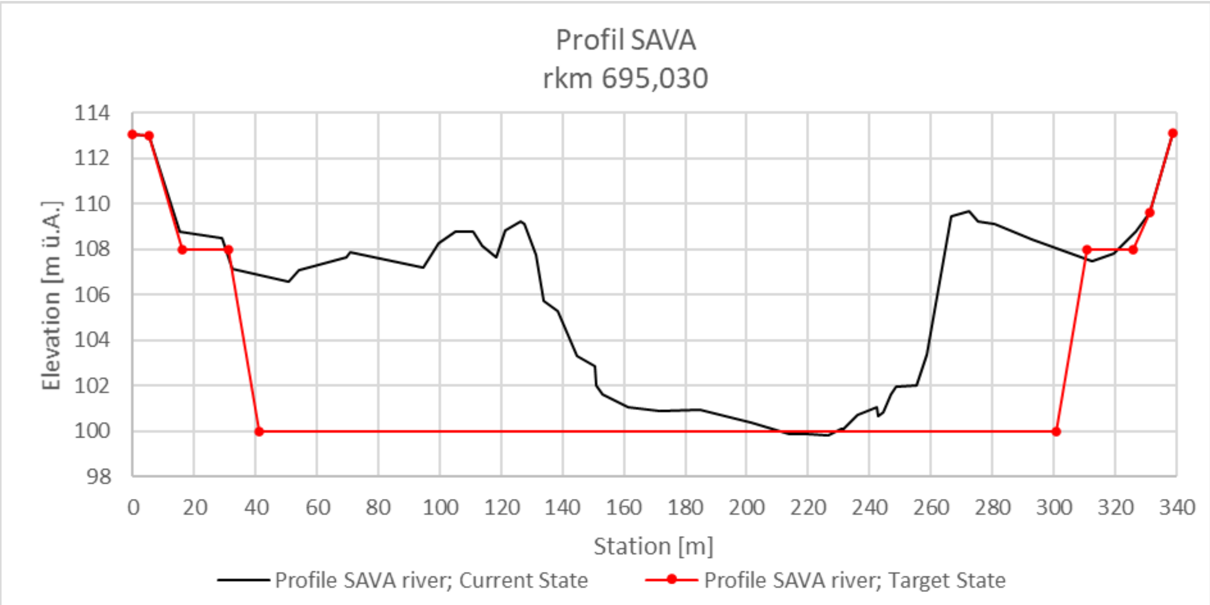


Figure 39: Profile with river widening potential of the river Sava at rkm 695,030, river section 5.

Profile at 681,717 rkm in section 6 was chosen to estimate the required channel width to establish a braided morphology.

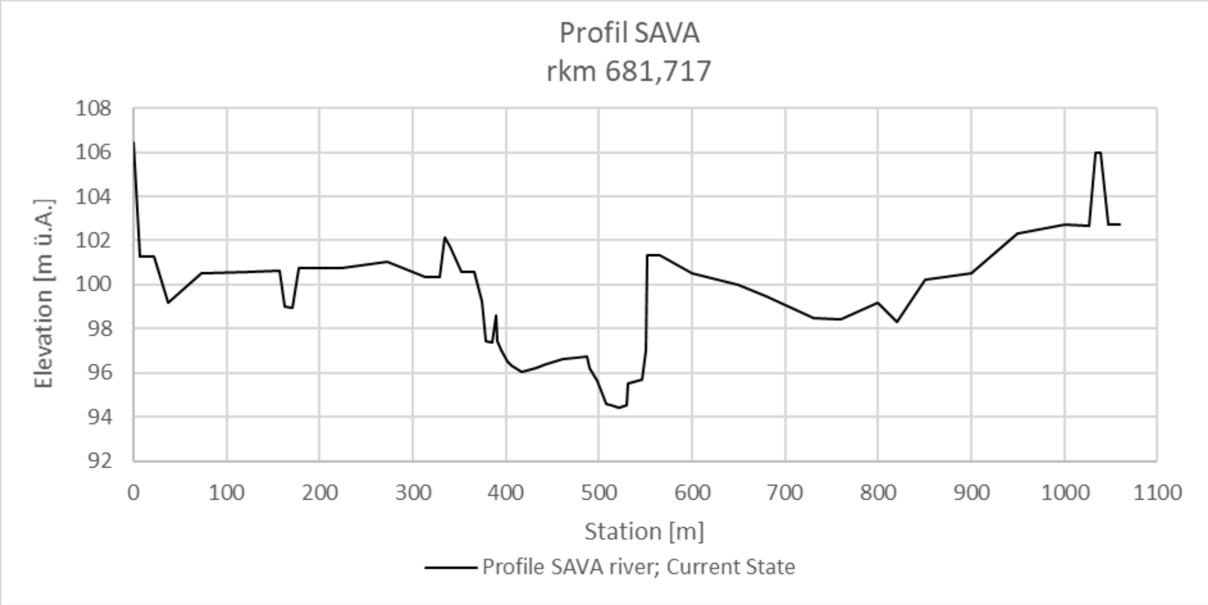


Figure 40: Profile of the river Sava at rkm 681,717, river section 6.

The profile geometry as given in the Figure 35 - Figure 40 is a simplified trapezoid profile. This is the simplified geometry defined in the model to run the hydraulic calculations. A braided riverbed is much more structured forming channels, gravel and sand – islands and floodplains. An example for a realistic, braided river morphology is given in Figure 41.

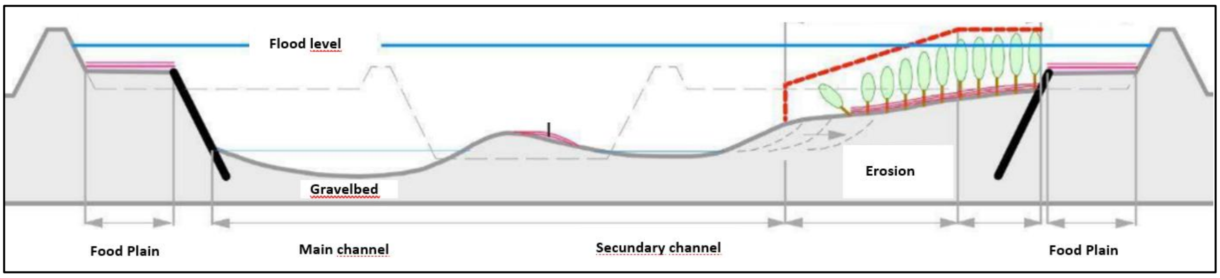


Figure 41: Example profile of braided river; Possible geometry for Sava upstream of Zagreb

In a realistic braided riverbed, the location of the main channel and the secondary channels changes with every higher discharge. Bank erosion and sedimentation of gravel and sand lead to dynamic balance. In case of small and middle discharge the flow occurs only in a part of the river profile, the other part of the cross section stays dry.

Therefore, a simplified cross section was applied to run the hydraulic calculations.

4.2.4 Morphology

4.2.4.1 Estimation of the natural river morphology and natural channel width

The estimation of the natural river morphology and the natural river width (“maximum width”) were carried out using different approaches. In the scientific literature there are various approaches for estimating the river morphology or for determining the optimal widths:

a) Branched river types – approach by [9] Bledsoe & Watson (2001):

The chance of developing a branched river system $P_{branched}$:

$$P_{branched} = \frac{[3{,}00 + 5{,}71 * log_{10}(J_V * \sqrt{Q_a}) - 2{,}45 * log_{10}(d_{50})]}{1 + \exp[3{,}00 + 5{,}71 * log_{10}(J_V * \sqrt{Q_a}) - 2{,}45 * log_{10}(d_{50})]}$$

Determination of the natural river widths without lateral limitation for different morphology types:

- Branched morphology:

$$w_{bf} = 2{,}61 * Q_a^{0{,}49} * d_{50}^{-0{,}76} * \varepsilon_w$$

- Single channels with alternating gravel bars:

$$w_{bf} = 4{,}86 * Q_a^{0{,}49} * \varepsilon_w$$

- Straight single channels:

$$w_{bf} = 3{,}36 * Q_a^{0{,}49} * \varepsilon_w$$

Determination of the maximum width ($b_{w,gr}$), taking into account the flow (Q), the slope (J) and riverbed material (d_{50}).

b) Non-branched / Straightened river types:

The natural river width („maximum width“) for a straightened river type (straight, pendulous, winding) is determined by the arithmetic mean value from the three approaches: [12] Henderson (1966), [11] Griffiths (1981) and [10] Ashmore (2001).

Approach by *HENDERSON:*

$$b_{w.gr} = 2{,}07 * Q * J^{1{,}167} * d_{50}^{-1{,}5} \ \ [m]$$

Approach by *GRIFFITHS:*

$$b_{w.gr} = 5{,}28 * Q * J^{1{,}26} * d_{50}^{-1{,}5} \ \ [m]$$

Approach by *ASHMORE:*

$$b_{w.gr} = 0{,}0098 * (p * g * Q * J)^{0{,}777} * d_{50}^{-0{,}7}$$

The calculations were based on the following parameters:

Slope	**J**	Mean slope; longitudinal Profile (Table 3)
Maximum outflow	**Q_a**	Average annual flood discharge [m³/s] (Table 3)
Medium grain diameter	**d_m** bzw. **d_{50}**	Medium grain-diameter, Grain-size distribution (Figure 46 and Figure 47)

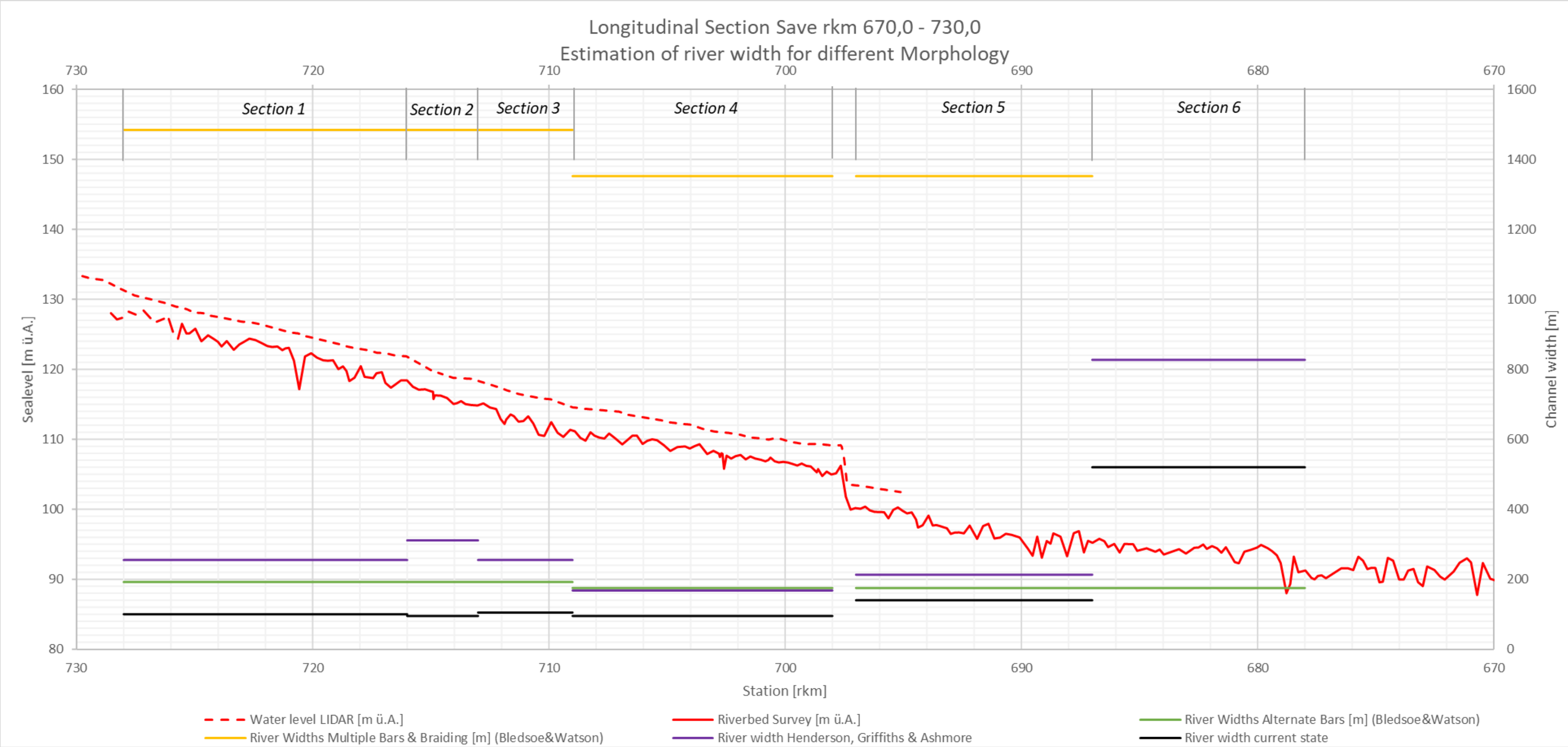


Figure 42: Estimation of the natural river width for different morphology.

In Figure 43 natural river width estimated with the models above for different river morphology are shown. The natural width for alternate bars varies from 180 to 200m (model Bledsoe&Watson) and from 200 to 300m (models of Henderson Griffiths and Ashmore). This is considerably higher than the river width in the actual state. Nevertheless, in the actual state (river width 90 tom 120m) the formation of alternating bars can be observed.

Natural river width for a braided system is much higher with about 1.400 to 1.500m.

4.2.4.2 DaSilva-Diagram

The “(B/h;h/D)-plan” of [8] Da Silva (1991) relates the ratio between channel width and water depth to the ratio between water depth and grain size, which allows delineating different morphological types. This diagram is used to estimate the channel width, which has to be provided to restore a certain morphology.

Morphological type of the different river-sections (see chapter 4.2.2) at current state

In the current state only Section 6 has a morphology of multiple bars and braiding. The river sections 1 to 5 lie in between plane bed (meandering) and alternate bars.

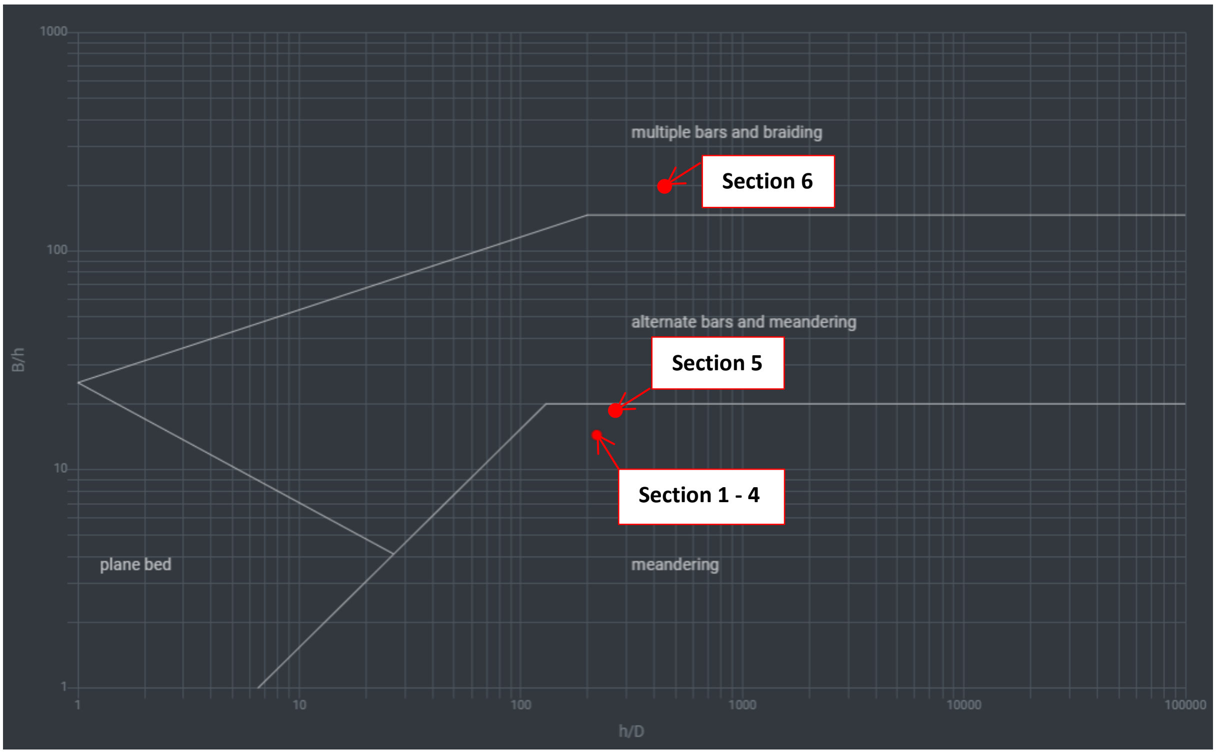


Figure 43: Estimation of the current state morphology based on channel width, channel depth and grain size (DaSilva, 1991)

The results of the DaSilva-Diagram coincide with the observation of the aerial photos. The actual width of 90 to 100m is just in the transition between plane bed and alternate bars. A slightly wider channel leads to the formation of gravel bars.

Morphological type of the different river-sections (see chapter 4.2.2) at target state

In a second Step the “(B/h;h/D)-plan” of Da Silva (1991) was used to determine the required channel width to re-establish the natural morphology in section 1. In the section 2-5 the “(B/h;h/D)-plan” was used to estimate the emerging morphology based on the maximum possible widening of the channel.

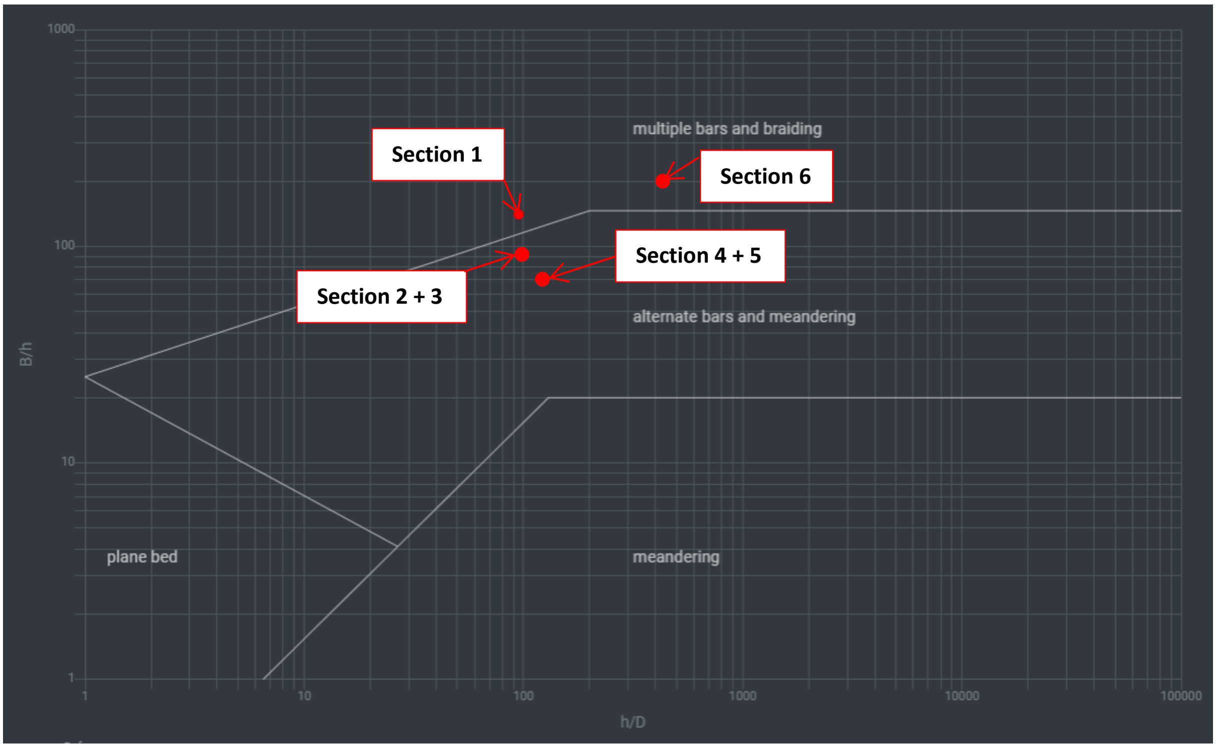


Figure 44: Estimation of the target state morphology based on channel width, channel depth and grain size (DaSilva, 1991)

For the future target river width of 200 to 300m was considered. If the future widening is applied to DaSilva-Diagram it can be observed that the target morphology moves clearly to a system of alternating bars, even the establishment of multiple bars is possible.

4.2.4.3 Summary Morphology

Based on different approaches, an estimation of the natural river morphology and natural channel width for the different section of the river Sava has been made.

Using the DaSilva-Diagram, the actual morphology type was estimated considering the actual river width. In the current state, the width of the main channel river morphology corresponds to confined single - thread (Plane bed) although in some river stretches the formation of alternating bars can be observed.

The estimation of the natural river width based on morphological models (DaSilva 1991, Bledsoe & Watson 2001) coincides with the observations of the aerial photos. A widening to >100m already leads to the formation of alternating bars. The formation of multiple bars and a braided system requires a river width of >400m.

Table 4: River Width and corresponding morphology for the river Sava in the project area

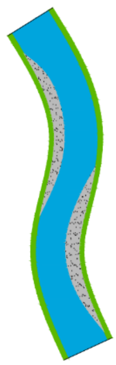
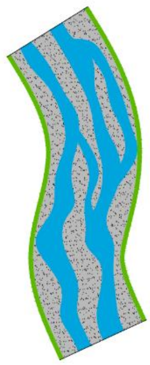
	River width [m]	
Current state (confined)	90 - 100	
Plane bed	< 100	
alternate bars (wandering)	100 - 400	
multiple bars & braiding	> 400	

Figure 45:Estimation of river width and morphology type for the river Sava.

Minimum length of river widening ([15] Ashmore 2011):

The required minimum length of a river widening was estimated with the approach of Ashmore 2011.

$$L_{dyn\_min} = 52{,}5 * Q^{0{,}45}$$

The approach considers a mean annual flood discharge to estimate the required length of a river widening to comply the ecological and morphological function. Considering a mean annual flood discharge of 1500 to 1800 m³/s the required minimum length of the widening is between 1,40-1,50 km.

4.3 Sediment

4.3.1 Grain Size distribution

As part of the regular hydrologic monitoring, suspended sediment measurements are made on four locations on the river Sava. This includes profile measurements of sediment concentration and sediment load as well as grain-size distribution of the suspended loads.

For the investigations on the river morphology, it is essential to consider the bedload instead of suspended sediment loads.

Systematic bedload measurements are currently not existing. Nevertheless grain-size distributions of bedload and bedload measurement have been made on three locations on the river Sava: Podsused, Rugvica and Jasenovac.

Historical data of bedload measurements are available for the hydrological station Podsused-Žičara (period 1975-1986). For Podsused bedload investigations exist for the period from 1994 to 1995.

The analysis of bedload composition has also been made at Rugvica and Jasenovac, according to the standard screen sieve fractions.

For the investigation of sediment transport along the river stretch of Zagreb, grain size distribution of the gauging stations Podsused and Rugvica were considered.

4.3.1.1 Hydrological station Podsused Žičara

For the present investigation, grain-size distribution and bedload measurements at the hydrological station Podsused were considered for the period from 1994 to 1995. The following figure shows the grain-size distribution on the gauging station Podsused which was taken in the year 1995.

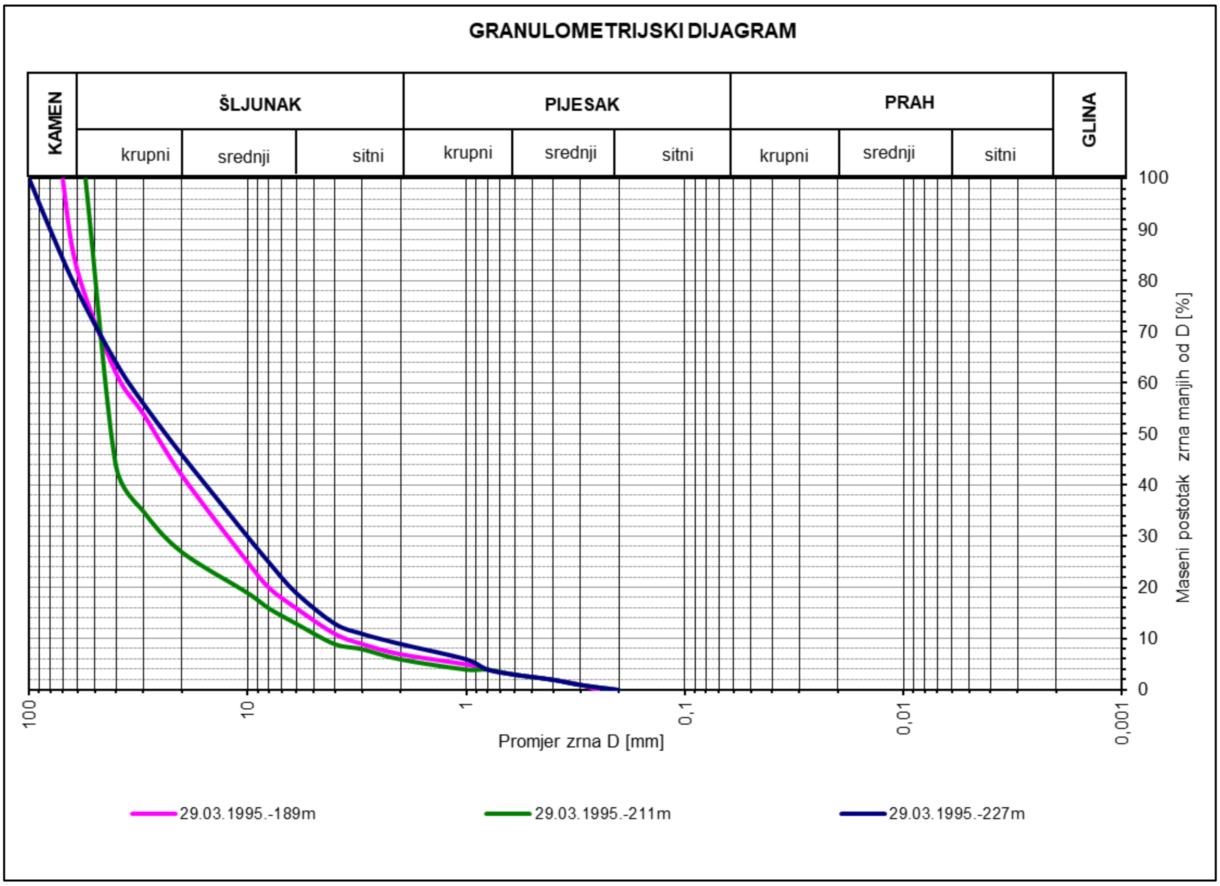


Figure 46: Grain size distribution of bedload at the gauging station Podsused from the year 1995 (Source: [6] HRVATSKE VODE (2019))

Table 5: Bedload grain size distribution at the gauging station Podsused; Characteristic diameters 1995 (Source: [7] HRVATSKE VODE (2019))

D [%]	D5	D10	D16	D25	D50	D75	D84	D90	D95
D [mm]	0,9	4	7,9	13,8	30,2	49	60,7	81	117

4.3.1.2 Rugvica

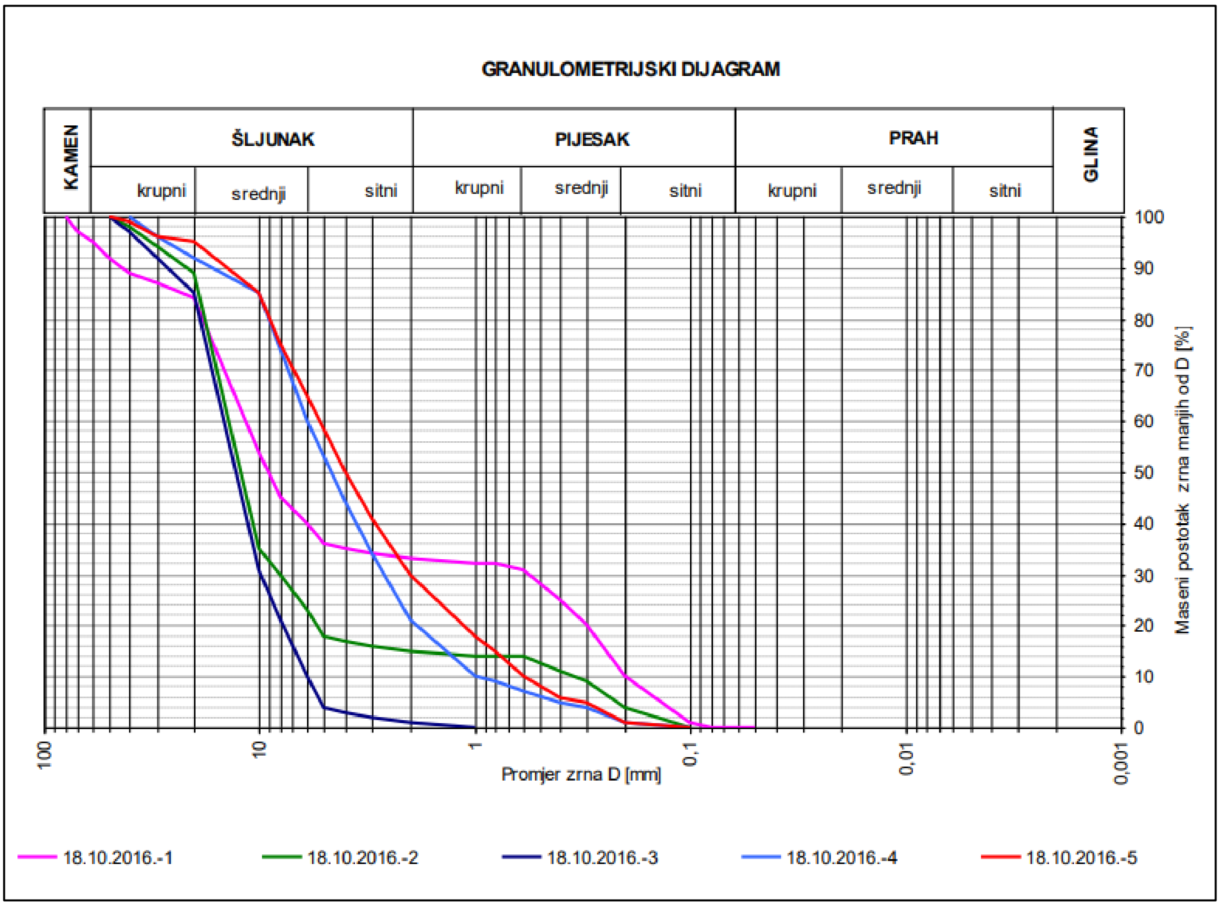


Figure 47: Grain size distribution of bedload at the gauging station Rugvica, from the year 2016 1995 (Source: [8] HRVATSKE VODE (2019))

For Rugvica gauging station investigations of grain-size distributions and bedload measurements exist for the period from 1980 to 2016. In this document the bedload data for Rugvica from the year 2016 was considered.

Table 6: Bedload grain size distribution at the gauging station Rugvica; Characteristic diameters (Source: [9] HRVATSKE VODE (2019))

D [%]	D5	D10	D16	D25	D50	D75	D84	D90	D95	D100
D [mm]	0.27	0.54	0.86	####	####	####	16.26	21.14	30.91	NA

Observing the grain-size distributions for Podsused and Rugvica there are conspicuous differences in the characteristic diameters. The mean diameter from the gauging station Podsused is about 30 mm and so considerably bigger than from Rugvica with about 6 mm. The difference appears due to the fact of deposition of larger grain sizes in the river-stretch downstream of rkm 697,0.

4.3.2 Sediment transport capacity

Potential sediment transport was calculated for the six defined river stretches (see chapter 4.2.2). The formula of Meyer-Peter & Müller ([13] E. Meyer-Peter, R. Müller (1949)) was applied to calculate the potential sediment transport in the characteristic profiles of each river section. Potential sediment transport was calculated for a discharge in the magnitude of an average annual flood on gauging station Rugvica (1500 m³/s). For the river sections 1 – 5 the grain-size distribution of gauging station Podsused was applied for the calculations. The potential transport in section 6 was calculated considering the bedload date from gauging station Rugvica.

In a first step, potential sediment transport of the current state was calculated and analysed for all six sections. Highest transport potential can be observed in between rkm 728,0 – 713,0 and from rkm 697,0 – 690,0 (grey line in Figure 48). This matches quite well with the stretches of the highest incision of the river channel shown in Figure 25.

In a second step, the potential widening of the river channel as described in 4.2.3 was applied to the characteristic profiles of each river section. Sediment transport was recalculated considering the new geometry (Orange line in Figure 48). Section 6 was considered as reference; therefore, no changes of the river geometry was applied.

The results of the calculation applying Meyer-Peter & Müller formula were compared with other models such as Smart & Jäggi ([14] Graeme M. Smart, Martin N. R. Jäggi (1983)):

In Figure 48 sediment transport potentials for the current state as well as for river widening are illustrated.

Potential sediment transport capacity reduces considerably with the new, wider channel geometry. Between rkm 690,0 – 716,0 transport capacity reduces to about 30 – 60 % of the current state (Table 7). In section 1 the reduction is even higher due to the higher potential for channel widening.

In Figure 48 there is a summary of the results of the transport capacity calculations.

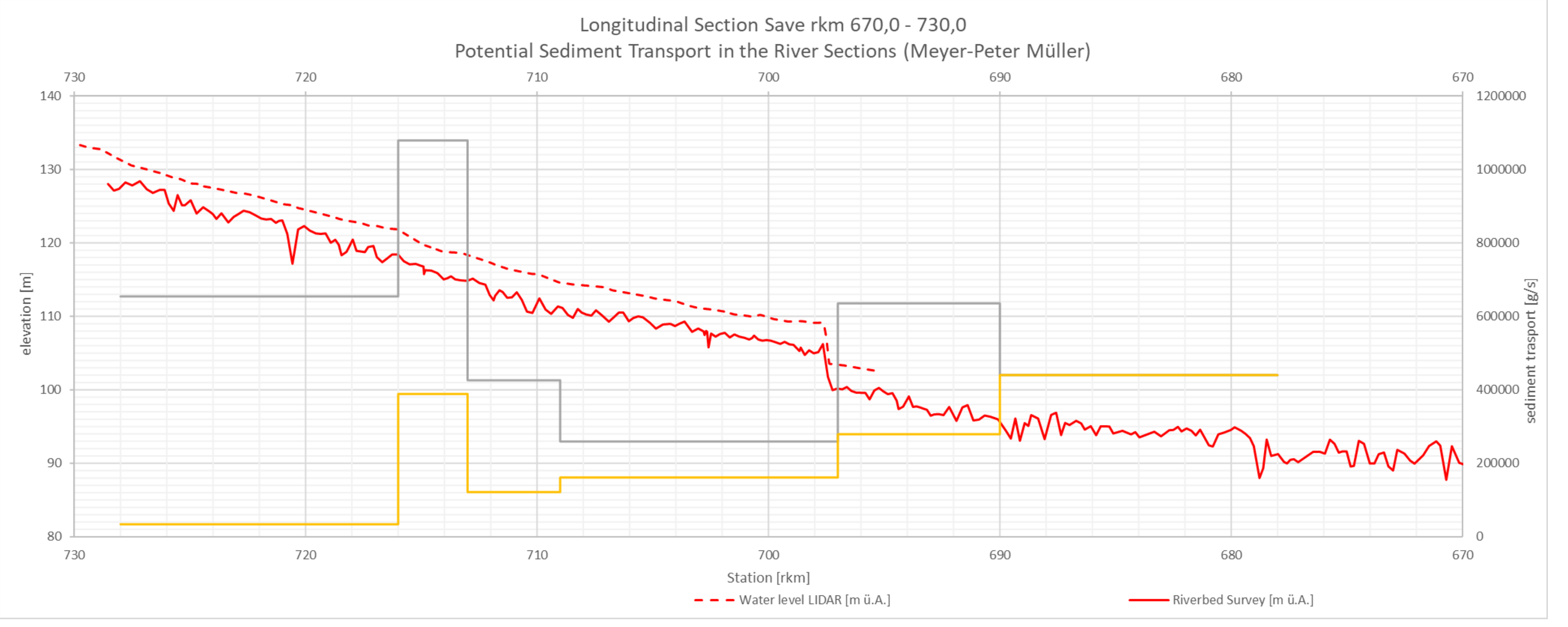


Figure 48: Potential sediment transport between rkm 670,0 – 730,0 at average annual flood discharge (based on transport formula Meyer-Peter and Müller, 1949) Grey line: current state; orange line: target state

Table 7: Potential sediment transport between rkm 670,0 – 730,0 at average annual flood discharge (based on Transport formulas of Meyer-Peter and Müller, 1949 and Smart-Jäggi, 1983).

				Current State				Target State					
Section	**Profile**	**Mean Slope**	**MHQ [m³/s]**	**Bottom width [m]**	**Depth H [m]**	**Current state; Sediment Transport Meyer-Peter Müller [g/s]**	**Current state; Sediment Transport Smart Jäggi [g/s]**	**Bottom width [m]**	**Depth H [m]**	**Target state; Sediment Transport Meyer-Peter Müller [g/s]**	**% of Current State**	**Target state; Sediment Transport Smart Jäggi [g/s]**	**% of Current State**
1	719,355	0,0010	1500	100	6,66	654.302,28	141.307,44	400	2,54	34.172,5	5%	2.283,28	2%
2	714,31	0,0012	1500	95	6,52	1.078.879,39	248.091,53	310	2,83	388.671,78	36%	103.808,24	42%
3	711,288	0,0010	1500	105	7,6	426.004,9	95.256,3	340	2,83	121.580,55	29%	31.081,24	33%
4	706,035	0,0008	1500	95	8,08	259.286,62	54.357,0	230	3,93	161.254,52	62%	37.586,76	69%
5	695,03	0,0010	1500	130	6,65	635.100,89	139.102,61	260	3,3	279.030,5	44%	69.501,02	50%
6	681,717	0,0005	1500	570	6,05	439.932,78	72.859,95	570	6,05	439.932,78	100%	72.859,95	100%

4.3.3 Potential annual Sediment transport

Potential annual sediment transport was calculated for the six investigated river sections. The formula of Meyer-Peter & Müller (1949) was applied to calculate the potential sediment transport in the characteristic profiles of each river section.

The calculations were performed using the flow duration curve, generated from the daily average flows 2013 on the gauging station Podsused (Figure 49). For the river section 1 – 5 the grain-size distribution of gauging station Podsused was applied for the calculations. The potential transport in section 6 was calculated considering the bedload data from gauging station Rugvica.

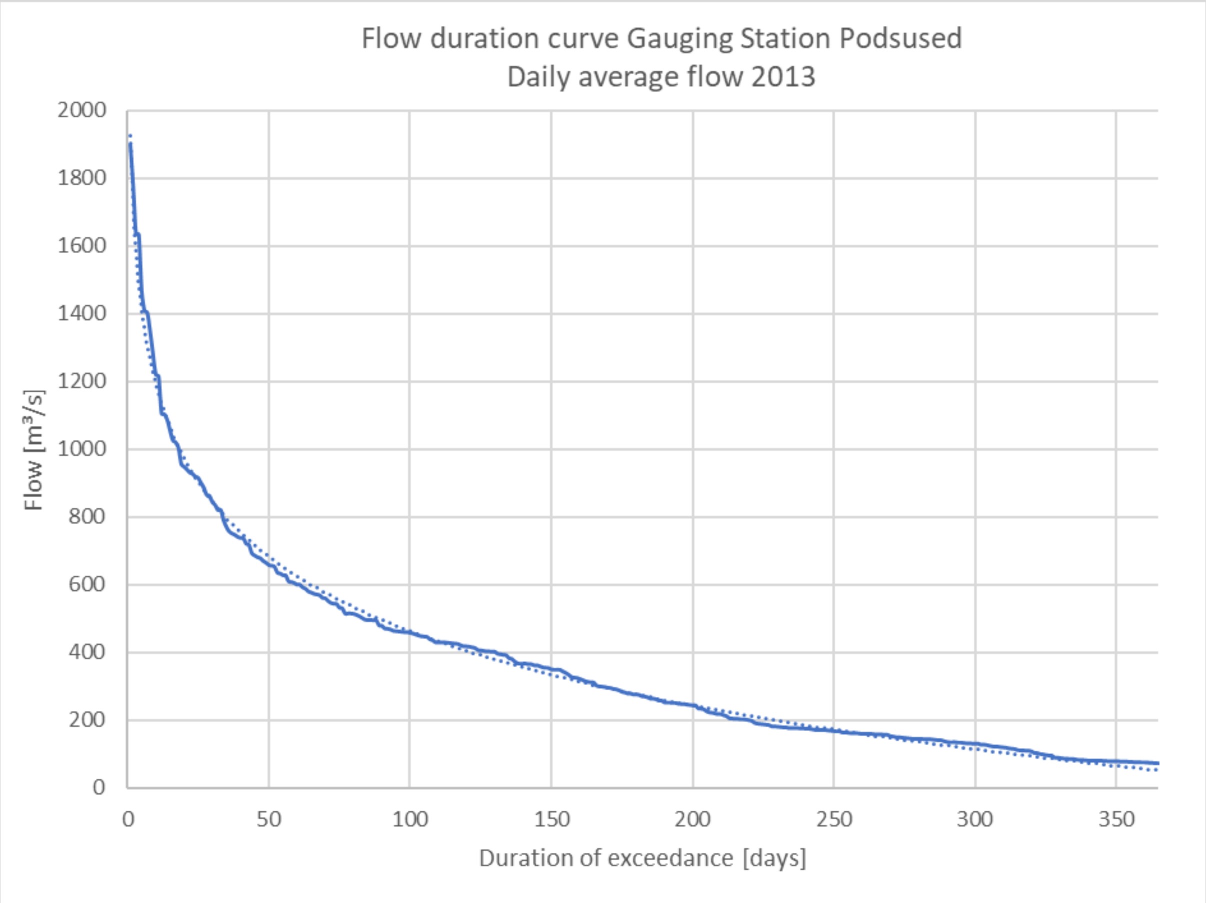


Figure 49: Flow duration curve gauging station Podsused (Source: [10] HRVATSKE VODE (2015))

Results show a considerable, potential reduction of the annual sediment transport in the river section 1-5. In the sections 1-3 the widening of the river channel reduces the annual potential sediment transport to about 10% of the current state. In sections 4 and 5 the possible reduction is about 20% of the current state.

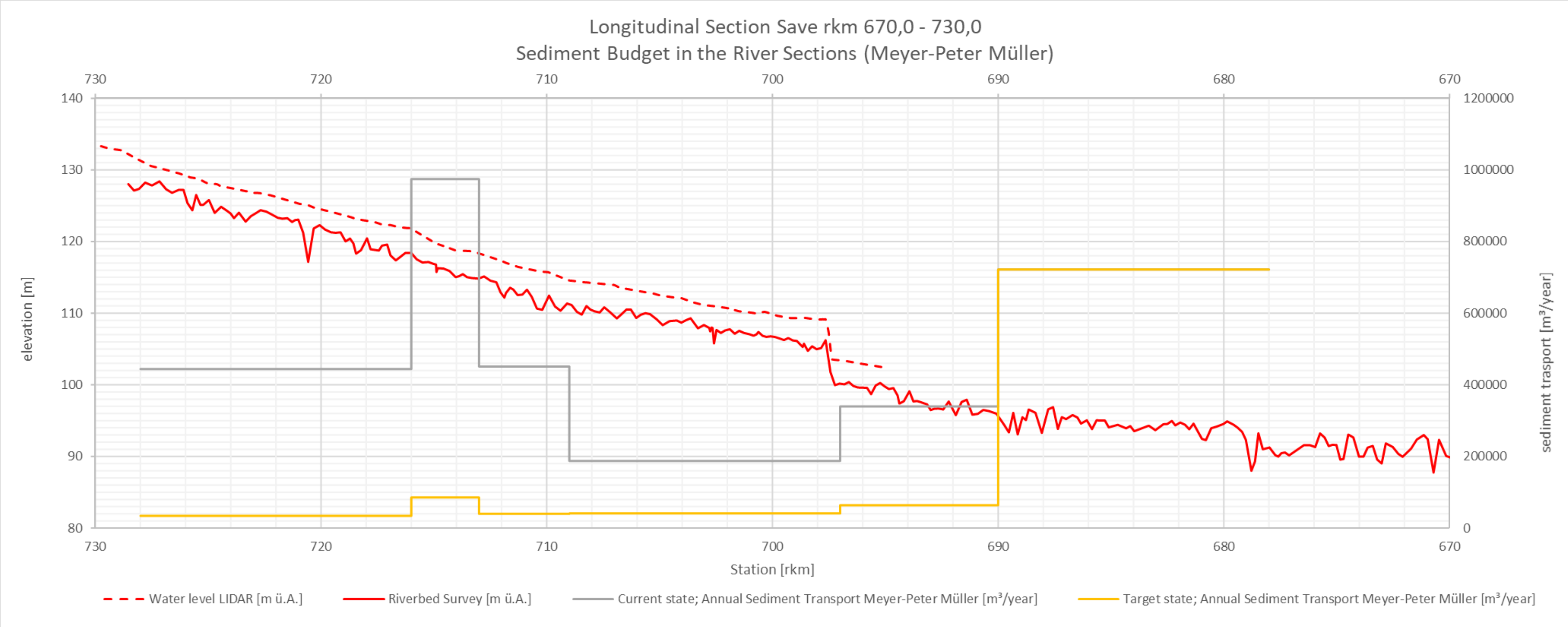


Figure 50: Annual potential sediment transport between rkm 670,0 – 730,0 based on flow duration curve from the gauging station Podsused and transport formula Meyer-Peter and Müller, (1949)

Table 8: Potential annual sediment transport between rkm 670,0 – 730,0 based on flow duration curve from the gauging station Podsused and transport formula Meyer-Peter and Müller (1949) and Smart-Jäggi (1983).

			Current State		**Target State**			
Section	**Profile**	**Mean slope [‰]**	**Current state; Annual Sediment Transport *Meyer-Peter Müller* [m³/year]**	**Current state; Annual Sediment Transport Smart *Jäggi* [m³/year]**	**Target state; Sediment Transport *Meyer-Peter Müller* [g/s]**	**% of Current State**	**Target state; Sediment Transport Smart *Jäggi* [g/s]**	**% of Current State**
1	719,355	1	443.979,68	103.415,67	34.172,5	8%	2.283,28	2%
2	714,31	1,2	974.260,53	241.110,97	85.417,64	9%	21.627,14	9%
3	711,288	1	450.994,83	105.857,15	39.762,5	9%	10.007,06	9%
4	706,035	0,7	187.611,23	41.526,4	40.887,1	22%	9.017,83	22%
5	695,03	1	339.643,67	79.943,92	63.898,5	19%	15.073,42	19%
6	681,717	0,5	721.736,17	121.752,78	721.736,17	100%	121.752,78	100%

4.4 Summary and Conclusions of the current state analysis

The river Sava is a typical alluvial river. Without regulations of the riverbed, the river Sava in the project area would be in a transition zone between a braided multi-channel river system (upstream Zagreb) to a meandering river (downstream Zagreb). Due to human influence, morphology and the geometry of the river and its riverbed have changed in the last centuries and decades.

From the Slovenian border to downstream of Zagreb the river Sava is completely channelized. The sections around the gauging station Podsused are regulated, partly with alternating gravel bars. The width of the riverbed is about 100 m. Around the city of Zagreb, the channel has the form of a double trapezoidal profile. The width of the riverbed is about 100 m. Continuous flood protection dikes and wide river forelands are typical for this river stretch. The distance between the dikes is about 300 m.

Downstream Zagreb, from Hruščica to Rugvica (rkm 675) there is the last remaining braided and anabranching stretch of the river Sava in the project area, but it is also severely suffering from the bedload deficit.

The first goal of the analysis of the current state was to identify river stretches, where incision is a major problem as well as stretches where the river Sava is close to their natural state. In total 6 river-section along the project area were defined.

For these stretches important parameters like channel geometry, discharge, mean slope and granulometry were derived based on existing data. These parameters have a major impact on sediment transport and river morphology.

Based on these parameters, sediment transport capacity and annual transport potential were calculated for each of the river sections.

In a second step, widening of the river channel was applied to the investigated river sections. The width of the widened river corridor was between 230 and 400 m.

Considering the new (wider) channel geometry, sediment transport capacity and annual transport potential were recalculated and compared to the current state.

Results show that a widening of the river channel leads to considerable reduction of the sediment transport capacity. Calculations show a reduction of sediment transport capacity to 5 -60 % of the current state. The reduction of the potential annual sediment transport is even higher.

For the calculations of sediment transport capacities in the widened riverbed (target state) the new channel geometry was presumed with a plain riverbed. Sediment transport in the model can happen along the whole width of the channel. In a branched riverbed sediment transport does not happen along the whole width of the channel. Therefore, the calculated sediment transport capacities for the widened river channel (target state) are likely to be comparatively low. Nevertheless, the widening of the channel leads to a considerable reduction of the sediment transport capacity subsequently to a reduction of the riverbed erosion.

Based on the available data, the assumptions were made and the calculations performed, the following can be summarized:

- The development of the Sava River in the last decades is comprehensible due to the measures taken (narrow regulation, lack of sediment input from upstream)

- River widening to an extent that is feasible in principle in terms of space availability has the potential to bring the morphological system closer to the original system again (alternating banks, braiding, gravel banks)
- The problems caused by the bedload deficit can be effectively countered by river widening (significant reduction of the transport capacity and thus of the required bedload input into the system to maintain a dynamic state of equilibrium of the bed)

Preserving the current situation regarding flood protection is a framework condition – this feasibility study shows that the flood protection for the city of Zagreb can be improved. By stabilization of the riverbed of even elevating the riverbed the situation around the derivation channel can be changed to the better. Measures upstream of Zagreb can improve function and capacity of retention areas.

First calculations show that the described measures also lead to a higher ground water level and the current situation can be improved (see Figure 51).

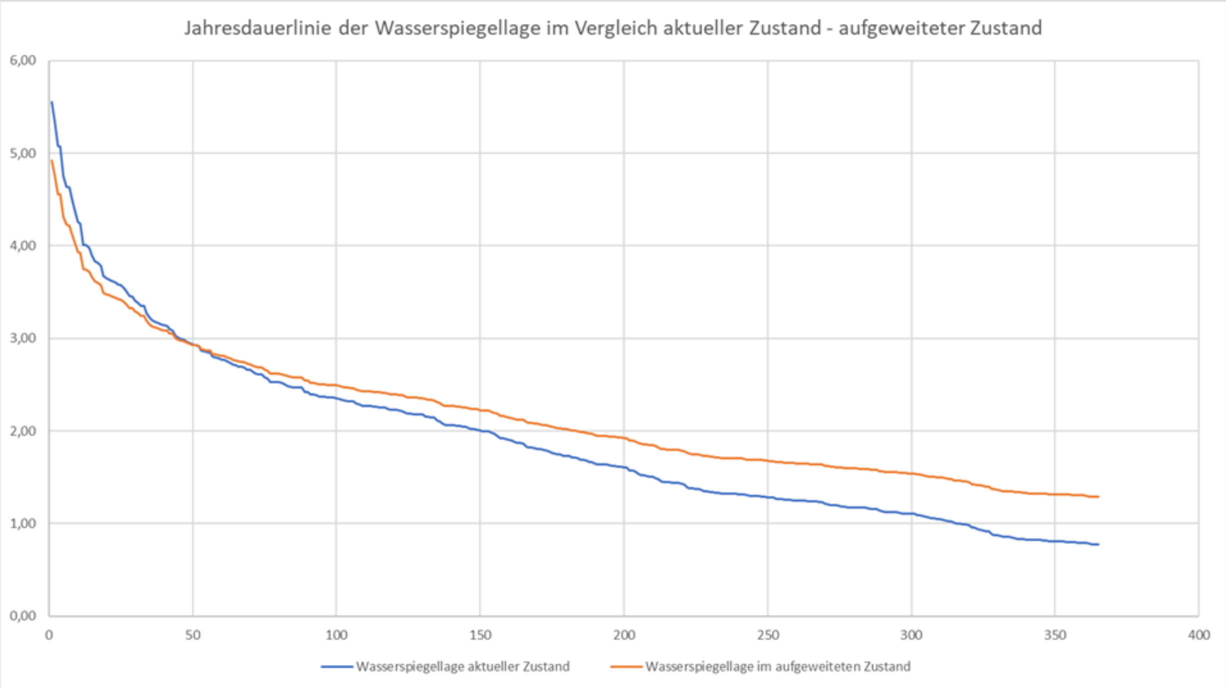


Figure 51: Blue line: current state of the water level. Red line: Water level after river widening.

5 Results

5.1 Framework conditions for riverbed stabilisation

Based on the collected information from the chapter 4, the framework conditions for riverbed stabilisation of the river Sava between Brežice and Rugvica are defined as follows:

- Revitalisation sites:
  - River width (target width):

rkm	Optimal target river width [m]
719	400
714	310
711	340
706	230
695	260
681	570

  - Minimal length of the revitalisation sites: 1,4 to 1,5 km
  - Width of initial channel: 10 – 40 Meter
  - Soft riverbanks: 1:10
  - Increase input of bedload material

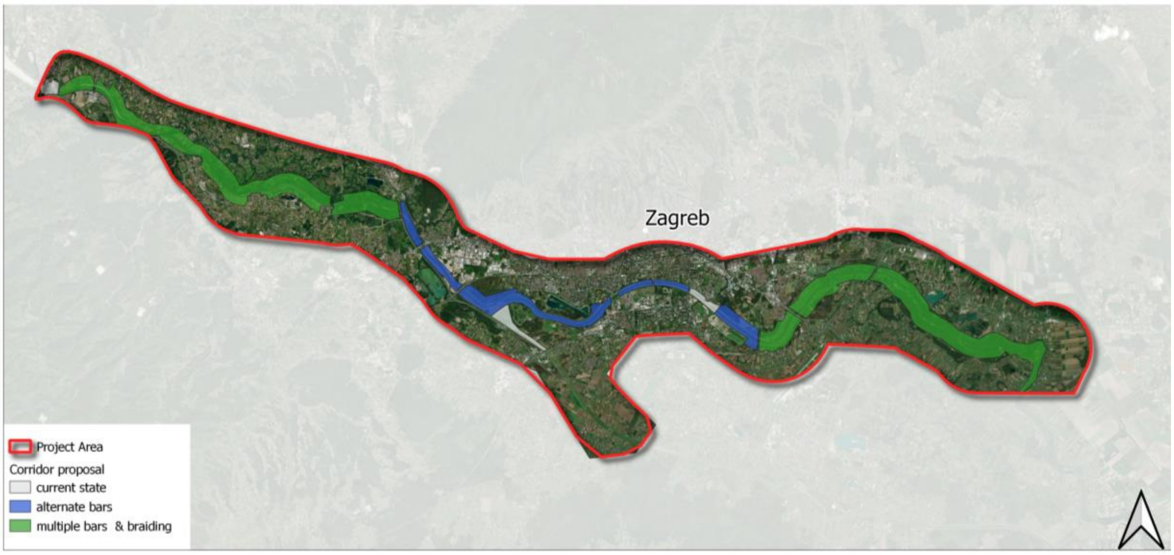


Figure 52: Corridor proposal.

5.2 Concept for river restoration project and feasibility study

Within the project area, the river Sava is a mostly monotonously regulated river. One of the biggest problems in the river stretch from Brežice to Rugvica is the riverbed degradation. The riverbed degradation is directly connected and causes problems within the following topics:

- flood protection that is not working optimally
- decreasing groundwater levels in the floodplain and foreland
- loss of biodiversity
- River Sava is not used as recreational site

This feasibility study shows first ideas and concepts to make the river Sava safer, related to flood protection or water supply and more alive, in relation to biodiversity and recreational use. The river restoration concept therefore specifically pursues different integrative goals:

- stabilize riverbed by riverbed widening, side erosion and increased bedload input (instead of ramps or hydropower stations)
- increase discharge capacity maintain and restore retention areas
- improve the ecological status
- create a unique recreational sites, that are within the city of Zagreb

To achieve these improvements for the river Sava, it is necessary to implement the following essential measures or a combination of these measures:

- building "initial channels"
- restoring soft banks
- widening the river
- flattening or lowering of river foreland areas
- reinforce and reset existing bank protection

With these measures, the river Sava is not only getting a "new, attractive face", step by step in a generation project, but it also becomes more secure and livelier.

From the point of river restoration, the river Sava from Brežice to Rugvica can be divided into 5 sections, to which similar measures can be assigned:

- section 1: from Brežice (rkm 737) downstream till the dikes end on both sides (rkm 730)
- section 2: upstream the city of Zagreb, from rkm 730 to rkm 715
- section 3: river stretch through the city of Zagreb from rkm 715 to rkm 695
- section 4: downstream of Zagreb from rkm 695 to rkm 687
- section 5: from the Ivanja Reka bridge at rkm 687 down to Rugvica (end of project area at rkm 672)

In addition, two other areas are required selectively to implement measures:

- Ramp and flood protection measures at rkm 693 (at the derivation channel Sava-Odra)
- Ramp between rkm 681 and rkm 682 (existing ramp at HEP – Toplinarstvo)

In the following tables the sections are described. This legend can be used to interpret the maps:

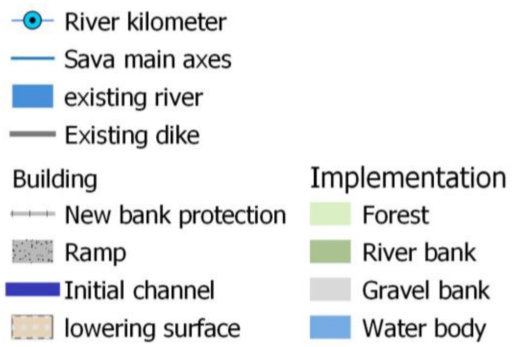


Figure 53: Legend for the following maps.

5.2.1 Section 1: from Brežice (rkm 737) to rkm 730

Table 9: River restoration concept for Section 1 from Brežice (rkm 737) to rkm 730.

Section 1	
Description: This section is about 7 km long, the average river width is around 100 meters. The riverbanks are very steep, the bank protection is covered with wood. The river Sava is bounded on both sides by dikes, that are on average approximately 200 meters away from the water body. The foreland is covered by wet grassland or softwood.	 Figure 54: Sample picture of the area and the river Sava in section 1 (Photo: REVITAL).

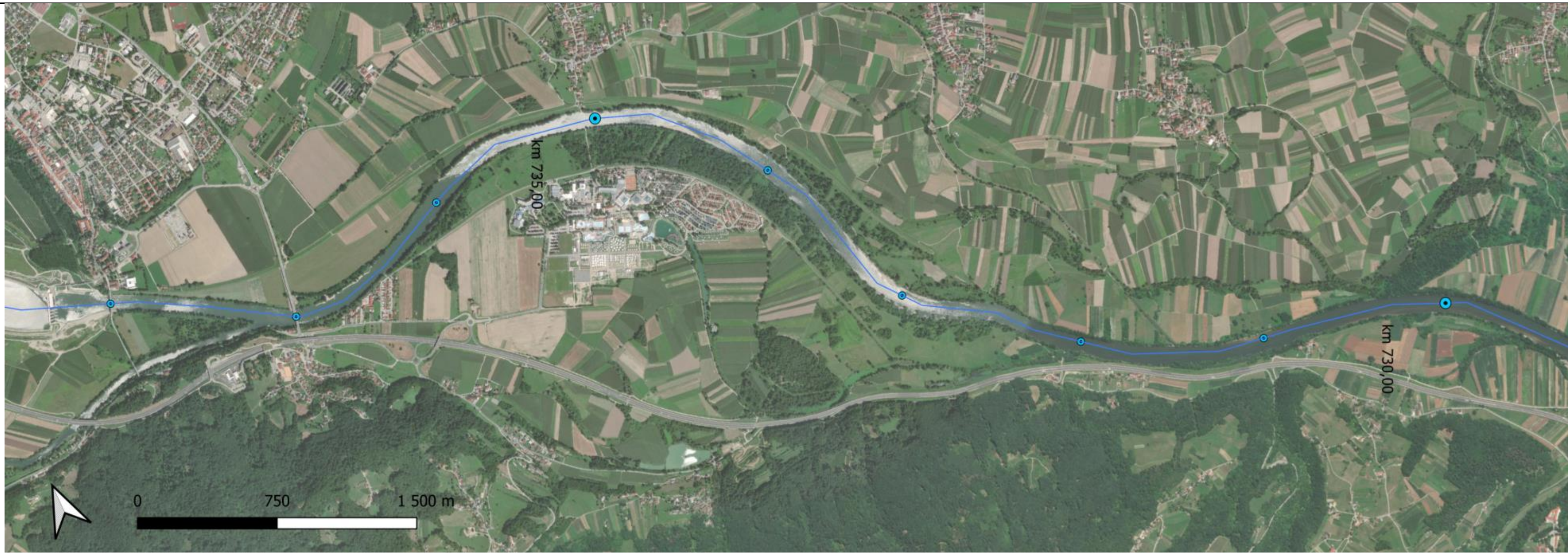


Figure 55: Actual situation of section 1 with aerial photo.

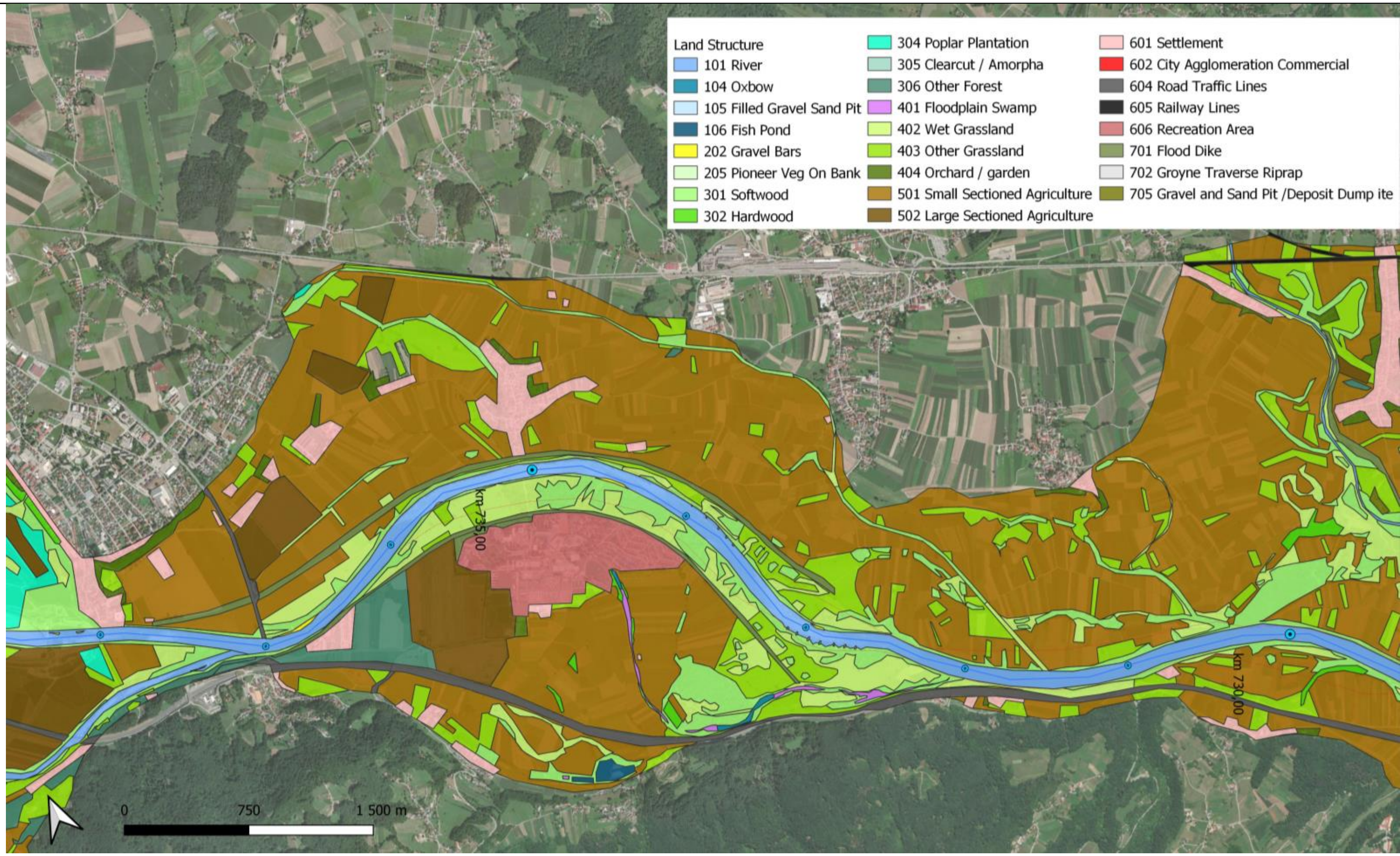


Figure 56: Land structure (Source: Sava White Book, 2016) in section 1 with aerial photo.

Transformation:	**Initial measures:**
From the monotonous canal to the braided river with gravel banks, islands.	- Building initial channels ○ Main initial channel 30 m wide

After the implementation of the described measures the average target river width will be around 230 m, including gravel bars, water body, soft / hardwood, grassland and flat embankments.	○ Small initial channel 15 m wide - Restoring soft banks with flat embankments - Reinforce and reset bank protection next to main initial channel (Figure 58)

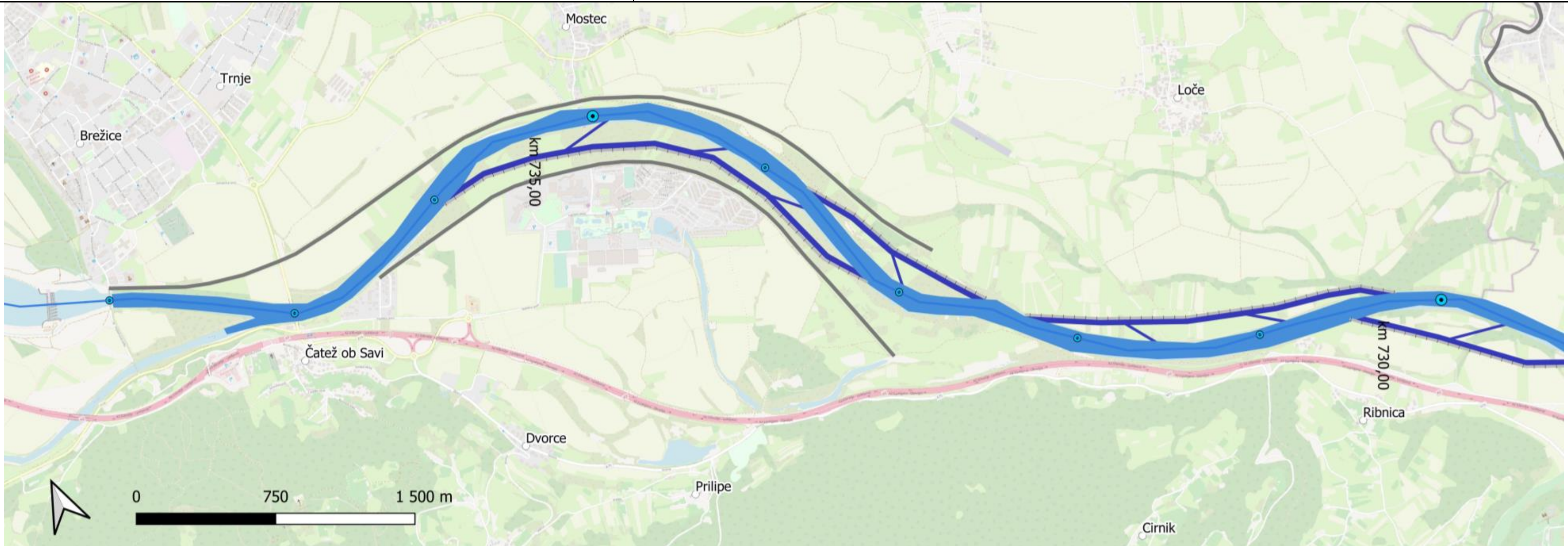


Figure 57: Possible initial measures in section 1.

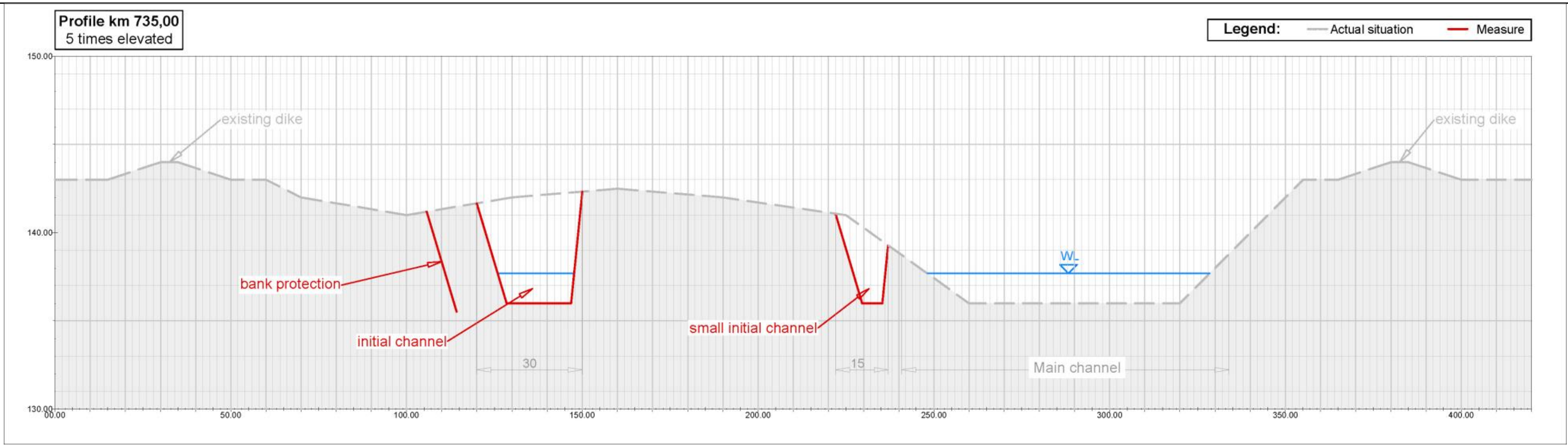


Figure 58: Cross section at rkm 735 of section 1 with actual situation and possible measures.

Benefits:

- Higher discharge capacity
- New gravel banks
- Development of recreational sites
- Riverbed stabilisation
- Potential for bed load input
- More river dynamic – natural dynamic processes lead to a good ecological status of the river Sava

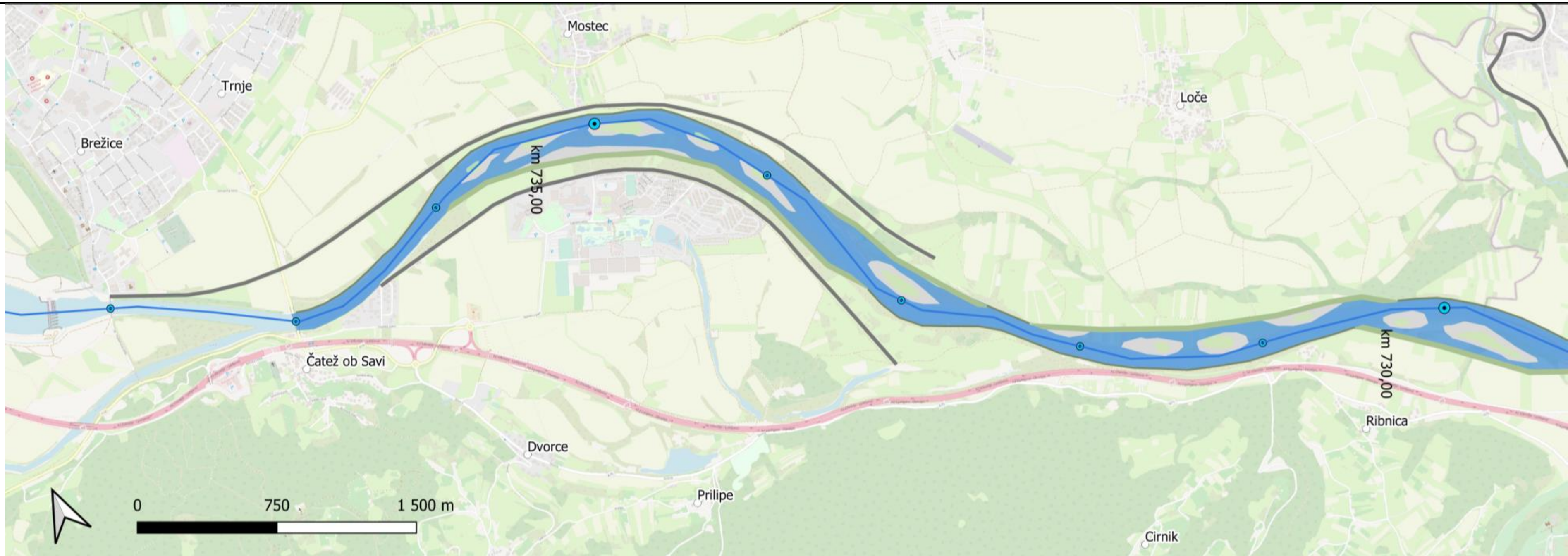


Figure 59: Target state of section 1.

5.2.2 Section 2: from rkm 730 to rkm 715 – Upstream the city of Zagreb

Table 10: River restoration concept for Section 2 – Upstream the city of Zagreb (from rkm 730 to rkm 715.)

<table>
<tr><th colspan="2">Section 2</th></tr>
<tr><td>Description:
This section is approximately 15 km long, the average river width is around 90 meters. The river is canalised and only on a short reach of the river a dike is close to the river (area around Samoborski Otok and Medsave). Some gravel banks, that are visible by average water level, still exist, on both sides of the river grassland and different sorts of forest dominate the area. Small areas are also used by agriculture.</td><td>
Figure 60: Sample picture of the area and the river Sava in section 2 (Photo: Mario Žilec).</td></tr>
</table>

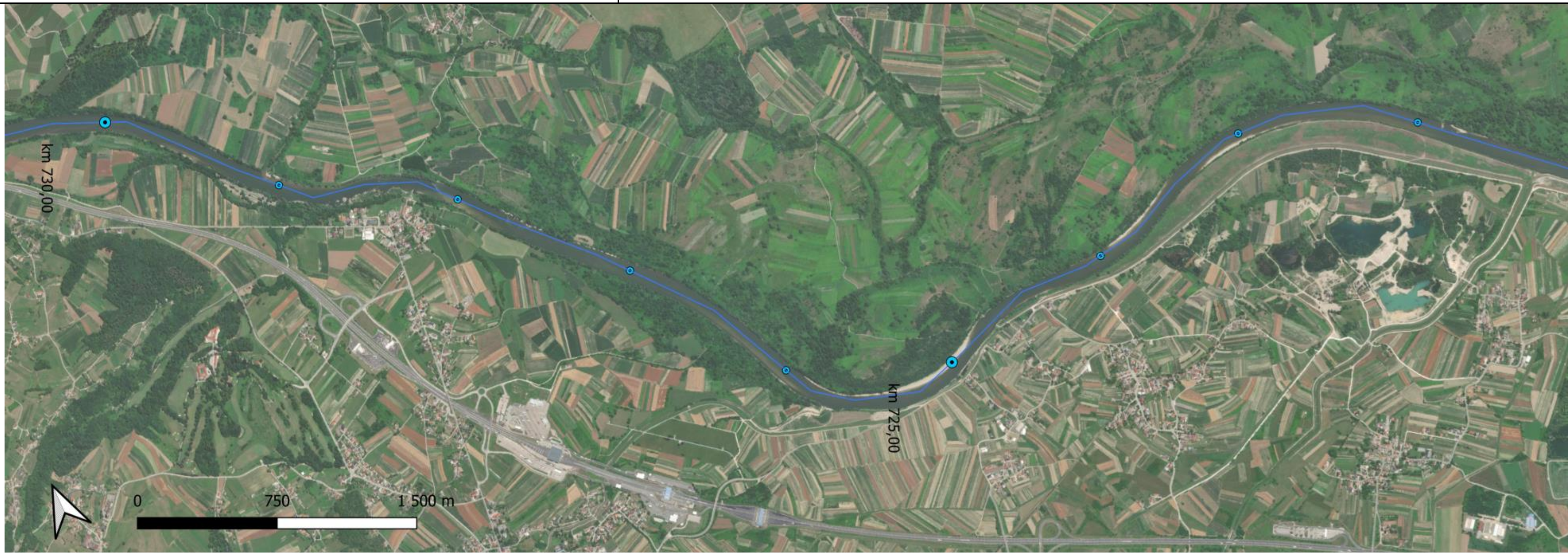


Figure 61: Actual situation of section 2 part 1 with aerial photo.

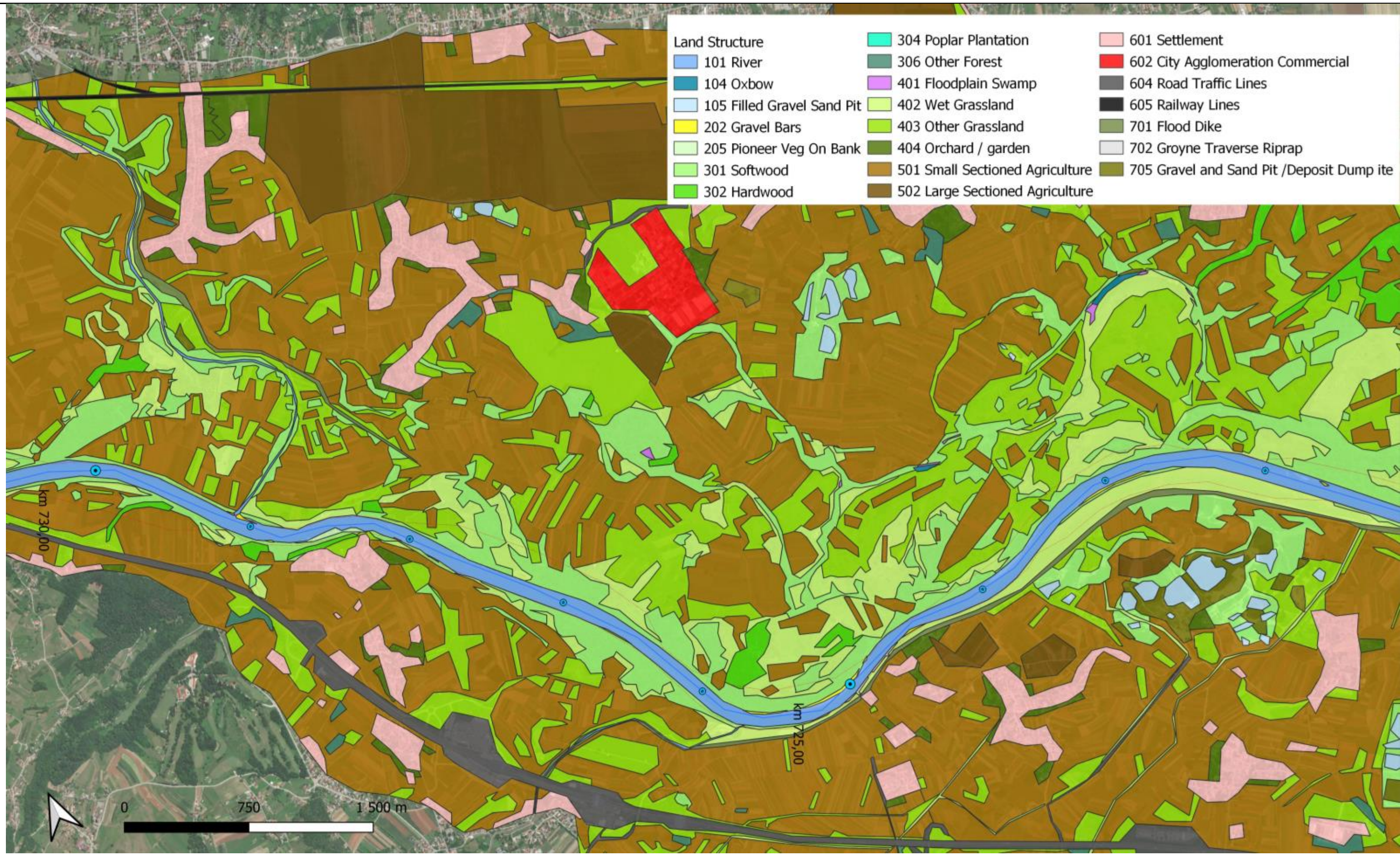


Figure 62: Land structure (Source: Sava White Book, 2016) in section 2 part 1 with aerial photo.

Figure 63: Actual situation of section 2 part 2 with aerial photo.

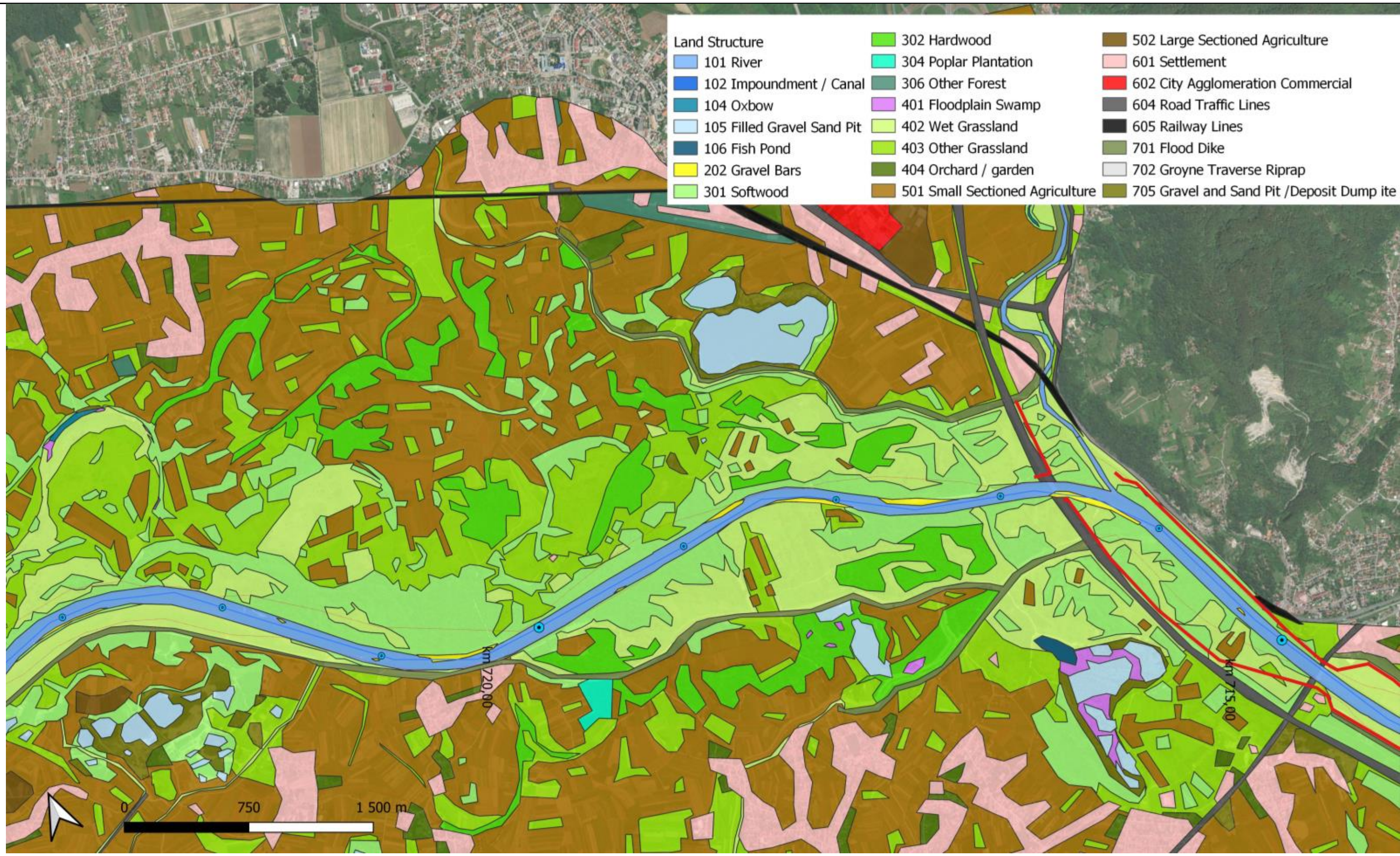


Figure 64: Land structure (Source: Sava White Book, 2016) in section 2 part 2 with aerial photo.

Transformation:	**Initial measures:**
From the monotonous canal to the braided river with gravel banks, islands.	- Building initial channels ○ Main channel 30 m wide

After the implementation of the described measures the average target river width will be around 270 m, including gravel bars, water body, soft / hardwood and grassland.	○ Side channel 15 m wide - Restoring soft banks with flat embankments - Reinforce and reset bank protection (where needed) to protect existing dikes (Figure 67)

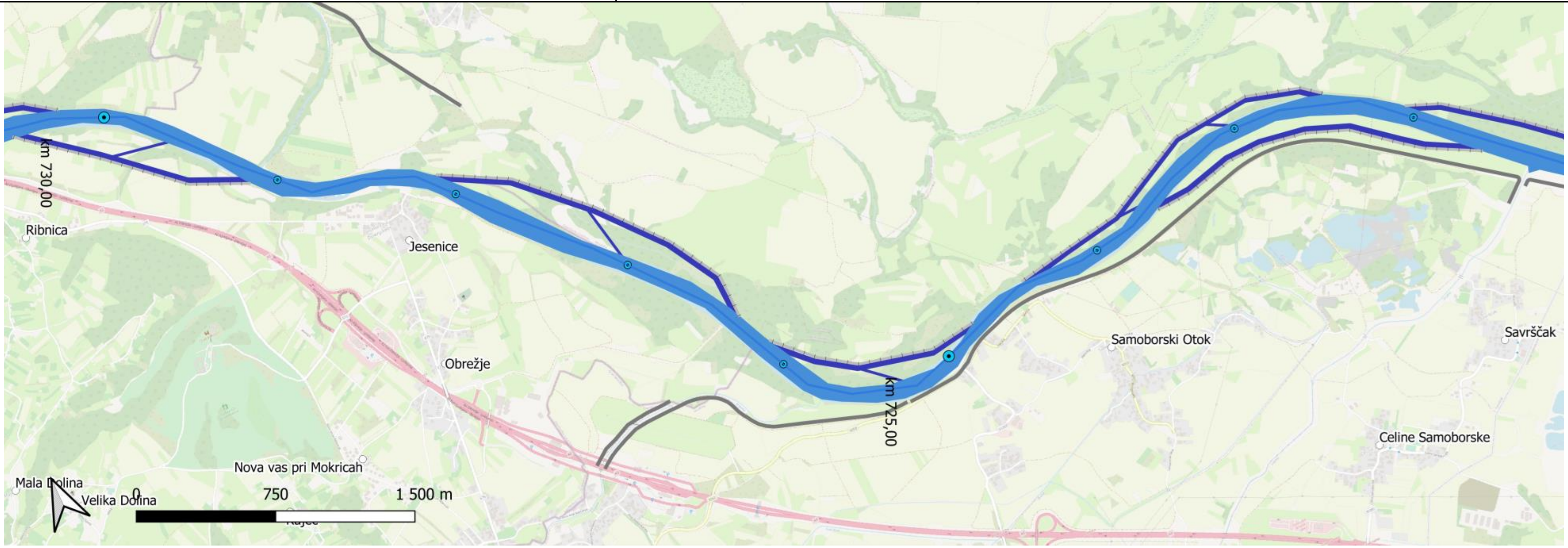


Figure 65: Possible initial measures in section 2 part 1.

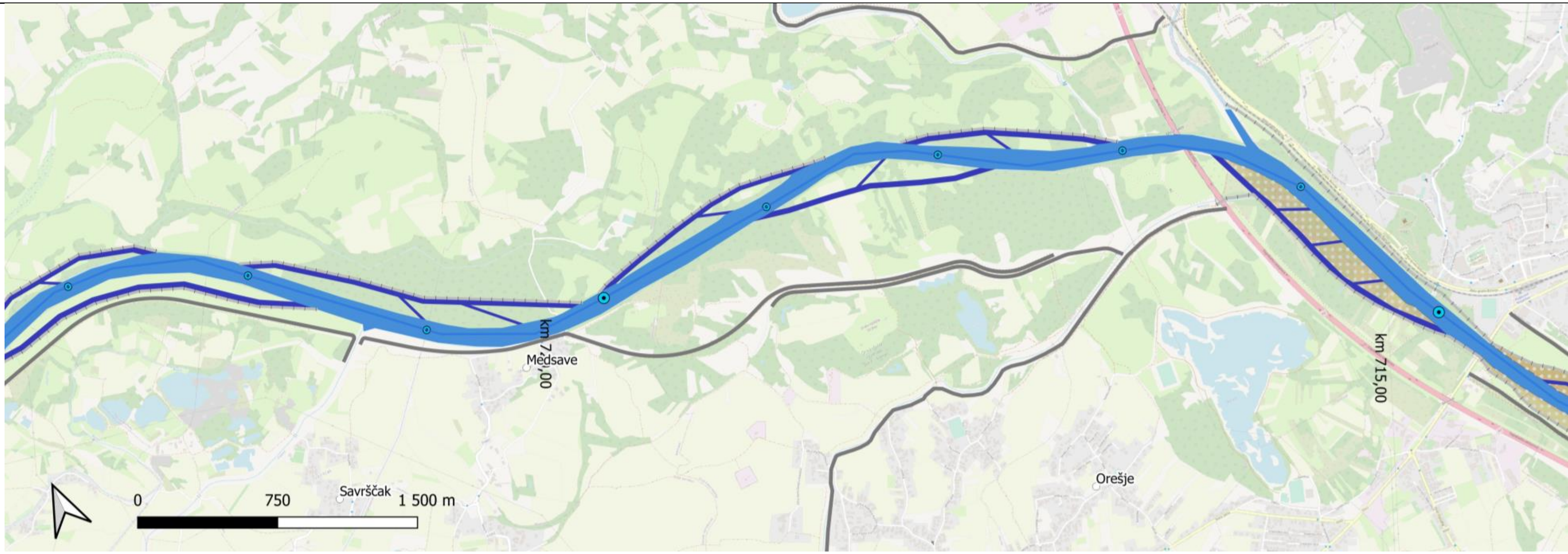


Figure 66: Possible initial measures in section 2 part 2.

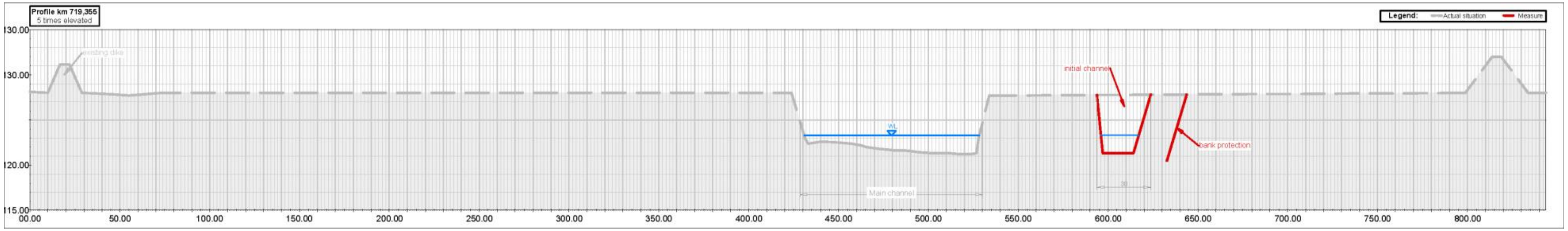


Figure 67: Cross section at rkm 719 of section 2 with actual situation and possible measures.

Benefits: - Higher discharge capacity - New gravel banks - Reconnected riparian forest - Riverbed stabilisation - Huge potential for bed load input - Additional retention space for the city of Zagreb - More river dynamic - natural dynamic processes lead to a good ecological status of the river Sava - Reconnecting existing hardwood forests with elevated ground waters

Figure 68: Target state of Section 2 part 1.

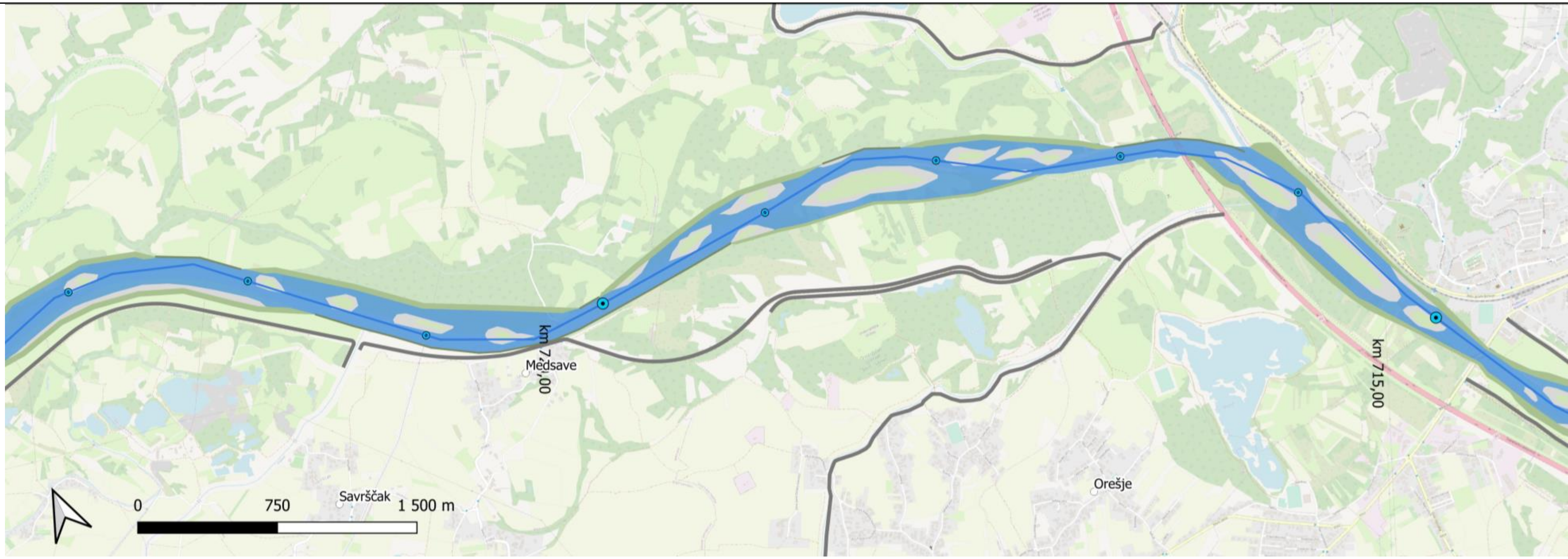


Figure 69: Target state of Section 2 part 2.

5.2.3 Section 3: from rkm 715 to rkm 695 (stretch through the city of Zagreb)

Table 11: River restoration concept for Section 3 from rkm 715 to rkm 695 (stretch through the city of Zagreb).

Section 3	
Description: This section is approximately 20 km long and covers the area where the river Sava runs through the city of Zagreb. The river width varies from 95 m up to 110 m. The river is canalised and is bounded on both sides by flood protection dikes. The steep embankments are mostly covered by trees and the difference between the foreland and the water body is up to 3 meters. Within the dikes there is grassland and some individual trees. Due to the riverbed incision of the river Sava, the view of the river is not perceived from the outside.	 Figure 70: Sample picture of the area and the river Sava in section 3 (Photo: Mario Žilec).

Figure 71: Actual situation of section 3 part 1 with aerial photo.

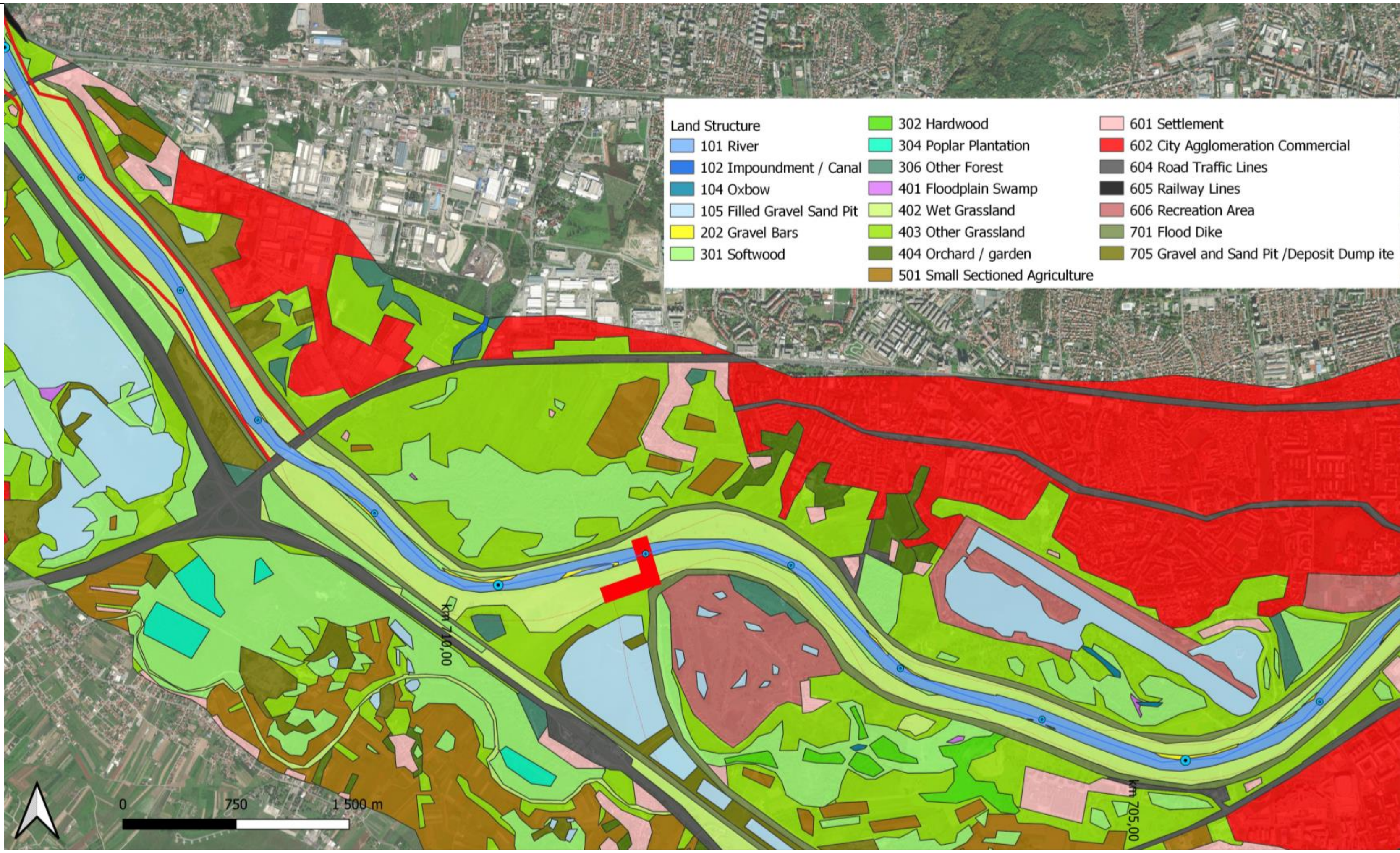


Figure 72: Land structure (Source: Sava White Book, 2016) in section 3 part 2 with aerial photo.

Figure 73: Actual situation of section 3 part 2 with aerial photo.

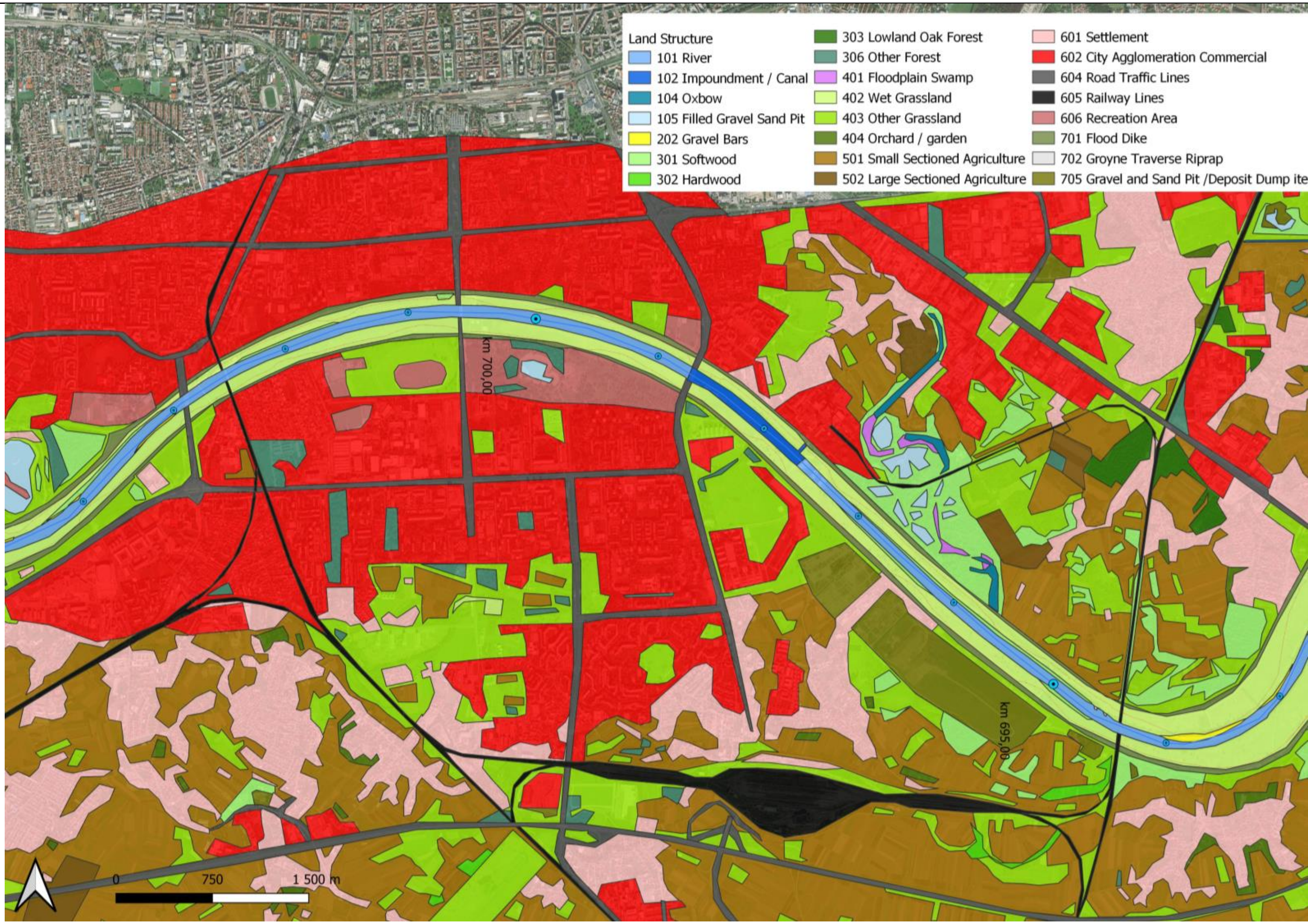


Figure 74: Land structure (Source: Sava White Book, 2016) in section 3 part 2 with aerial photo.

Transformation:	**Initial measures:**

From the monotonous canal to the river with alternating gravel banks.
 	
After the implementation of the described measures the average target river width will vary between 200 m and 300 m, including gravel bars, water body, softwood and grassland.
	- Building initial channels
	    o Main channel 25 m wide
	    o Side channel 15 m wide
	- Restoring soft banks with flat embankments
	- Reinforce and reset bank protection to protect existing dikes (Figure 77)
	- Lowering foreland

Figure 75: Possible initial measures in section 3 part 1.

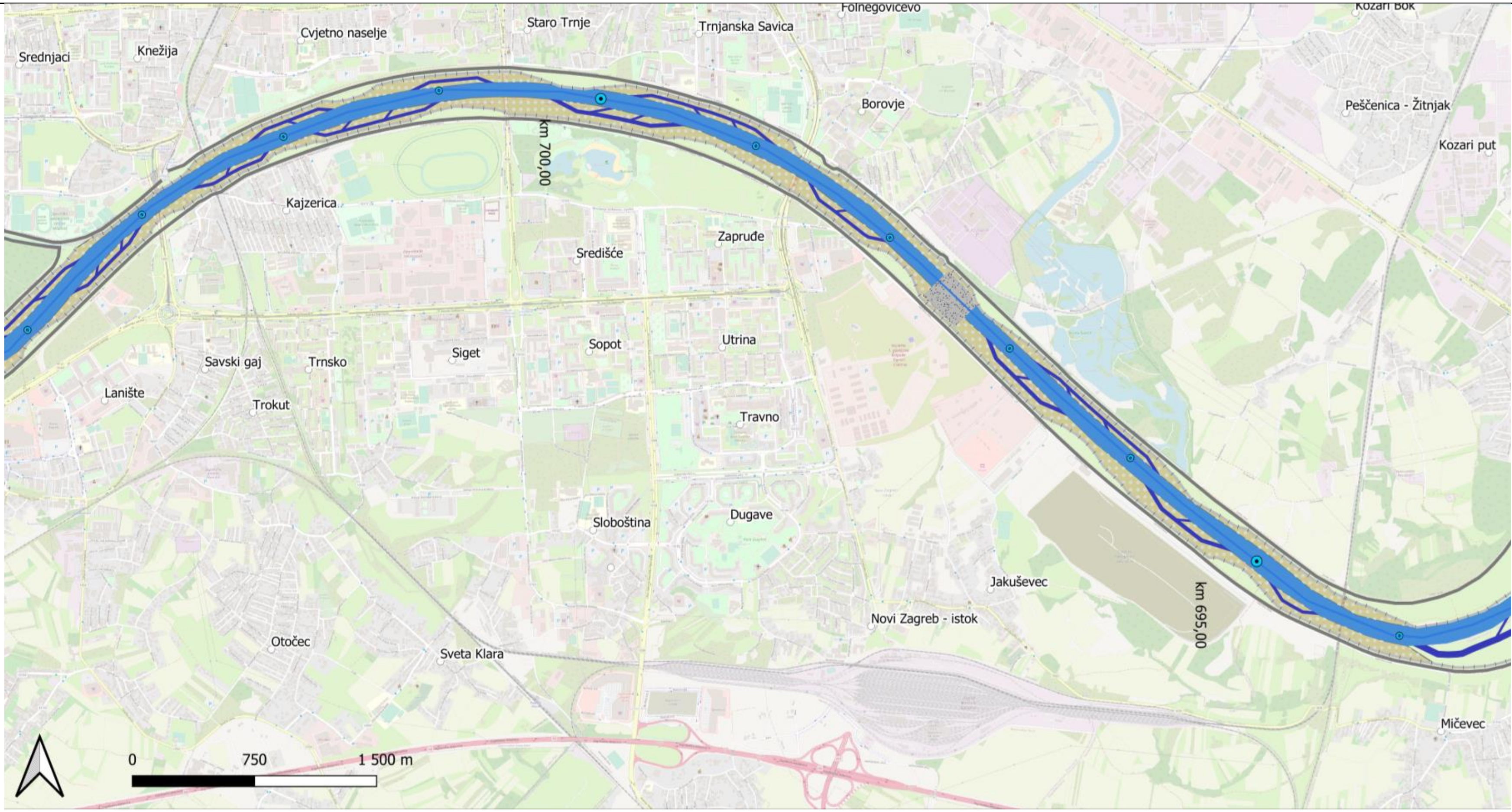


Figure 76: Possible initial measures in section 3 part 2.

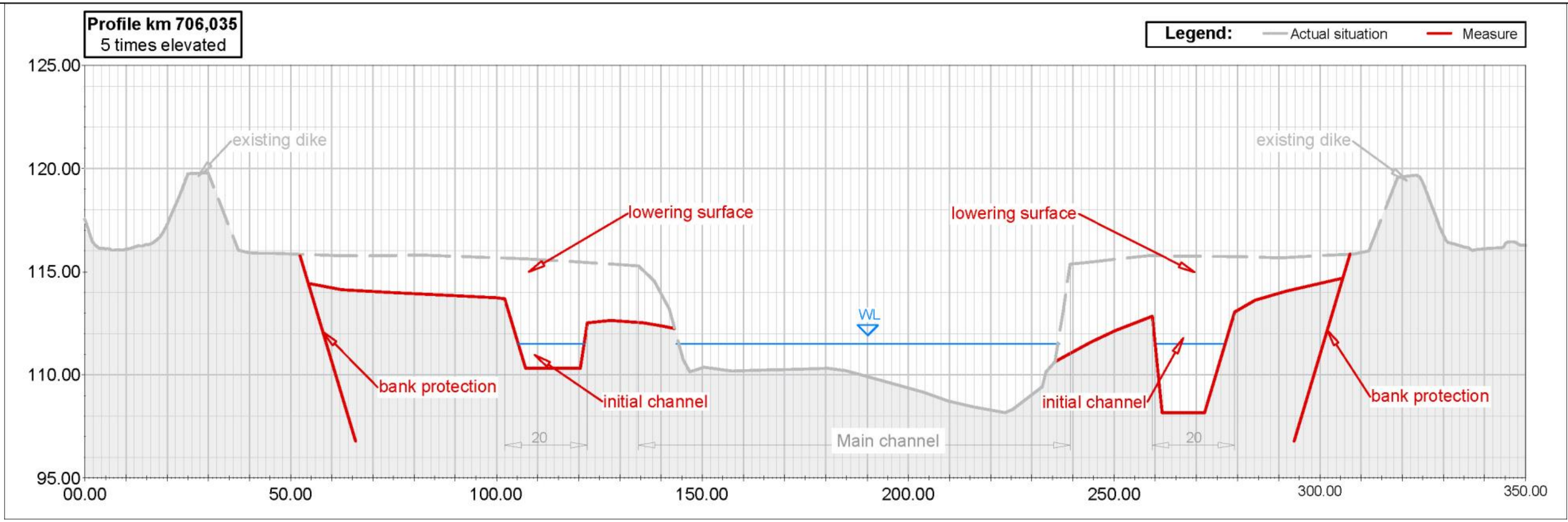


Figure 77: Cross section at rkm 706 of section 3 with actual situation and possible measures.

Benefits:

- Higher discharge capacity
- New gravel banks
- Riverbed stabilisation
- Additional flood retention area for the city of Zagreb
- Reconnecting derivation channel Sava-Odra
- New recreational sites
- More river dynamic – natural dynamic processes lead to a good ecological status of the river Sava

Figure 78: Target state of Section 3 part 1.

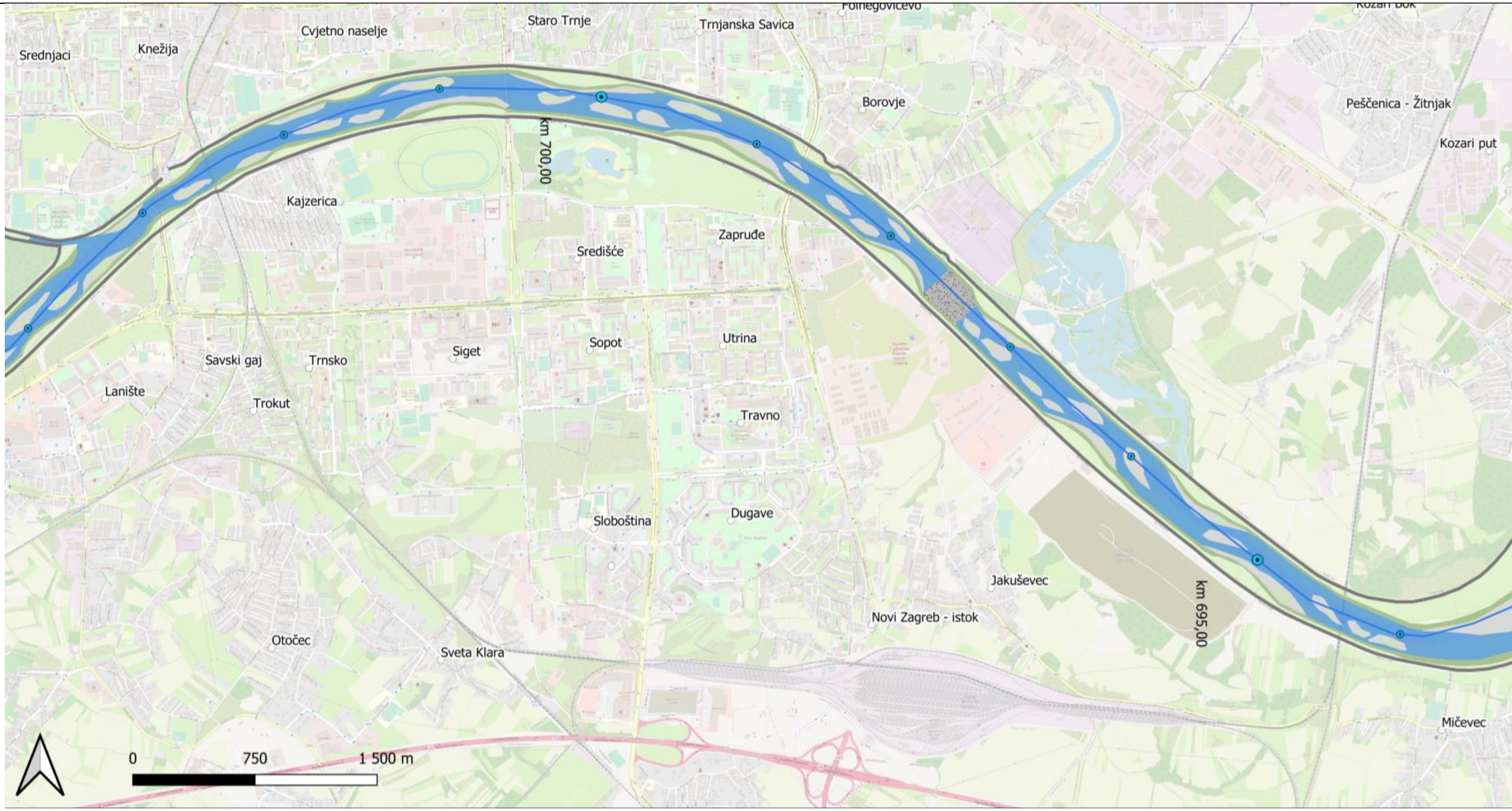


Figure 79: Target state of Section 3 part 2.

5.2.4 Section 4: from rkm 695 to rkm 687 (downstream of the city of Zagreb)

Table 12: River restoration concept for Section 4 downstream if the city of Zagreb (from rkm 695 to rkm 687)

<table>
<tr><th colspan="2">Section 4</th></tr>
<tr><td>Description:

This section is approximately 8 km long and covers the area downstream the city of Zagreb. The river width varies from 100 m up to 112 m. The river is canalised and is bounded on both sides by dams. Huge areas of grassland are between the dikes and the river. In the lower part softwood and hardwood forests, that are not well connected to the water body exist.</td><td>

Figure 80: Sample picture of the area and the river Sava in section 4 (Photo: REVITAL).</td></tr>
</table>

Figure 81: Actual situation of section 4 with aerial photo.

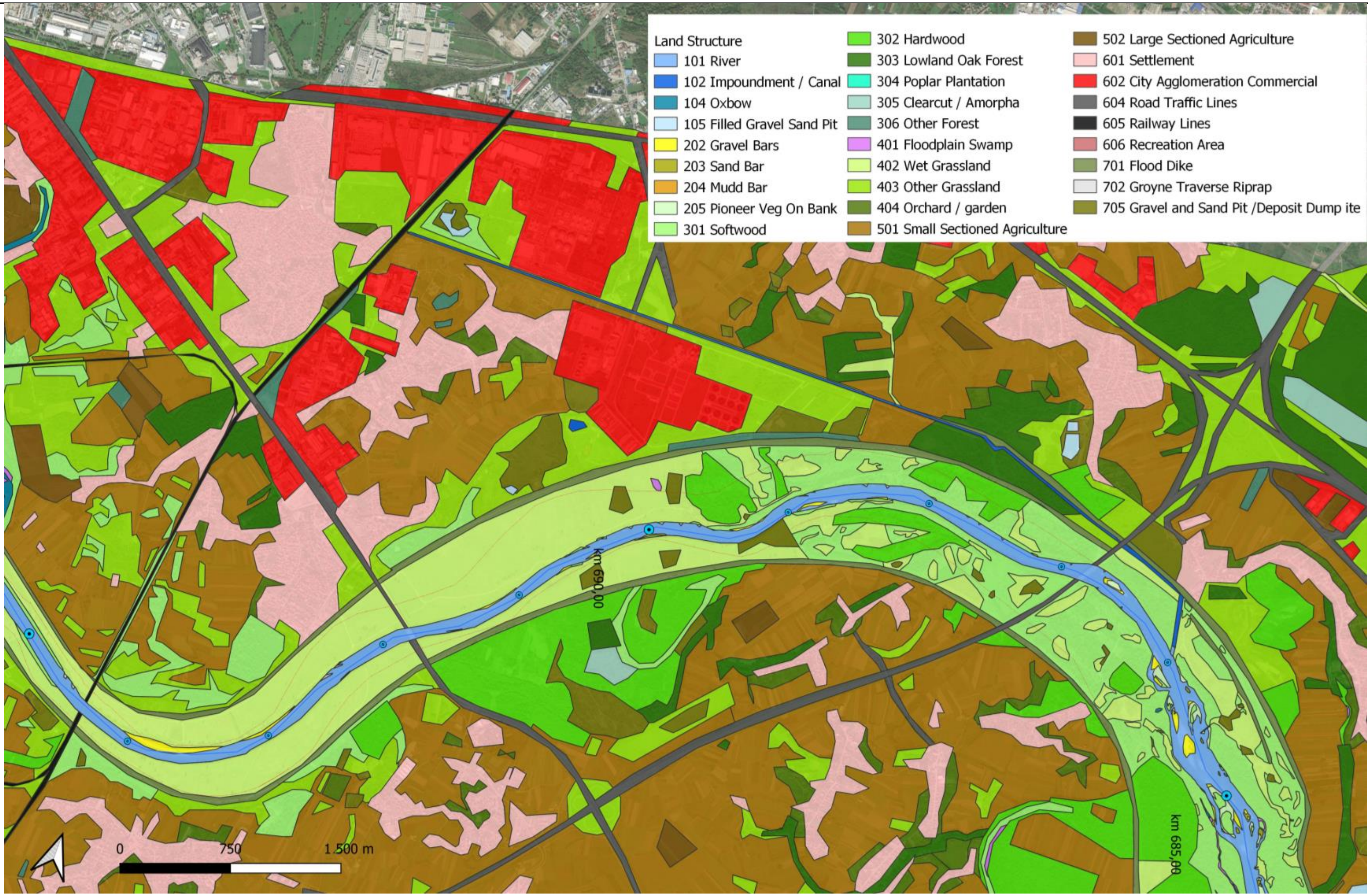


Figure 82: Land structure (Source: Sava White Book, 2016) in section 4 with aerial photo.

Transformation:	**Initial measures:**

From the monotonous canal to the river with alternating gravel banks.
 	
After the implementation of the described measures the average target river width will vary between 350 m and 500 m, including gravel bars, water body, softwood, hardwood forest and wet grassland.
	- Building initial channels
	   ○ Main channel 40 m wide
	   ○ Side channel 15 m wide
	- Restoring soft banks with flat embankments
	- Reinforce and reset bank protection to protect existing dikes (Figure 84)

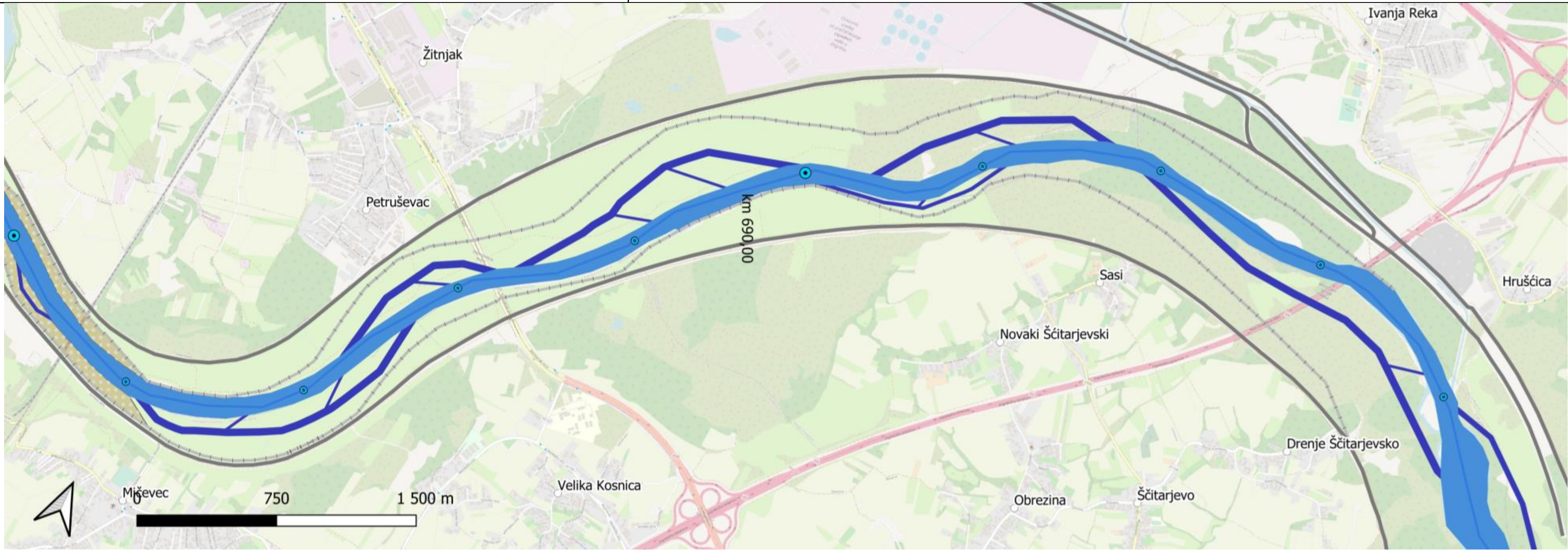


Figure 83: Possible initial measures in section 4.

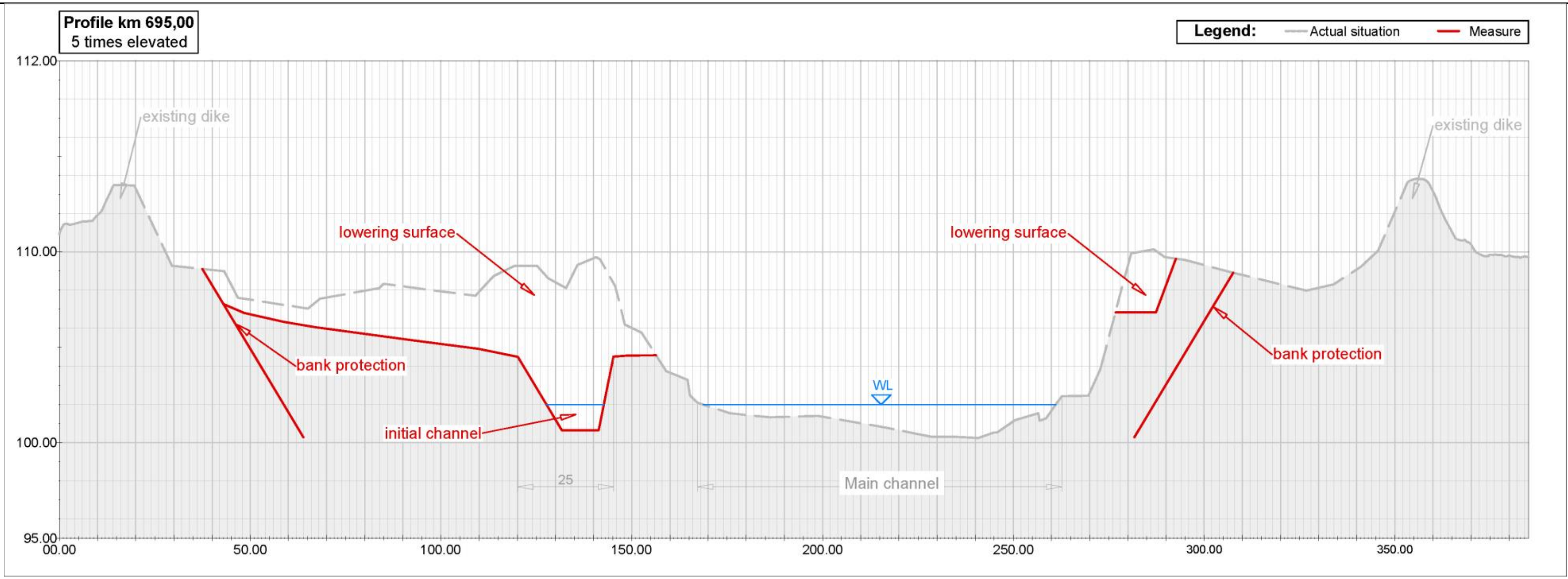


Figure 84: Cross section at rkm 695 of section 4 with actual situation and possible measures.

Benefits:

- Higher discharge capacity
- New gravel banks
- Riverbed stabilisation
- New recreational sites
- More river dynamic – natural dynamic processes lead to good ecological status of the river Sava
- Reconnection of existing hardwood forests with increasing ground water levels

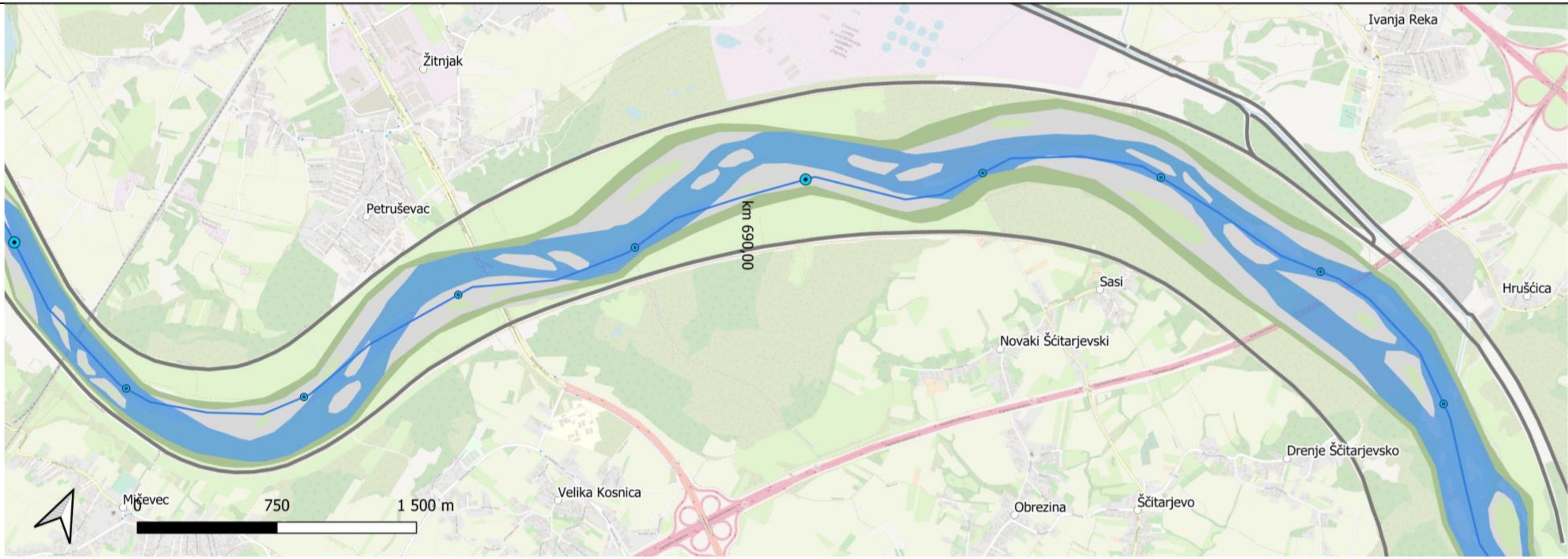


Figure 85: Target state of Section 4.

5.2.5 Section 5: from rkm 687 to rkm 672 – from Ivanja Reka bridge to Rugvica

Table 13: River restoration concept for Section 5 from Ivanja Reka bridge to Rugvica (from rkm 687 to rkm 672).

Section 5	
Description: This section is approximately 15 km long. This river stretch corresponds almost to the natural state. Huge areas of softwood and hardwood forests cover this river stretch. Some areas of grassland or small sectioned agriculture occur.	 Figure 86: Sample picture of the area and the river Sava in section 5 (Photo: Mario Žilec).

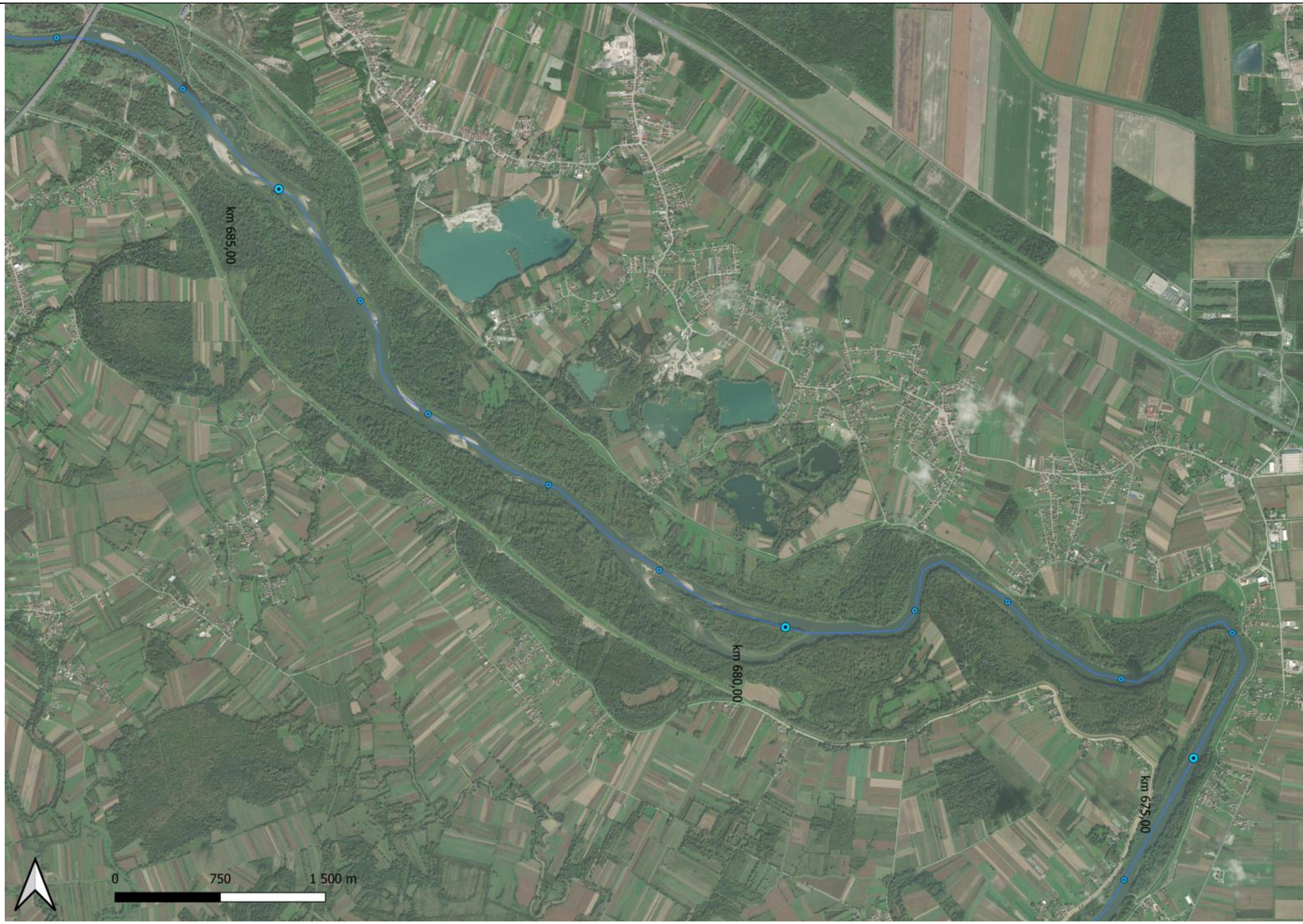


Figure 87: Actual situation of section 5 with aerial photo.

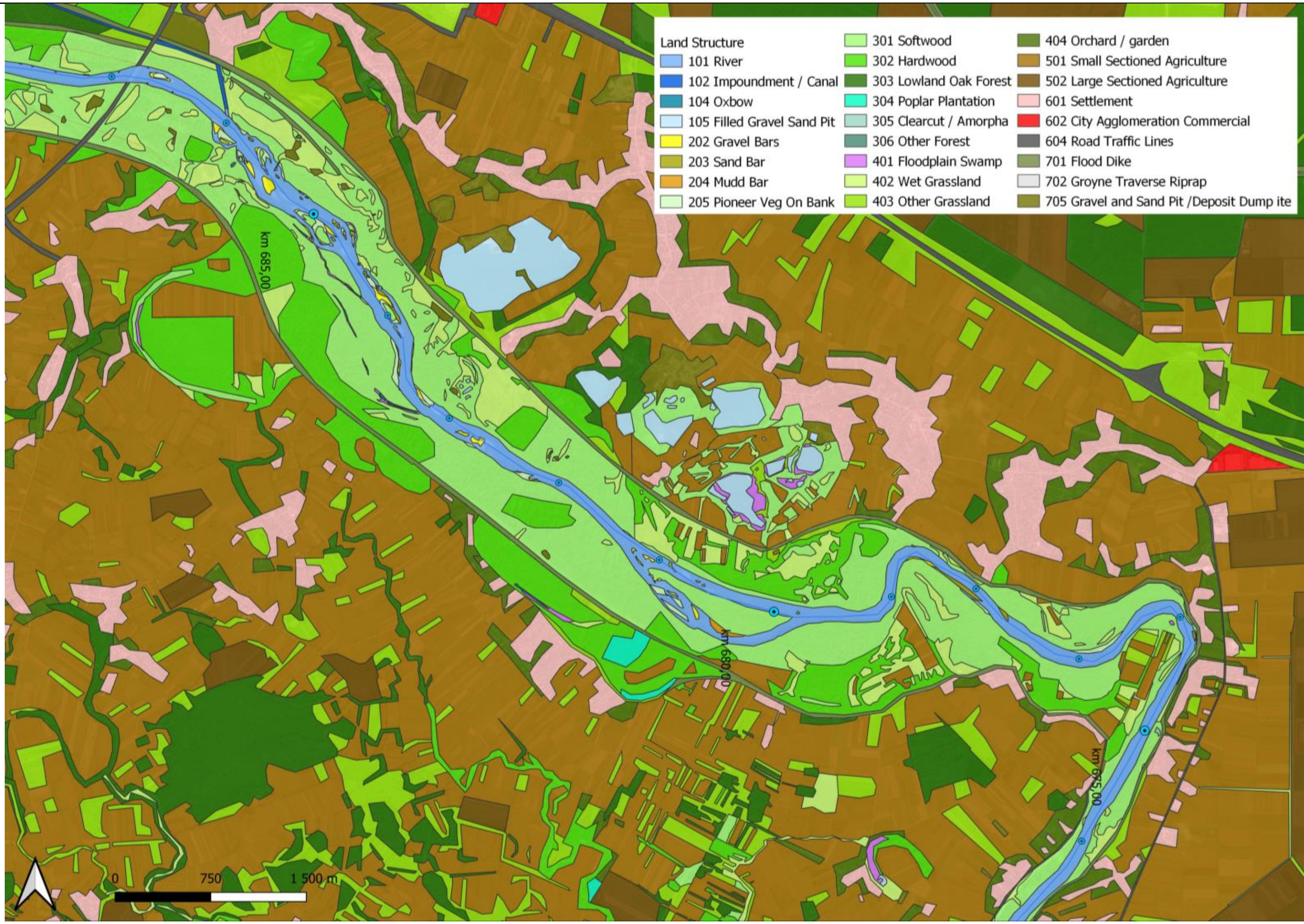


Figure 88: Land structure (Source: Sava White Book, 2016) in section 5 with aerial photo.

Transformation:	**Initial measures:**

After the implementation of the described measures the average target river width will vary between 350 m and 500 m, including gravel bars, water body, softwood, hardwood forest and wet grassland.	- Building initial channels (Figure 90)
	    ○ Main channel 30 -40 m wide
	    ○ Side channel 15 m wide

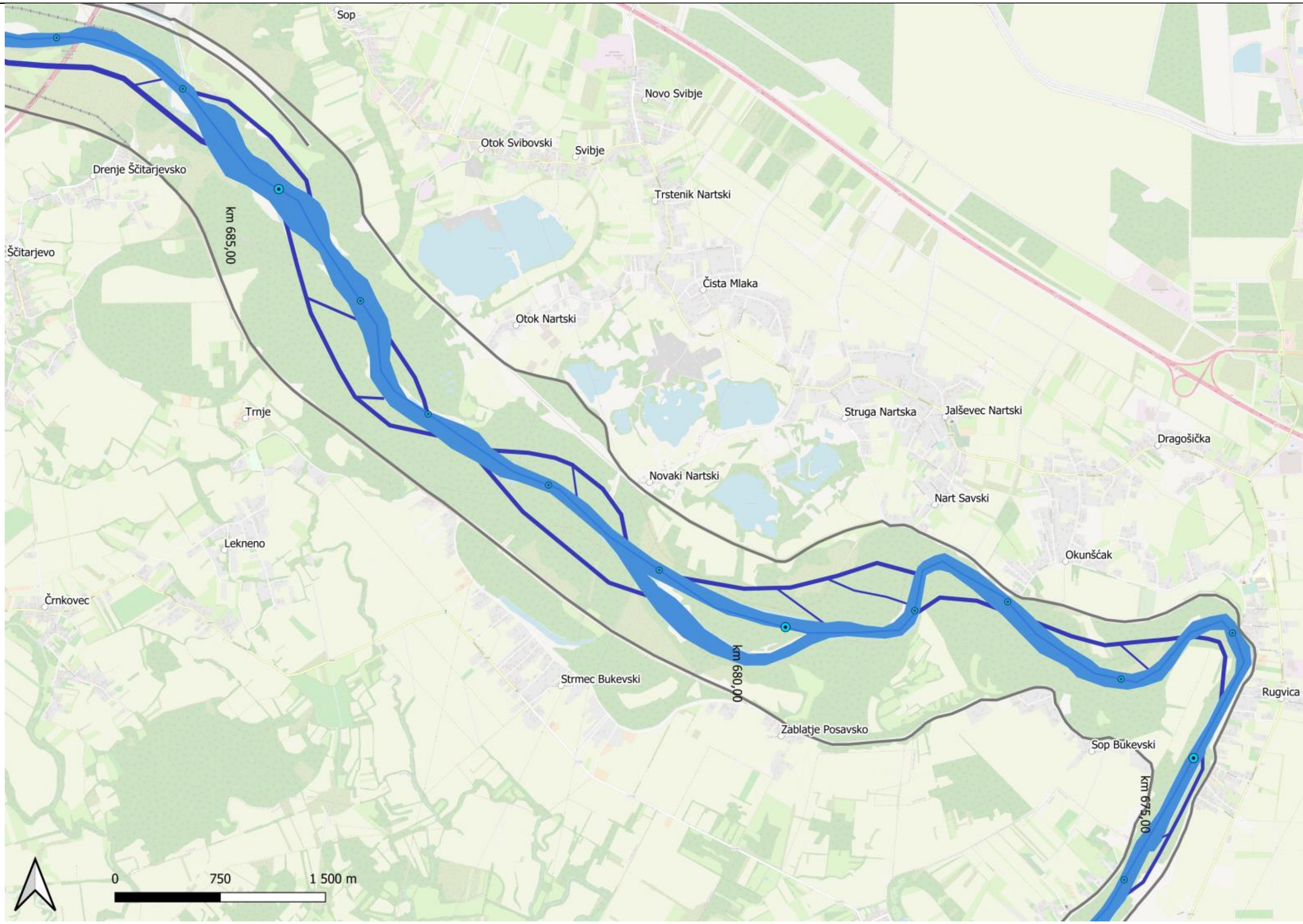


Figure 89: Possible initial measures in section 5.

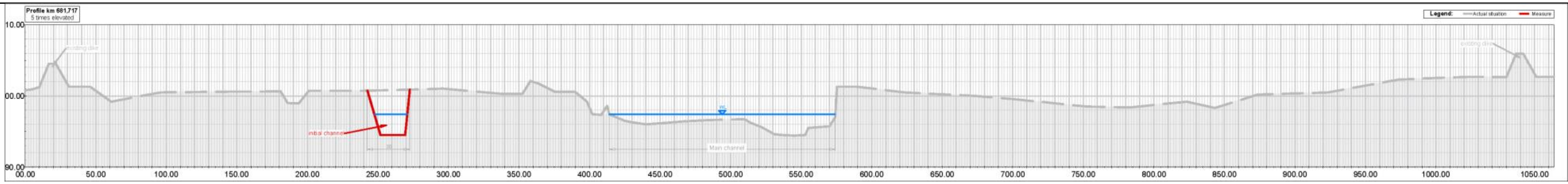


Figure 90: Cross section at rkm 681 of section 4 with actual situation and possible measures.

Benefits:

- Higher discharge capacity
- New gravel banks
- Riverbed stabilisation
- New recreational sites
- More river dynamic – natural dynamics processes lead to a good ecological status of the river Sava
- Reconnecting existing hardwood forests through increased ground water levels

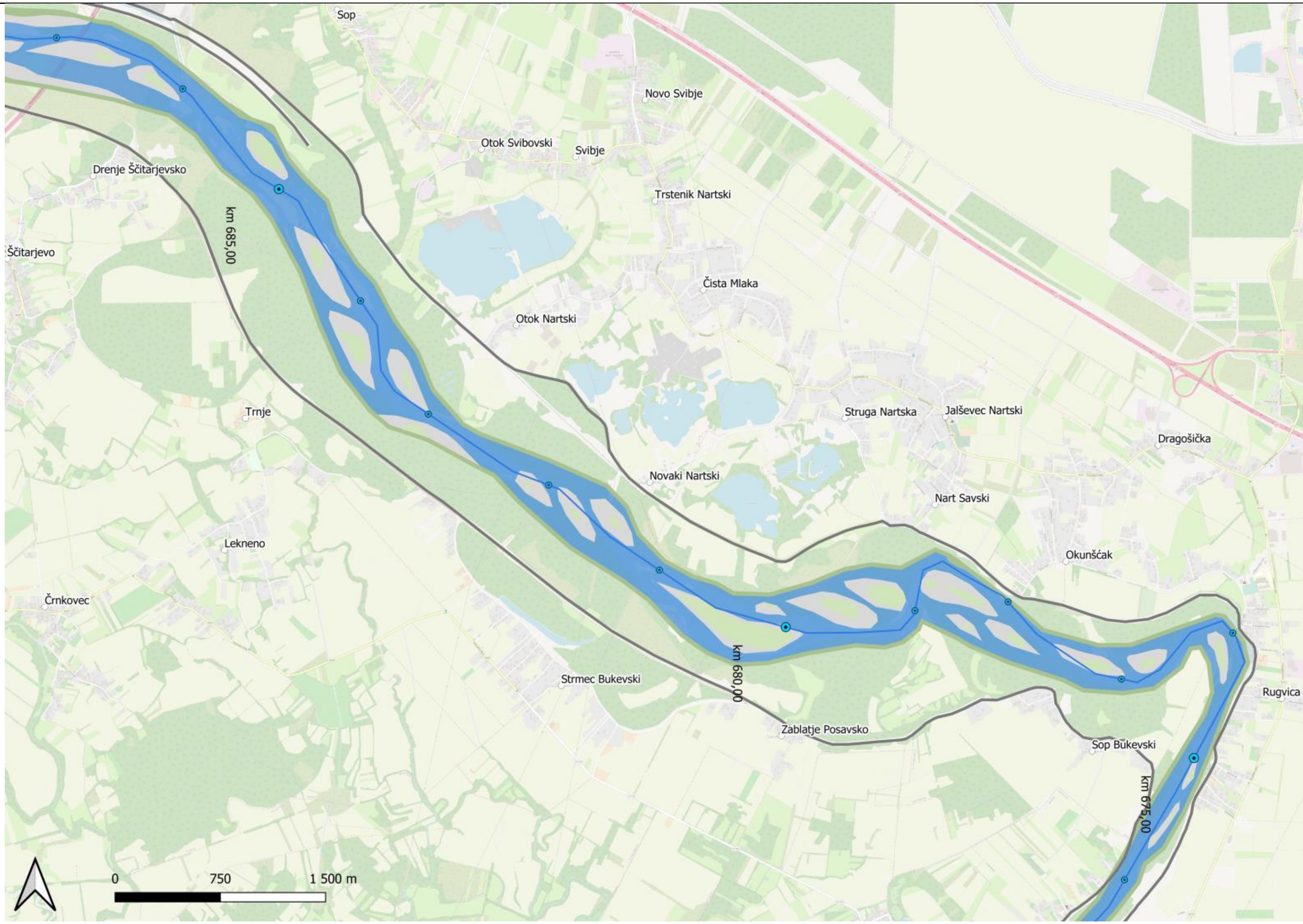


Figure 91: Target state of Section 5.

5.2.6 Ramp and measures at rkm 709 (at the derivation channel Sava-Odra)

Table 14: River restoration concept around rkm 709, derivation channel Sava-Odra.

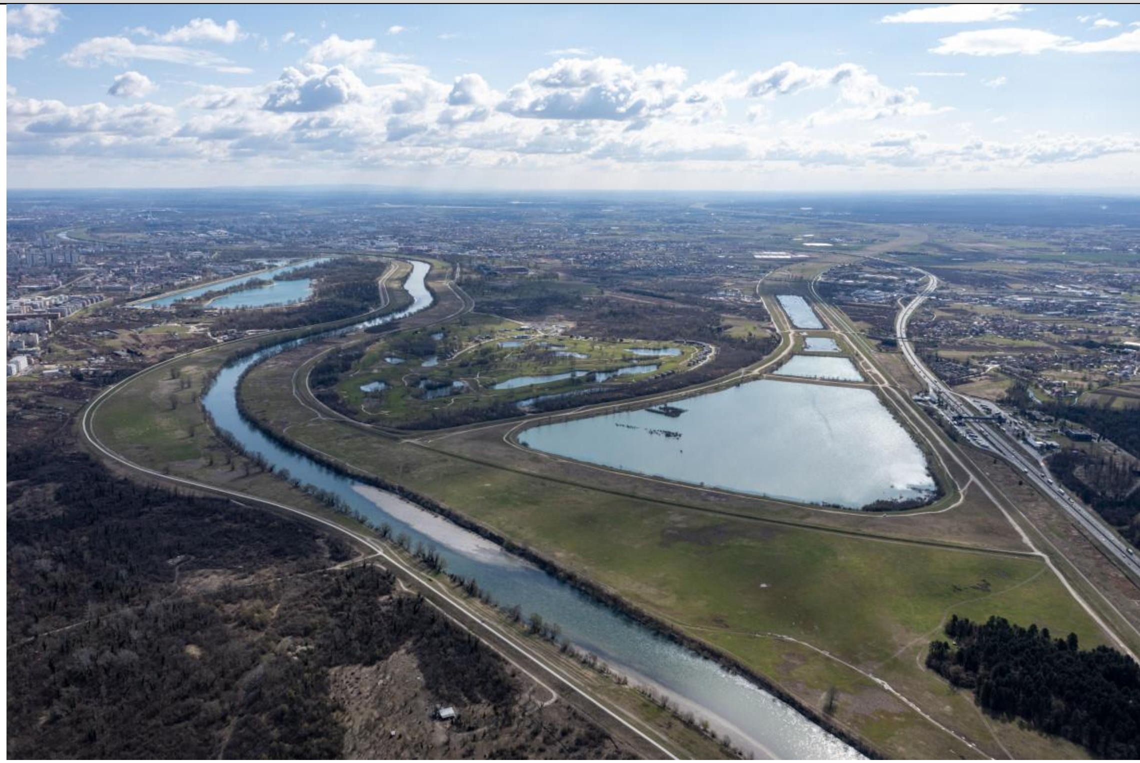
Section 1	
Description: At rkm 709 an important flood protection measure for the city of Zagreb is located, the derivation channel Sava-Odra. Currently the flood protection is not working properly, due to the riverbed incision.	 Figure 92: Sample picture of the area around the derivation channel Sava-Odra (Photo: Mario Žilec).

Figure 93: Actual situation around the derivation channel Sava-Odra.

Figure 94: Land structure (Source: Sava White Book, 2016) around the derivation channel Sava-Odra with aerial photo.

Measures:

- Reset dikes to prevent material from being deposited in the derivation channel
- Building an open brank weir, 280 – 300 meter long, parallel to the flow direction
- Building a new 130-meter-long fish passable ramp for riverbed stabilisation, support of the open brank weir and to make sure the flood protection system works (Figure 95)

Figure 95: example of fish passable ramp of the river Salzach (Source Theo Steidl)

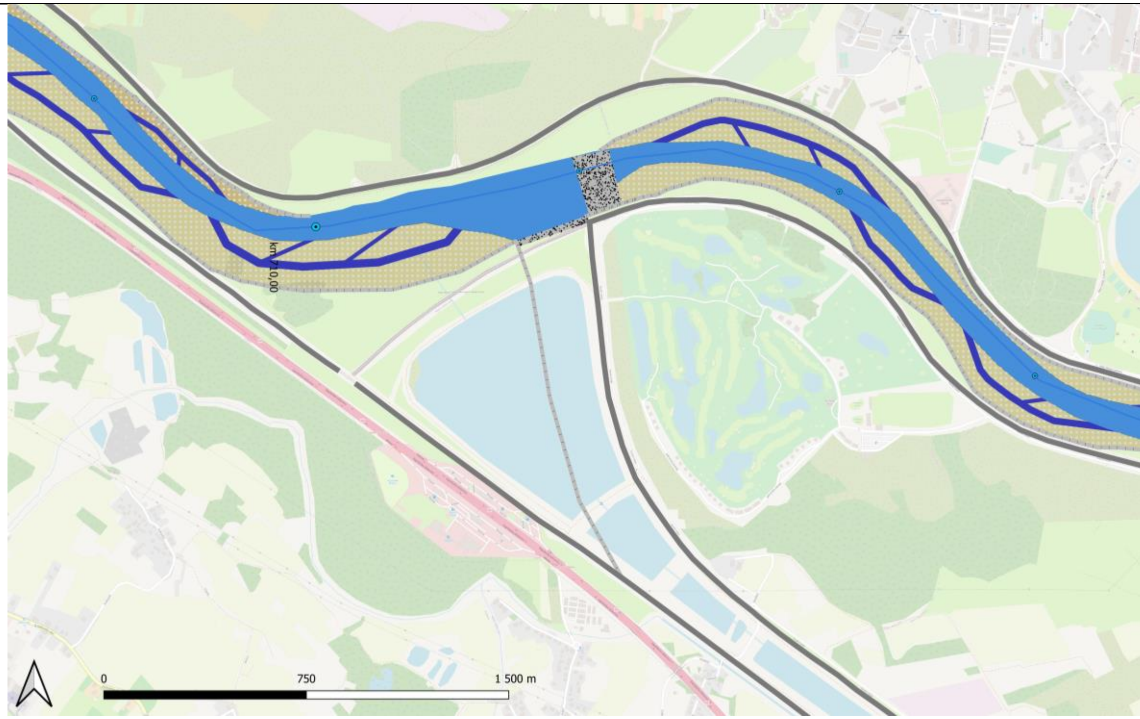


Figure 96: Possible measures around the derivation channel Sava-Odra.

Benefits:

- Riverbed stabilisation
- Reconnected derivation channel Sava-Odra and functioning flood protection
- Fish migration possible in the river Sava
- Gravel remains in the main river and not in the derivation channel

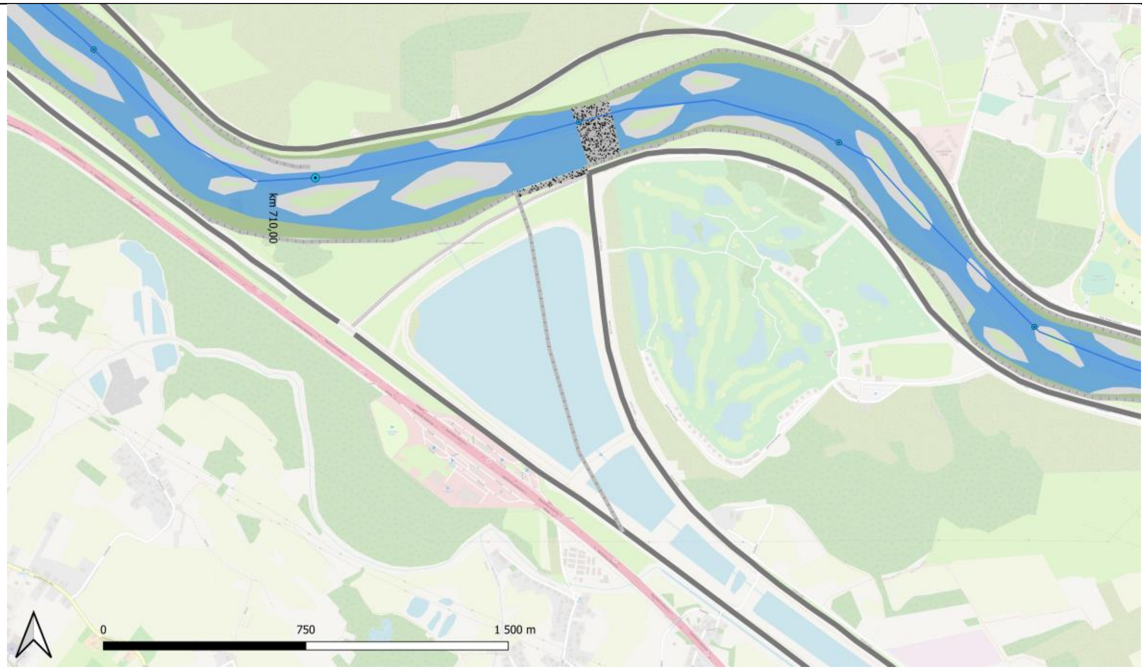


Figure 97: Target state of the area around the derivation channel Sava-Odra.

5.2.7 Ramp at existing HEP Toplinarstvo

Table 15: River restoration concept around HEP Toplinarstvo.

Section 1	
Description: At rkm 697 next to the existing HEP Toplinarstvo there is an existing ramp, that keeps the water level constantly elevated for the purpose of the termal plant. Next to the ramp huge rocks are located to be put back onto the ramp to stabilize the ramp.	 Figure 98: Ramp near HEP Toplinarstvo (Photo: Mario Žilec).

Figure 99: Actual situation around the HEP Toplinarstvo.

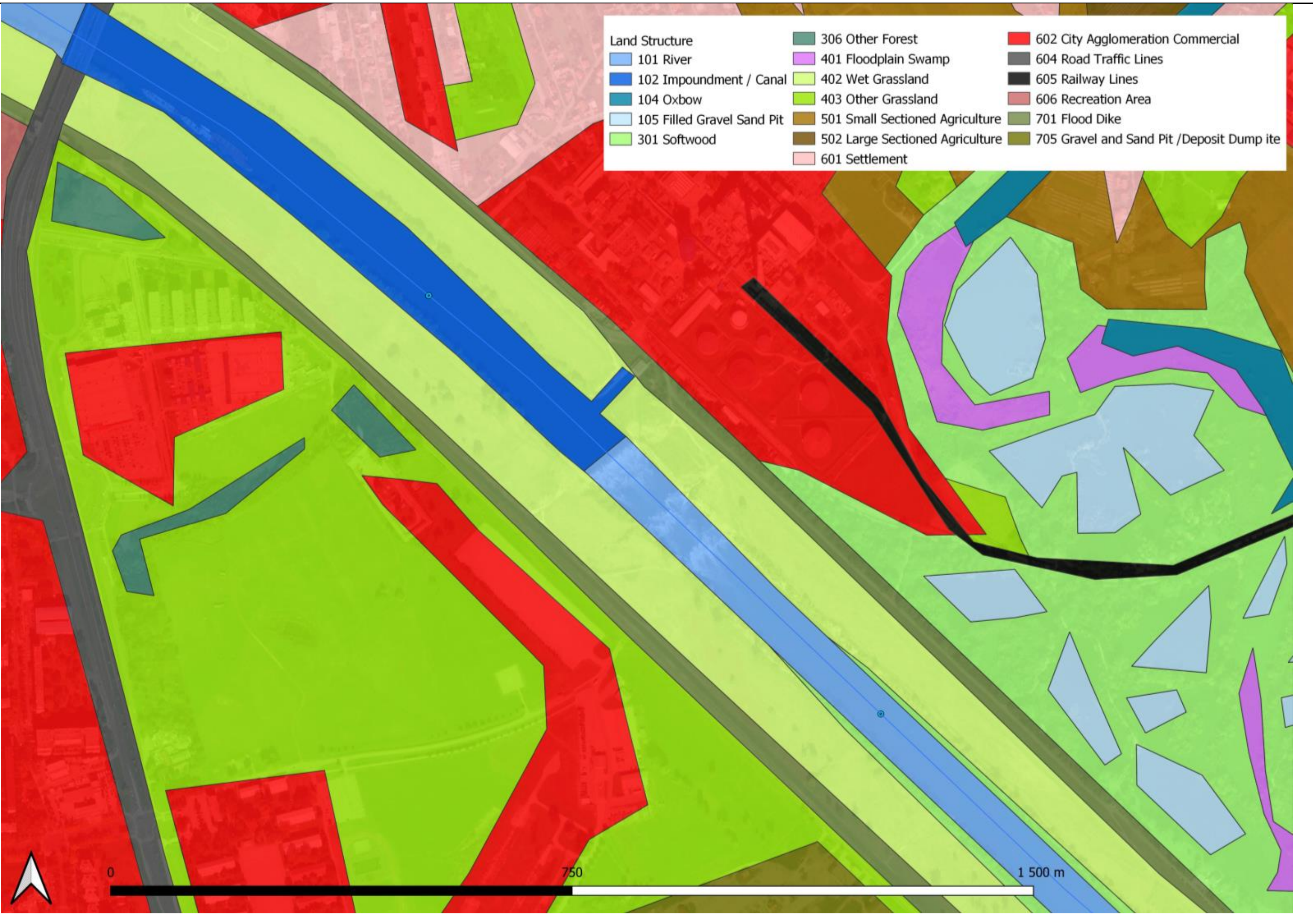


Figure 100: Land structure (Source: Sava White Book, 2016) around the HEP Toplinarstvo.

Measures:

- Rebuild a 270-300-meter-long fish passable ramp for riverbed stabilisation (Figure 100)
- Integrate the ramp in measures implemented up and downstream the existing ramp

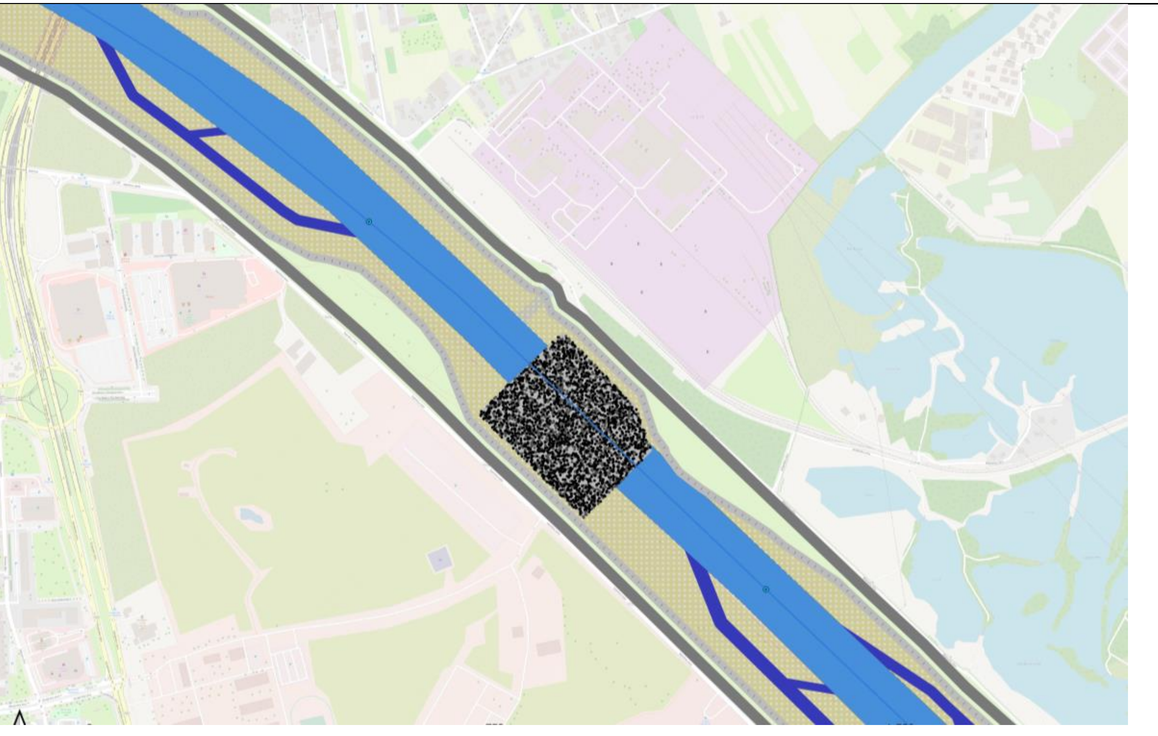
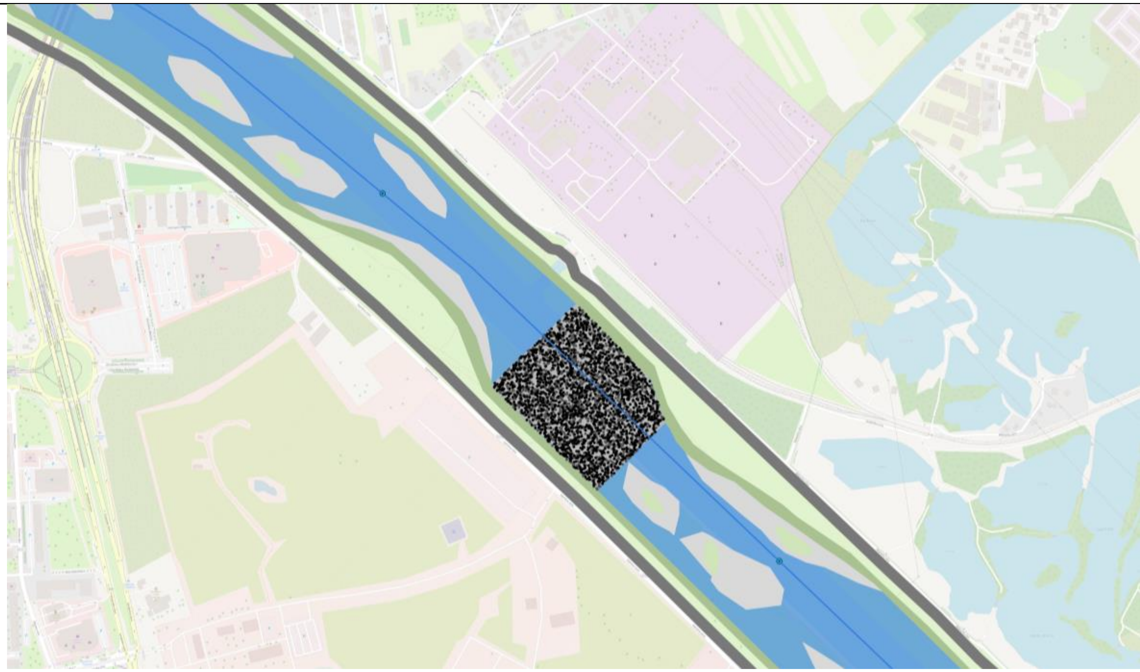


Figure 101: Possible measures around the HEP Toplinarstvo.

Benefits: - Riverbed stabilisation - Fish migration possible	 Figure 102: Target state of the area around the HEP Toplinarstvo.

5.3 Cost benefit analysis

5.3.1 Initial channel

The costs for initial channels are estimated based on the following assumptions:

- Bank slope: 1:2
- Difference in height (surrounding area and new riverbed of initial channel): 5 [m]

Table 16: Estimated costs for initial channels.

Width [m]	length [km]	Cross-sectional area / linear meter	Excavation cubature [m³]	Excavation [€/m³]	Costs [€]
15,00	7	125	915.000	8	€ 7.320.000
20,00	2	150	240.450	8	€ 1.923.600
25,00	1	175	194.600	8	€ 1.556.800
30,00	32	200	6.441.600	8	€ 51.532.800
40,00	8	250	1.974.000	8	€ 15.792.000
Total length [km]	**50**				
Total costs [€]					**€ 78.125.200**

5.3.2 Open brank weir and ramps

The costs for open brank weir and ramps are estimated based on the following assumptions:

- Layer thickness: 0,8 [m]
- Solid content; 0,65
- Density of water building blocks: 2,8 [to/m³]
- Costs for water building blocks: 60 [€/to]

Table 17: Estimated costs for open brank weir and ramps.

		Volume [m³]	material water building blocks [to]	Costs [€]
Lengths of open brank [m]	280,00	6.720	12.230	€ 733.824
area ramp 1 [ha]	3	22.758	41.419	€ 2.485.124
Area ramp 2 [ha]	6	46.188	84.061	€ 5.043.675
Total costs [€]				**€ 8.262.623**

5.3.3 Bank protection

The costs for new bank protection are estimated based on the following assumptions:

- Bank slope: 1:2
- Difference in height (surrounding area and new riverbed of initial channel): 5 [m]
- Cross-sectional area / linear meter: 11,8 [m²/lm]
- Layer thickness: 0,8 [m]
- Volume: 7,8 [m³]

- Density of water building blocks: 2,8 [to/m³]
- Costs for water building blocks: 60 [€/to]

Table 18: Estimated costs for bank protection.

	Length [km]	material water building blocks [to]	**Total costs [€]**
Lengths of new bank protection	80	1.140.768	**€ 68.446.076**

5.3.4 Lowering foreland

The costs for lowering the foreland are estimated based on the following assumptions:

- Costs for excavation: 8 [€/m³]
- Lowering surface: 2 [m]
- Cross-sectional area / linear meter: 11,8 [m²/lm]
- Layer thickness: 0,8 [m]
- Volume: 7,8 [m³]
- Density of water building blocks: 2,8 [to/m³]
- Costs for water building blocks: 60 [€/to]

Table 19: Estimated costs for lowering foreland.

	Area [ha]	Volume for excavation [m³]	**Total costs [€]**
Lowering foreland	331	6.614.334	**€ 52.914.672**

5.3.5 Summary Cost benefit analysis

Based on the assumptions for costs in the chapters before, the estimated costs are rounded to a near whole number (Mio €). After adding the costs for implementing the measures, costs for accompanying measures, normally calculated with 20 %, and costs for unexpended, calculated with 10% are added. After adding these costs to the costs for implementation, planning services and building supervision, normally around 10% from total, are added. This gives us estimated cost around **315 Mio. €**.

Table 20: Estimated total costs.

Measures	**amount**	**cost per Unit**	**Estimated costs [Mio. €]**
Initial channels	~ 50 km	€ 1.600.000	€ 80
open brank weir, ramps	~ 9 ha	€ 1.111.111	€ 10
Bank protection	~ 80 km	€ 875.000	€ 70
Lowering foreland	~ 331 ha	€ 151.057	€ 50
Subtotal 1			**€ 210**
accompanying measures (~ 20% from subtotal 1)			€ 50
Unexpected (~10% from subtotal 1)			€ 25
Subtotal 2			**€ 285**
planning services, building supervision (~ 10% from subtotal 2)			€ 30
Total			**€ 315**

5.3.6 Benefits

Table 21: Benefits for different sectors after implementation.

Benefit	Description	Section 1	Section 2	Section 3	Section 4	Section 5	Ramp 1	Ramp 2
River maintenance - less effort	Riverbed stabilisation leads to less need for maintenance.	X	X	X	X	X	X	X
	Natural bed load input instead of technical gravel input or ramps.	X	X	X	X	X		
	Gravel remains in the river, is not transported into derivation channel.						X	
Flood protection improved	Increased discharge capacity improves flood safety.	X	X	X	X	X		
	Additional flood retention area for Zagreb.	X	X	X				
	Flood relief through reconnected derivation channel, thus flood protection works again.						X	
Good ecological status of river	Natural dynamic processes are improved and preserved, river habitats can develop in a natural or near-natural way and the side arm system is adequately endowed and flowed through.	X	X	X	X	X		
	Fish migration is possible again.	X	X	X	X	X	X	X
Riparian habitats improved	More typical riparian habitats, especially gravel banks, pioneer vegetation and softwood will be initiated.	X	X	X	X	X		
	Hardwood forests get reconnecting to ground water.		X		X	X		
Protected areas - goals supported	Objectives of protection, in particular species and habitats of dynamically shaped river, riparian forests and meadow habitats are supported.	X	X			X		

Benefit	Description	Section 1	Section 2	Section 3	Section 4	Section 5	Ramp 1	Ramp 2
Better ground water conditions	Higher or stable groundwater level favour agricultural production.	X	X		X	X	X	X
	Ground water recharge and level increase would ensure drinking water for Zagreb agglomeration	X	X	X	X		X	X
Beauty of landscape	A near-natural river makes the landscape appear more beautiful for both, locals and tourists.	X	X	X	X	X		
Recreation and a healthy lifestyle	New recreational sites bring people closer to their river again.	X		X	X			
Tourism	Potential for biking and canoeing promotes regional economy.	X	X	X	X	X		
Fishery	River restoration creates better places and conditions for fishermen.	X	X	X	X	X		
Jobs	The implementation of the initial measures creates jobs for decades.	X	X	X	X	X	X	X
Regional welfare	Sava will be a sustainable natural resource for regional welfare.	X	X	X	X	X	X	X

5.3.7 Priorities for implementation

The order of implementation depends largely on the type of funding:

- If nature conservation has priority and co-financing might come from the LIFE Nature Fund of the European Union, sections 2 and 5 should be given priority.
- If the emphasis is on recreational use, stopping riverbed deepening and improving the ecological condition of water bodies (e.g., hydro morphology), implementation should start with section 4.

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