Data Collection, hydraulic and morphological modelling of the Danube River and the Sava River in the Republic of Serbia
Lot 1: Hydraulic and morphological modelling of the SRB-HRV common stretch of the Danube River
404-02-00086/2022-06

BOTTLENECKS VARINATS DEFINED

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Abbreviations

Abbr.	Meaning
HNWL	High Navigation Water Levels
DEM	Digital Elevation Model
km	Kilometer
LNWL	Low Navigation Water Levels
m	Meter
m^3/s	Cubic meters per second
Max	Maximum
Min	Minimum
Q	Discharge
MCA	Multi-Criteria Analysis
GIS	Geographic Information System
WWF	World Wide Fund for Nature
TEN-T	Trans-European Transport Network
IWT	Inland Waterway Transport

EXECUTIVE SUMMARY

This study addresses critical navigational and environmental bottlenecks along the joint Serbian-Croatian stretch of the Danube River between km 1433 and km 1295.6. The primary objective is identifying problematic areas and proposing innovative river training measures that balance safe navigation with ecological preservation. The study focuses on four key sectors—Apatin, Civutski/Zidovski rukavac, Drava Confluence, and Staklar—where sedimentation, erosion, and morphological instability have compromised the required 200-meter fairway at Low Navigation Water Levels (LNWL).

Proposed Measures and Modelling Approach

The report presents a suite of structural interventions including chevrons, sills, detached groynes, and sidearm channels. Each measure is conceptualised to stabilize the navigation channel and enhance the natural sediment dynamics and improve habitat connectivity along the river. Owing to the innovative nature of several proposed structures—such as chevrons replacing traditional groynes—their performance is yet to be validated. Therefore, these measures are slated for detailed evaluation using a state-of-the-art 2D hydraulic model, which will simulate the complex interactions between flow, sediment transport, and morphological evolution under a structural scenario.

Risk Analysis and Uncertainties

While full-scale risk assessments are contingent upon the forthcoming modelling results, the current preliminary risk analysis has identified several key areas of uncertainty:

- **Hydraulic and Sediment Transport Variability:** There is inherent uncertainty in predicting how the flow will re-distribute with the introduction of new structures. Potential risks include unintended acceleration of water currents, uneven sediment deposition, or even exacerbated erosion in localized areas. Sensitivity analyses integrated into the 2D model will help identify the parameters that most affect these outcomes.

- **Structural Performance:** Preliminary considerations suggest that while these measures could offer significant improvements in maintaining the navigation channel, there is a risk that their performance may vary under extreme discharge events and climate change. Further model calibration and validation against historical data are essential to mitigate these concerns.

- **Ecological Impacts:** Although the proposed interventions are designed with ecological sustainability in mind—aiming to restore more natural flow conditions and enhance habitat diversity—there is still a risk of short-term disturbance during construction and potential long-term changes in habitat connectivity and quality. An adaptive monitoring program

should be designed to verify that ecological impacts remain within acceptable limits and that mitigation measures are effective over time.

- **Implementation Uncertainties:**
  Given that the measures are still under the planning phase, factors such as construction feasibility, cost-effectiveness, and regulatory approvals also pose a degree of uncertainty. These aspects will be addressed in subsequent phases after the 2D modelling phase has provided a clear indication of expected outcomes.

Conclusion

The study sets the foundation for a comprehensive re-evaluation of river training approaches on the Danube. By coupling traditional hydraulic techniques with modern, nature-inclusive designs, the proposed measures aim to enhance navigability while preserving the river's ecological integrity. The forthcoming 2D hydraulic modelling will play a pivotal role in quantifying the effects of the interventions, resolving uncertainties, and refining the risk analysis. Ultimately, this integrated approach seeks to inform decision-makers on the optimal balance between infrastructural development and environmental sustainability.

1 INTRODUCTION

1.1 Background and Purpose of the Study

The joint Serbian-Croatian stretch of the Danube River (km 1433–1295.6) represents a critical European waterway where navigational challenges intersect with ecological preservation goals. This regulated stretch faces persistent navigational issues—from sedimentation in Apatin and upstream of the Drava Confluence to flow instability at the confluence—compromising the target 200-meter fairway width required for safe navigation.

This engineering study addresses the critical bottlenecks along the joint Serbia-Croatia stretch (km 1408.20–1295.6), focusing on structural solutions to achieve and maintain the required 200-meter fairway width at the Low Navigation Water Level. The analysis integrates traditional hydraulic engineering methods with modern sediment management techniques. It applies PLATINA 2000 standards as design boundaries and adheres to WWF ecological recommendations and NATURA 2000 areas according to the Habitats Directive (Directive 92/43/EEC of May 21, 1992 on the conservation of natural habitats and wild fauna and flora) and the Birds Directive (Directive 2009/147/EC of the European Parliament and of the Council of November 30, 2009 on the protection of wild birds) and databases on the monitoring of the hydrological, hydraulic and morphological characteristics and biological component of water conditions according to the Water Framework Directive (Directive 2000/60/EC of the European Parliament and the Council of October 23, 2000) of protected ecological areas, as well as 5-country Biosphere Reserve initiative, as operational constraints.

The engineered solutions maximise navigational efficiency while maintaining the critical sediment balance and meeting prescribed ecological design thresholds. Proposals will be discussed within the Stakeholder's Forum platform, including participation of both national waterway authorities.

1.2 Scope of the river training works analysis

Scenario setup marks the initial phase of the modeling process. Each scenario is defined as an educated hypothesis that will be rigorously tested through the model. The resulting outputs will then be critically analyzed and evaluated against the pre-established Multi-Criteria Analysis (MCA) criteria.

The project encompasses a common stretch of the Danube River between Serbia and Croatia, extending from km 1433 to km 1295.5 (see Figure 1).

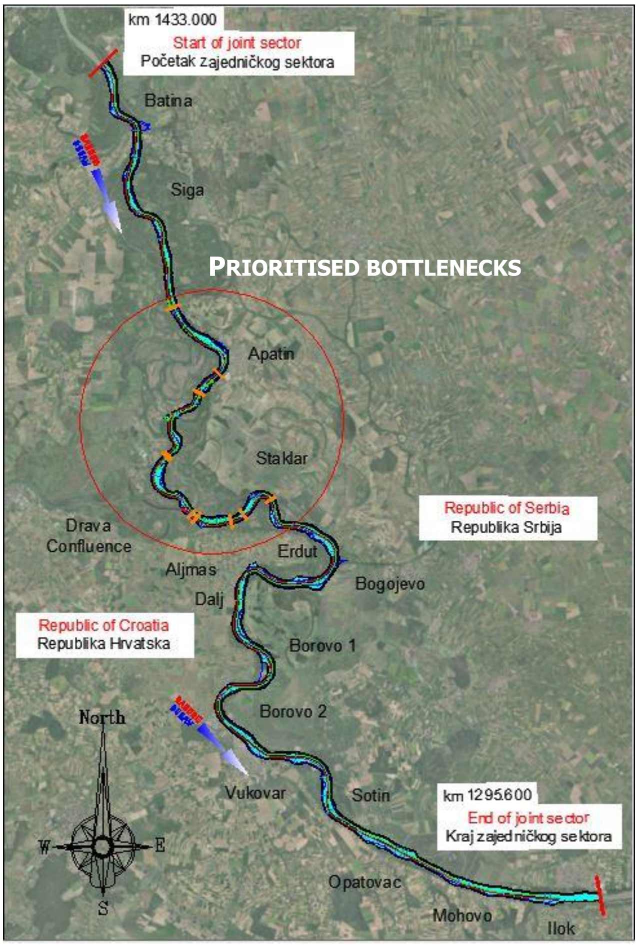


Figure 1 - The map of the common stretch between Serbia and Croatia 1433 and km 1295

The bottleneck analysis and prioritization have narrowed the focus to the key problem areas presented in Table 1 and illustrated in Figure 2. Consequently, this report concentrates on the stretch between km 1408.2 and km 1373.4, where the priority bottlenecks have been identified.

Table 1 - Prioritised bottlenecks

No.	Sector	Chainage (from km to km)	Quantity of sediment within the fairway of 2.5m depth &			
			Width 100m	Width 120m	Width 150m	Width 200m
3	Apatin	1408.2 - 1400.0	7,035.00	14,635.00	26,821.00	54,311.00
4	Civutski Rukavac	1,397.2 - 1,389.0	343.00	1,494.00	8,164.00	52,977.00
5	Drava Confluence	1,388.8 - 1,382.0	-	441.00	4,221.00	22,013.00

No.	Sector	Chainage (from km to km)	Quantity of sediment within the fairway of 2.5m depth &			
			Width 100m	Width 120m	Width 150m	Width 200m
7	Staklar	1,376.8 - 1,373.4	733.00	1,571.00	3,823.00	14,781.00

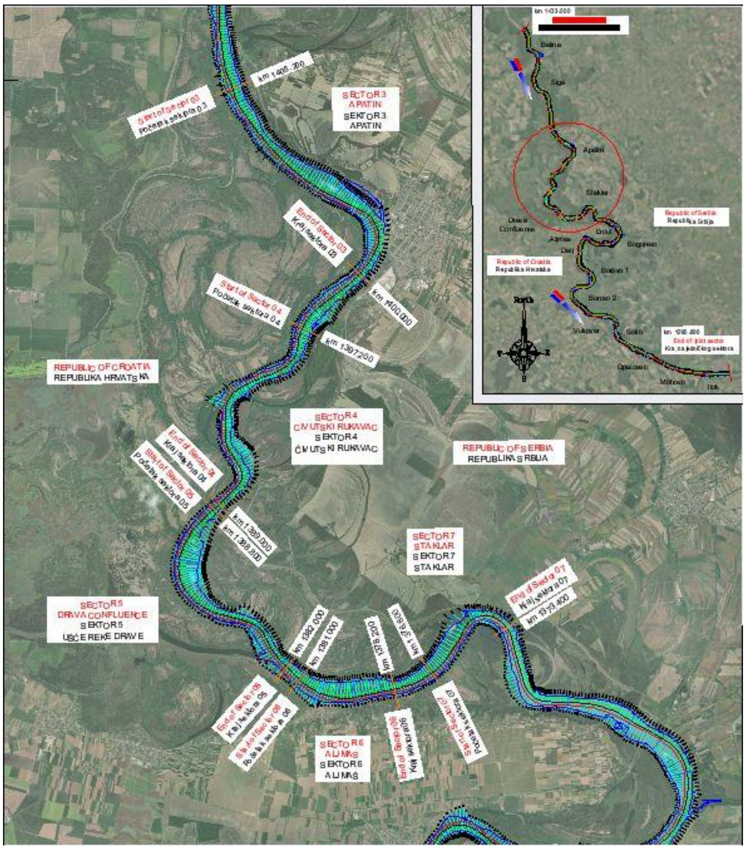


Figure 2 - The map of the common stretch, designated as a stretch with the priority bottlenecks

1.3 Importance of Environmental and Morphological Considerations

Inland waterway transport (IWT) offers a sustainable alternative to road and rail by emitting far fewer greenhouse gases per ton-kilometer (EU Transport White Paper, 2011). However, expanding navigation requires that engineering works be conducted with ecological integrity in mind, as river interventions (e.g., channelization, bank stabilization) may disrupt habitats and alter sediment dynamics. The EU's Sustainable and Smart Mobility Strategy (2020) targets a 30% shift of freight from roads to waterways and rail by 2030, recognizing IWT's lower carbon footprint. Although navigation inherently reduces congestion and emissions, its infrastructure—such as groins and locks—can risk deteriorating ecosystems. Innovative solutions, like replacing traditional groins with chevrons, exemplify how nature-inclusive design can mitigate these trade-offs by ensuring navigability while preserving river morphology. The TEN-T Core Network prioritizes such measures, in line with the EU Green Deal's zero-pollution goals. By integrating ecological resilience into waterway planning, Serbia and Croatia can achieve dual benefits: greener freight transport and healthier river ecosystems.

It is important to emphasise that the Trans-European Transport Network recognises the Rhine-Danube corridor as a key route, and EU transport plans are underway to support projects aimed at bottleneck removal along inland waterways.

Therefore, this project will primarily focus on the removal of bottlenecks, with particular attention to:

- **Restoring and maintaining the required 200-meter fairway width.**
- **Minimizing ecological deterioration while addressing structural shortcomings.**
- **Incorporating nature-inclusive engineering solutions that balance navigational efficiency with habitat preservation.**

This dual approach aims to reconcile the need for improved navigation with the imperative to safeguard environmental integrity.

Habitat Preservation: Prioritize designs that maintain or restore natural habitats (e.g., fish spawning grounds, floodplain connectivity) to support biodiversity.

Sediment Dynamics: Avoid over-stabilization; allow natural sediment transport to sustain geomorphological processes and reduce riverbed erosion which leads to the lowering of the water surface.

Soft Engineering: To minimise ecological degradation, favour non-structural measures (e.g., bioengineering, fairway realignment, bedload management) over hard infrastructure.

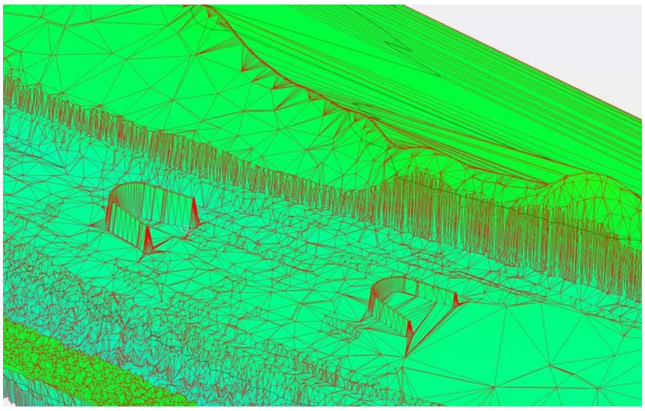
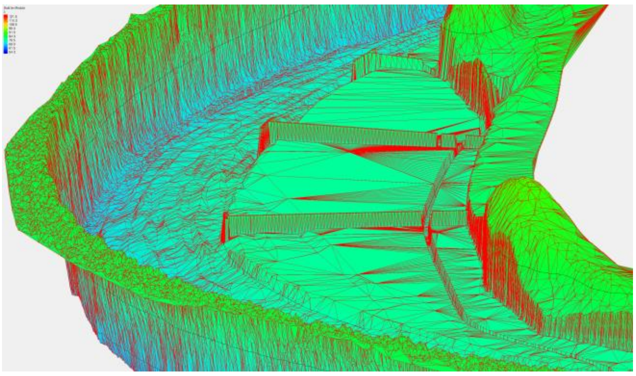
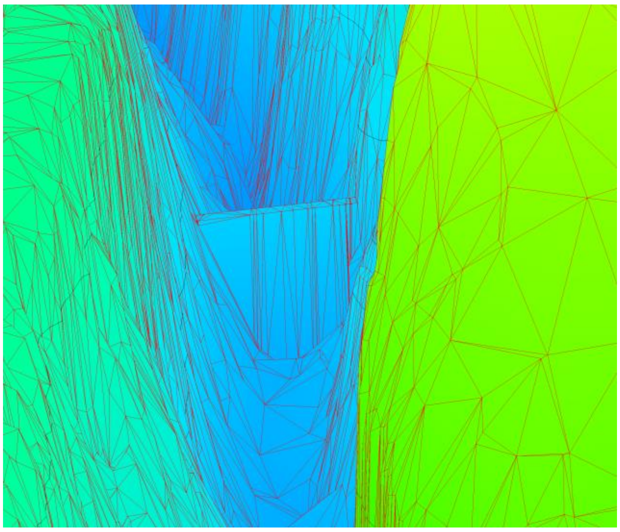
The collaborative approach and engagement of environmental experts ensures compliance with the EU Water Framework Directive (WFD) goals, the Habitat Directive and national regulations.

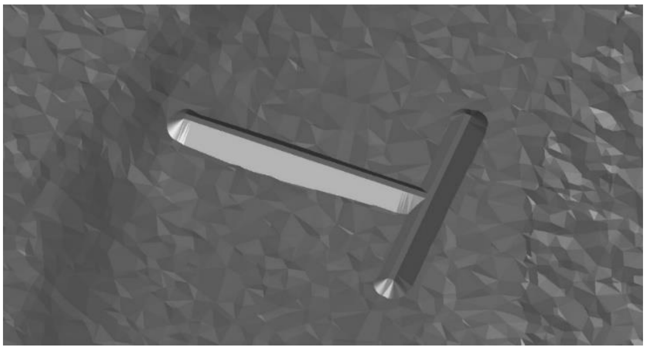
Equally, the proposed and analysed solutions in the project will be based on nature-inclusive solutions, which will be presented in the next chapter.

1.4 Eco-friendly structural nature-inclusive solutions

One of the scenarios focuses on soft engineering measures that are not directly modeled. While some interventions are structural, they incorporate nature-inclusive elements. In these proposed scenarios, the consultant has opted to test various eco-friendly structures, evaluating and validating both the navigational and ecological benefits and risks in consultation with key stakeholders. A complete list of the eco-friendly structures considered during scenario development is provided in Table 2.

Table 2 - Breakdown of the structures used in the scenario development

Structure	3D presentation in model
Chevron	
Sidearm channel	
Submerged bottom sill	

Detached Groyne	

Nature-inclusive structures are designed to enhance navigation conditions, primarily navigation fairway outlines, and concurrently provide more sustainable ecological conditions in the intervention zone. For example, comparing the groyne and chevron will present ecological benefits gained by shifting the river structures from the groynes to chevrons.

1. **Reduced Bank Erosion** -Chevrons deflect currents gently (unlike groins) which trap sediment and starve downstream areas, often exacerbating erosion.
2. **Improved Sediment Distribution** - Chevrons promote more natural sediment transport, maintaining bedload continuity and reducing dredging needs.
3. **Habitat Enhancement** - Their open design allows fish passage and creates varied flow conditions (pools/riffles), supporting aquatic biodiversity.

Chevrons offer significant navigational benefits. They stabilise channels without creating abrupt flow disruptions, resulting in a safer and more predictable navigation environment compared to the turbulence induced by traditional groins. Unlike groins, which tend to accumulate debris and require dredging, chevrons are less prone to blockage and siltation, thereby reducing maintenance costs.

Similarly, sidearm openings serve as an effective mitigation measure by diminishing erosion and sedimentation in the main riverbed near the channel. Additionally, sidearm channels enhance the river's capacity to erode downstream sediments, which benefits the overall channel stability and self-adjustment over long stretches. They also provide:

1. **Restoration of Natural Hydro-morphology** - Sidearms help restore a more natural multi-channel structure, improving overall river ecosystem health.
2. **Habitat Diversity & Refuge Creation** - They create low-flow zones that provide refuge for fish, amphibians, macroinvertebrates, and aquatic vegetation, especially during high-flow events.
3. **Improved Spawning and Nursery Habitats** - Sidearms often have shallower, calmer waters ideal for fish spawning and juvenile development.
4. **Enhanced Biodiversity** - The variety of flow conditions and sediment types supports a greater diversity of flora and fauna.

5. **Riparian Zone Revitalization -** Reconnecting floodplain features through sidearms supports riparian vegetation growth and wetland formation.

The observed stretch is characterised by a naturally narrow riverbed, which has been further constricted by existing hydro-technical structures. In sharply curved sections such as Apatin and Staklar, intensive erosion has deepened the channel to depths of 15–20 meters—an unusual condition for the Danube River. Consequently, the use of submerged sills has been evaluated, with consideration given to both their positive and adverse effects on the river ecosystem. The following section details these impacts.

Potential Ecological Benefits

1. **Habitat Creation & Enhancement** - Submerged sills can create microhabitats (e.g., pools upstream and riffles downstream), enhancing aquatic species' habitat diversity. They often provide shelter and feeding grounds for fish, especially in low-flow conditions.

2. **Sediment Retention and Bed Stabilisation** – The sills are helping us in stabilising or even enhancing the low water table, reducing riverbed incision, increasing shear stress on shallow areas close to the main channel, and better distribution of flow over the riverbed (navigation channel). By reducing flow velocities, sills help retain sediments, benefiting aquatic vegetation and benthic organisms. Stabilised beds mitigate the risk of habitat degradation caused by excessive erosion or sediment transport.

Sill's utilisation also has certain drawbacks, reflected as a Barriers to Aquatic Organisms, which may be the consequence of poorly designed sills, may hinder fish migration and movement of aquatic species, especially for weaker swimmers or during low-flow periods.

2 METHODOLOGY

The 136-kilometre study area along the Danube, from km 1433 to km 1297, has been thoroughly examined to address navigational challenges while considering ecological sustainability as a key aspect. Divided into four sectors, this stretch contains eight critical locations where the fairway fails to achieve the required 200-meter width at Low Navigation Water Level. These bottlenecks were analyzed using a comprehensive approach that balances navigational needs with environmental protection.

From a navigational perspective, the study focused on assessing hydraulic conditions, fairway maintenance requirements, and potential structural interventions such as groins, chevrons, or sills. Dredging was considered only a secondary measure for urgent situations, emphasizing sustainable, long-term solutions instead. On the ecological side, the analysis incorporated findings from previous environmental screenings conducted by Croatian experts, with particular attention given to habitat preservation and natural sediment dynamics.

Historical cross-sectional data (EP) were employed in the morphological analysis, while available DEMs served as the basis for both 1D and 2D modelling. The engineering assessment followed a three-stage process:

Review of Existing Conditions: Using GIS mapping and conceptual analysis, we conducted a detailed examination of the current morphological state, including the impact of historical river structures and operational measures, e.g. dredging (even if the latter was not applied for many years).

Stakeholder Engagement: The initial scenarios were presented and discussed in forums with stakeholders, where feedback was used to refine potential solutions.

Regulatory Coordination: Finally, the relevant authorities in Serbia and Croatia discussed and approved the proposed measures, ensuring alignment with national and EU waterway and environmental policies.

3 EXISTING CONDITIONS AND BOTTLENECK ANALYSIS

3.1 Identification of critical locations

The priority bottleneck sectors listed in Table 1 were analyzed using a Digital Elevation Model (DEM) developed for 1D modeling and data on Low Navigation Water Levels (LNWL) obtained from a hydrologic study. These data sets were integrated within GIS software to produce a 2D map, which is colour-coded based on a 25-dm contour line. Areas where the riverbed is shallower than 25 dm are shown in dark blue, while deeper areas appear in light blue (Figure 3). Additionally, a 200-meter-wide navigational fairway—with a centerline and chainage marks at every 100 m—was overlaid on the map. The left side of the fairway is displayed in green and the right side in red.

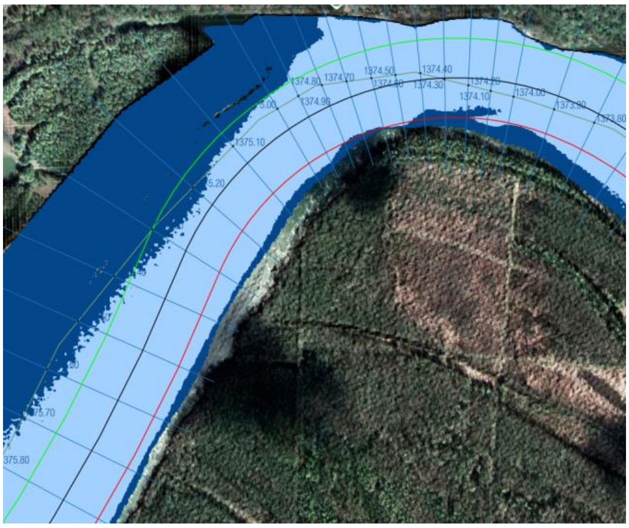
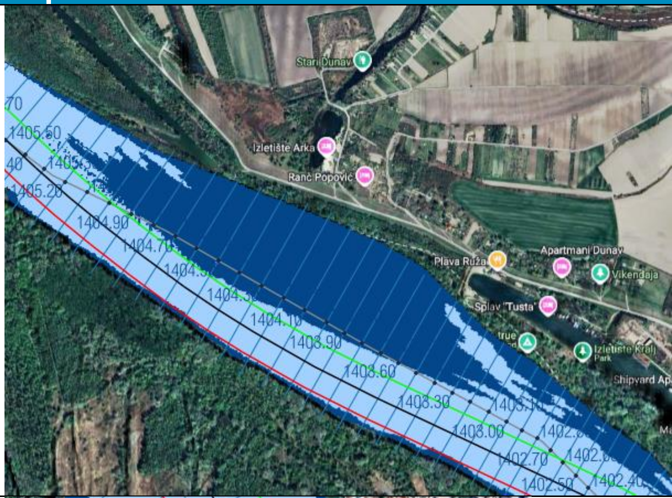
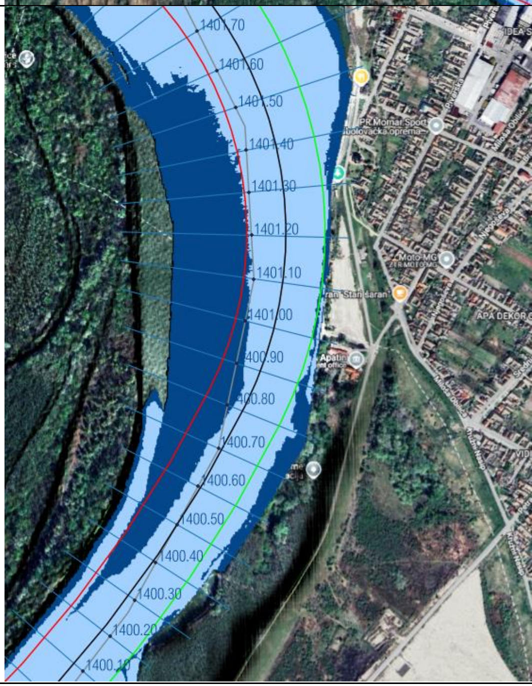


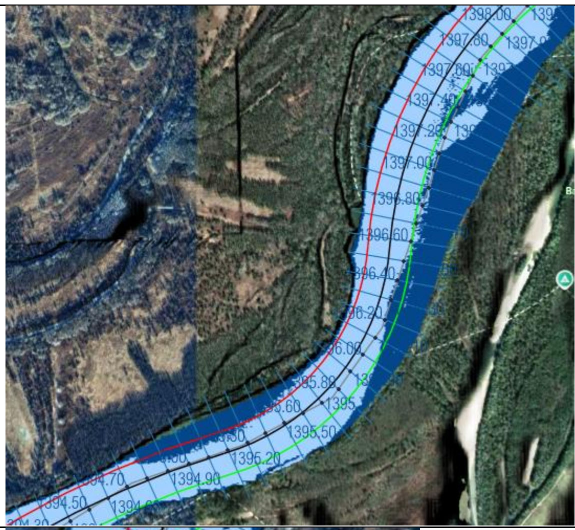
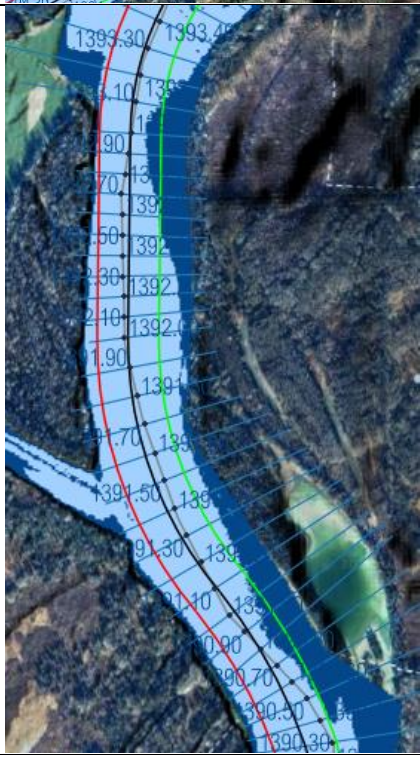
Figure 3 - An example of the map developed for the analysis of the critical locations along the section with priority bottlenecks

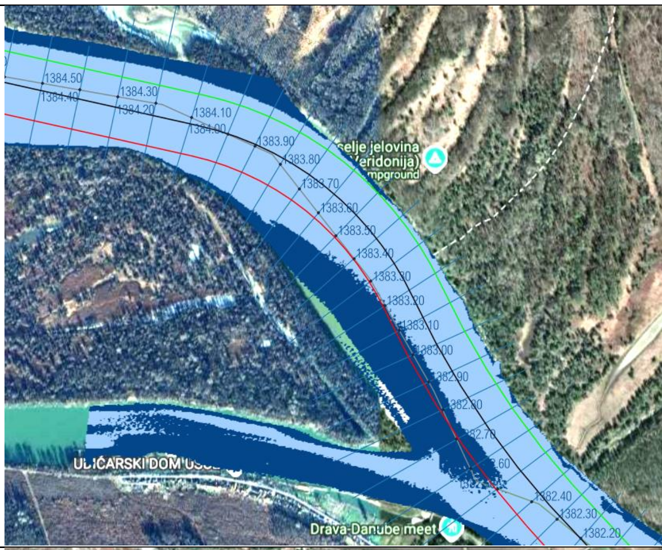
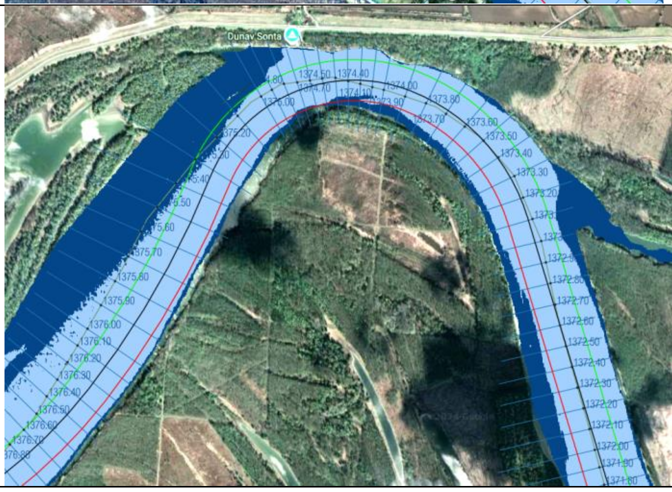
The locations where the edge of the navigational fairway crosses the dark blue areas (areas shallower than 25dm) are pinpointed as "critical locations"; as such, they are comprehensively analysed in the next chapter.

The list of the pinpointed critical locations is given in Table 4.

Table 3 - The list of identified locations

No.	Chainage	Sector	Map
1.	km 1405.4 - km 1403.0	Apatin	
2.	km 1401.7 - km 1400.2	Apatin	

3.	km 1397.2 - km 1394.7	Civutski / Zidovski rukavac	
4.	km 1393.2 – km 1390.5	Civutski / Zidovski rukavac	

5	km 1383.7 – km 1382.3	Drava confluence	
6	km 1376.8 - km 1373.4	Staklar	

3.2 Assessment of current issues (navigation, sedimentation, erosion, ecological impacts)

3.2.1 Apatin km 1,408.2 – 1,400.0 – Sector 3

As indicated in Table 3, the Apatin sector contains two critical locations. The first—located between km 1405.4 and km 1403.0—does not precisely fit the established criteria (the navigational fairway edge intersects the 25-dm contour). Nevertheless, this location has historically been a neuralgic point for navigation, and therefore, it is designated as critical. Figure 5 illustrates the historical development of cross-section EP27 at km 1403.5, corroborating the assertion of the area's inherent volatility. The critical sandbar was formed at the beginning of the 21 century in the middle of the river bed. At this time, the growing structure slowly shifted downstream and closed the entire cross-section. The navigation was temporarily redirected along the left riverbank with severe limits on available widths. The EP 27 (Figure 5) shows the development of the observed sandbar, where it is notable that in 2021, a significant amount of sand reduced the cross-section area and split the water flow into two branches. The present position of the sandbar is favorable and it would be useful from the navigation perspective to remain there.

The Apatin sector has experienced relatively small number of structural interventions over time. Specifically, only four short groynes, constructed after 2000 on the Croatian side, are present (see Figure 4).

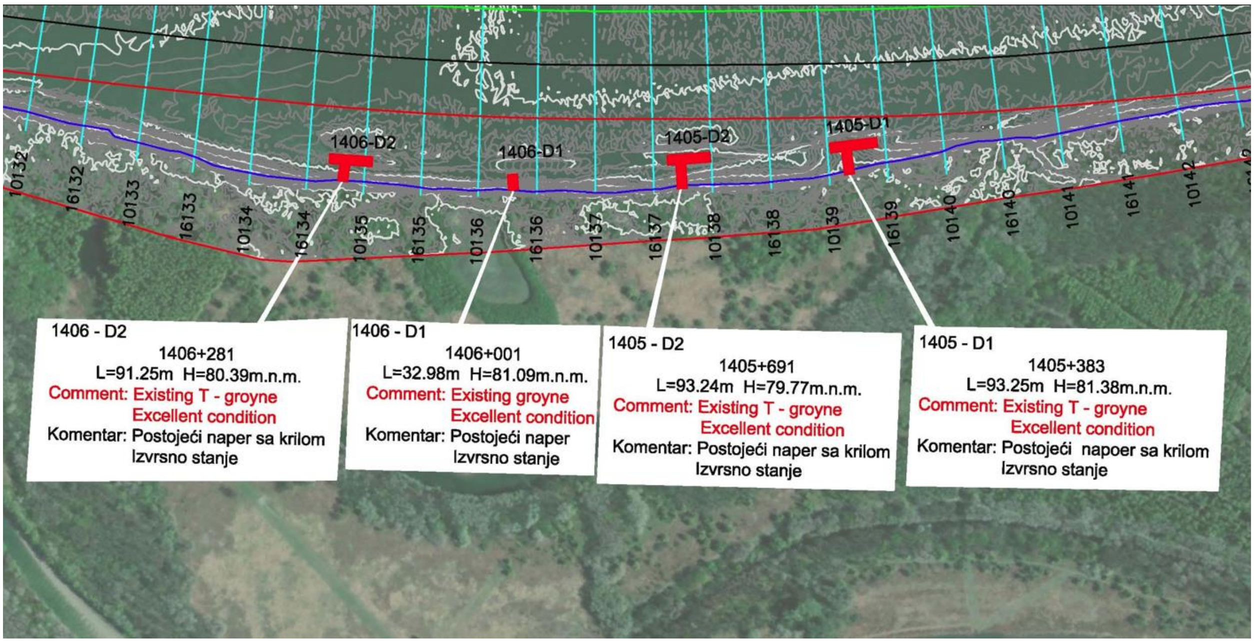


Figure 4 - The map of the existing t groynes on the Croatian side located between km 1406.281 and km 1405.383 with legend and condition

In this case, the consultant faces a challenging task: to propose a solution that requires minimal intervention to correct the sandbar while minimising ecological impact.

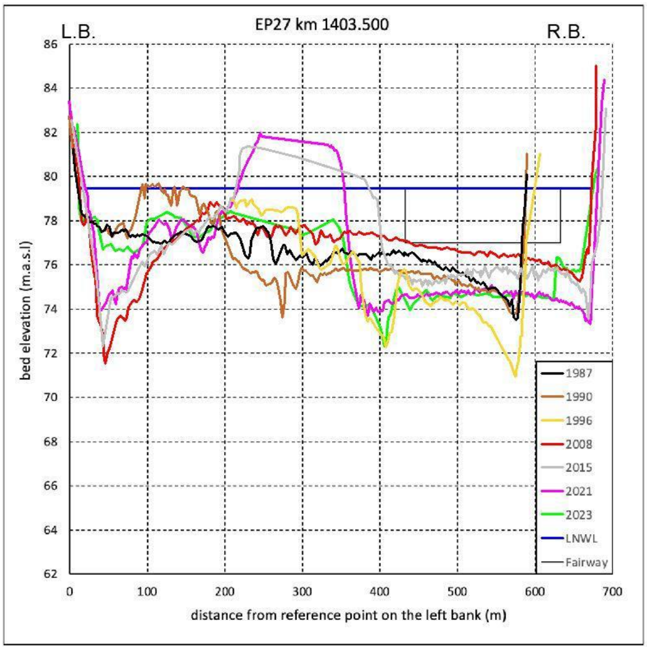


Figure 5 - EP 27, km 1403.5 – Volatile nature of the observed stretch and intensive riverbed alternations over time

The second critical location, as noted in Table 3, is more straightforward since it represents the narrowest part of the fairway along the entire common stretch between Serbia and Croatia. Here, the available navigational outline is approximately 120 meters, located in a sharp bend that generates adverse turbulence due to the curved channel. The cross-section of this stretch exhibits a typical triangular shape, with the left riverbank composed of solid rock that remains stable over time. Consequently, secondary turbulences erode the riverbed, deepening it to between 15 and 20 meters relative to the LNWL. Simultaneously, helicoidal turbulence deposits the eroded material onto the concave right riverbank, further suppressing the fairway and impeding navigation. Figure 6, which presents a cross-section EP 32, clearly corroborates the morphological and flow analyses.

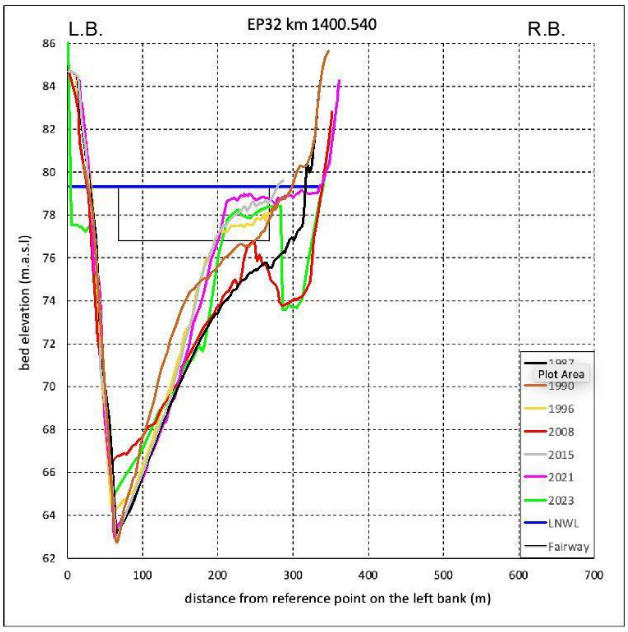


Figure 6 - EP 32, km 1400.540 – historical development, shows extreme depths along the left river bank and fixed position of the left riverbank over time

From an environmental perspective, the Apatin stretch lies within ecologically important and legally protected areas on both sides of the Danube. This includes the Serbian Gornje Podunavlje Special Nature Reserve and the Croatian Kopački Rit Nature Park, as well as the Mura-Drava-Danube Transboundary Biosphere Reserve and the Kopački Rit Natura 2000 site (HR2000394).

Species of conservation interest in this area include the white-tailed eagle (*Haliaeetus albicilla*), the black kite (*Milvus migrans*), the kingfisher (*Alcedo atthis*), and the sand martin (*Riparia riparia*). These species rely on the natural structure of riverbanks and riparian habitats for nesting and foraging. Although construction works and modifications to river morphology can temporarily alter local habitat conditions, careful planning and the implementation of mitigation measures—such as preserving key vegetation zones and scheduling works outside sensitive breeding periods—can help reduce disturbances and maintain ecological balance.

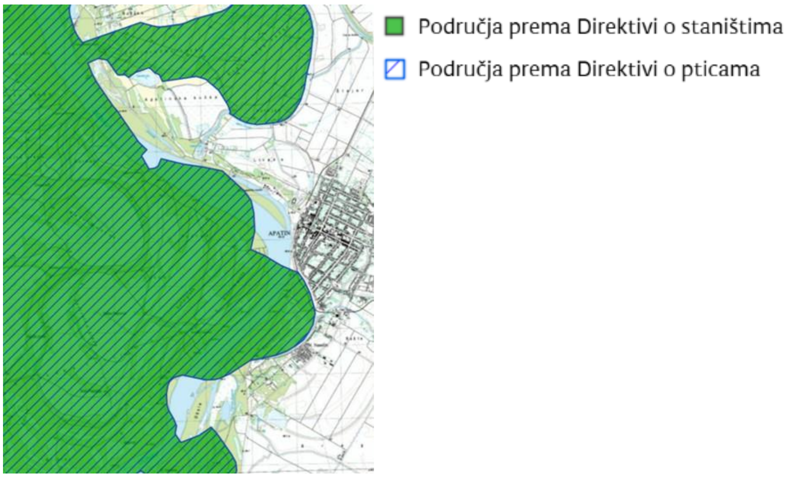


Figure 7 - Apatin sector and Natura 2000 protected zones

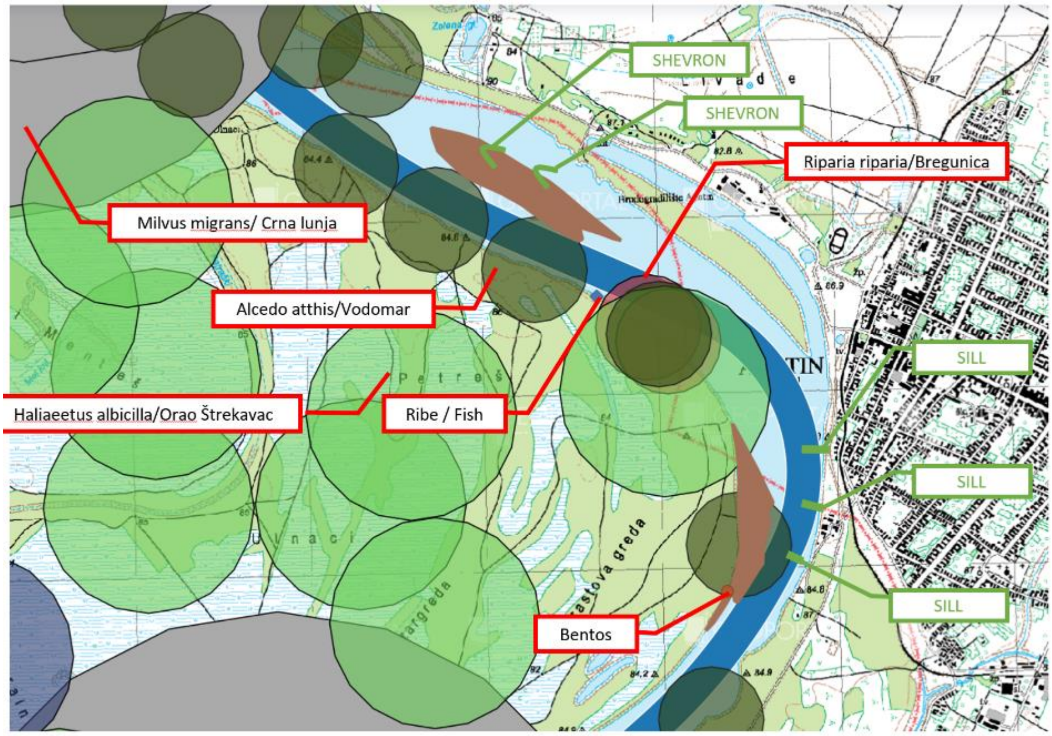


Figure 8 - Apatin - Screenshot of the GIS map with results of the environmental screening

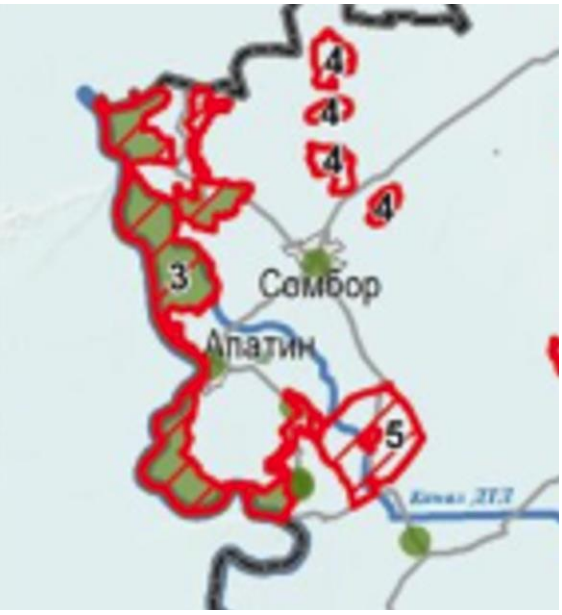


Figure 9 - Ecological Network map of the protected areas in Serbia

3.2.2 Civutski/Zidovski Rukavac (km 1397.2 – 1389.0) – Sector 4

Civutski/Zidovski Rukavac ranks second after Apatin in terms of the volume of material that must be removed to achieve the required fairway dimensions, according to the methodology employed for prioritizing critical sectors. Along this stretch, four distinct locations are identified as critical. Information from Croatian authorities indicates that the Civutski Rukavac sector requires continuous monitoring and maintenance, as even small amounts of deposited material can disrupt navigation given this section's narrow configuration relative to other Danube segments.

Figure 10 illustrates how the morphology of this sector was analysed using three available cross-sections with historical data.

Civutski/Zidovski Rukavac ranks second after Apatin regarding the volume of material that must be removed to achieve the required fairway dimensions (based on the methodology used for critical sector prioritisation). Along this stretch, four different locations are marked as critical. According to the information from the Croatian authorities, Civutski rukavac Sector permanently requires monitoring and maintenance. The map shows (Table 3) that the stretch is very narrow compared to other stretches on the Danube, and small deposited amounts may cause navigation issues.

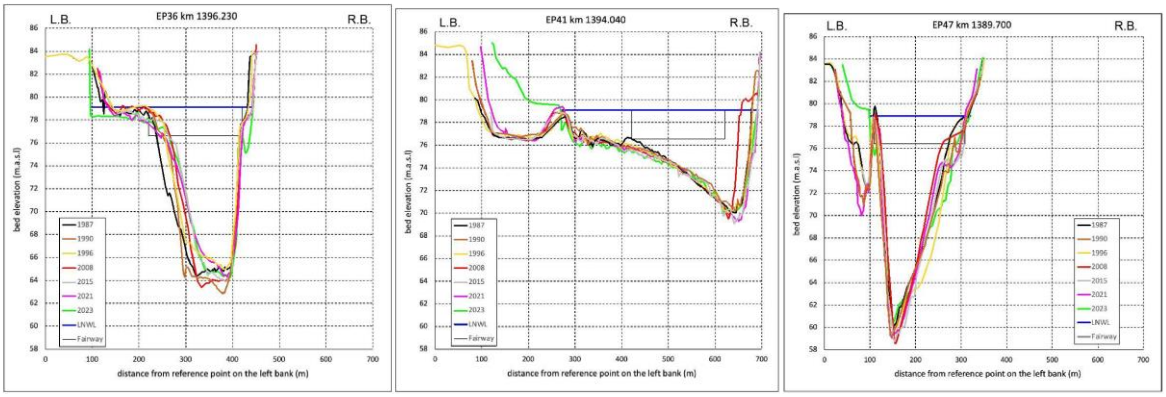


Figure 10 -EP 36 km 1396.230, EP 41 km 1394.040 and EP 47 km 1389.700 The chronology of changes in the representative cross-sections

The conclusions which flow out of the morphological analysis are showing that:

1. The cross-section has remained stable over time. The riverbed width and depth at this location are fixed, with no indications for significant future changes.
2. The riverbed is relatively narrow (in some sections, as little as 200m), but this is compensated by depths reaching 20m, likely due to convenient geological conditions.
3. Bottlenecks and sand deposits have formed in areas where previous river training works were implemented. Two possible explanations for this behaviour are:
    a. The designed fairway width may have been miscalculated, leading to material deposition in already narrowed sections.
    b. The river carries large amounts of sediment, so any discontinuity creates bedload deposition and sedimentation conditions.

These conclusions should be carefully considered during the design of structural measures.

Figure 11 - The contractions in the Civutski / Zidovski rukavac sector on km 1394.6 and 1389.5

Additionally, natural contractions are observed downstream of the identified bottlenecks. The first contraction occurs at km 1394.6, where the riverbed narrows to 200 m, while the second contraction, at km 1389.7, is even more pronounced, with a width of less than 200 m. These constrictions produce a local backwater effect that slows the water current and promotes sediment deposition (see Figure 11).

Historically, the Civutski/Zidovski Rukavac stretch has been critical for navigation. This is evidenced by the multiple training structures executed in the sector. Figure 12 clearly shows the location of these structures as detailed in Table 4.

Table 4 - Civutski/Zidovski Rukavac - The list of the executed structures on the Right and Left riverbank

	Left Riverbank				Right Riverbank				
r.b.	Station	Object type	Length (m)	Label	Station	Object type	Length (m)	Elevation (mnm)	Label
13	1396+720	Groyne	115.44	\					
14	1395+420	Sills	153.7	\					
15	1395+300	Sills	81.64	\					
16					1393+691	Groyne	72.97	80.09	1393-D2
17					1393+117	Sills	262.05	79.2	1393-D1
18	1389+880	Groyne	153.7	\					
19	1389+810	Groyne	81.64	\					
20	1389+525	Groyne	150.33	\					

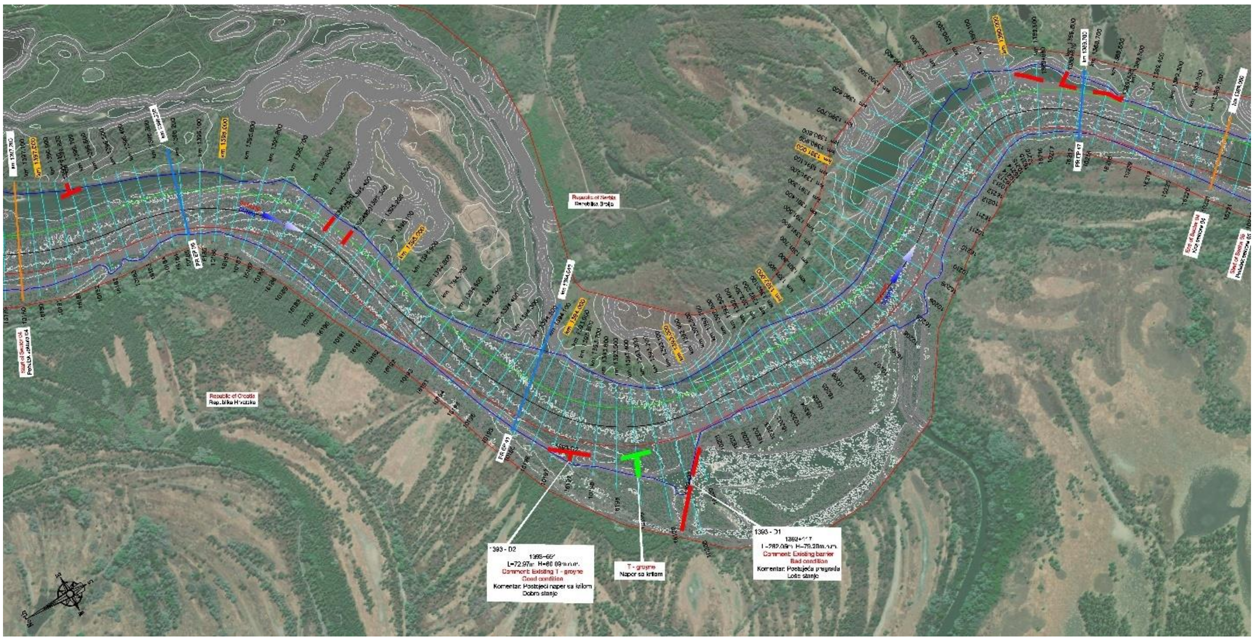


Figure 12 - CIVUTSKI/ZIDOVSKI RUKAVAC – map of the sector with locations of the existing structures (red colour)

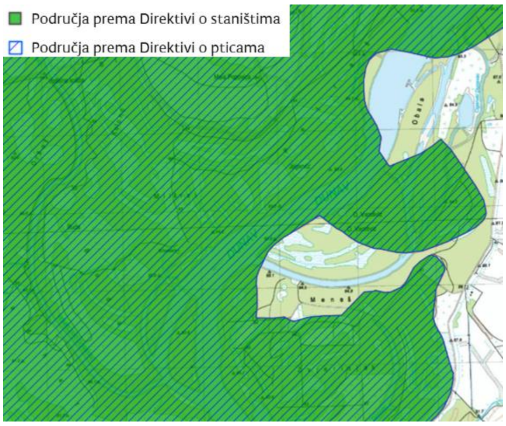


Figure 13 - Civutski/Zidovski rukavac - Natura 2000 protected zones

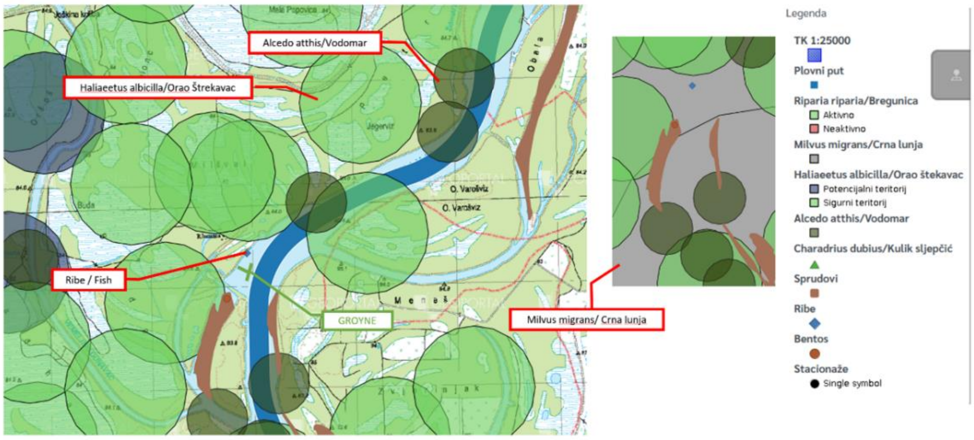


Figure 14 - Civutski/Zidovski rukavac Screenshot of the GIS map with results of the environmental screening

The sector Čivutski/Zidovski Rukavac river sector is in the nature-protected areas. On the Serbian side- the protected area is Gornje Podunavlje Special Nature Reserve, and on the Croatian side is - Kopački Rit Nature Park, as well as the Mura-Drava-Danube Biosphere Reserve and the Kopački rit Natura 2000 site (HR2000394). (Figure 13 and 14)

3.2.3 Drava Confluence (km 1388.8 – 1382.0) – Sector 5

The Drava confluence is a typical river confluence where two significant water flows meet, creating complex hydraulic conditions. One of the key effects observed in this area is the backwater effect, which slows the flow and leads to intensive bedload deposition in zones of reduced velocity.

There are two cross-sections with a historic array of surveys for the morphological analysis. One cross-section EP 52, km 1383.700 is upstream of the confluence, and the second EP 55 1382.190 is downstream (Figure 15).

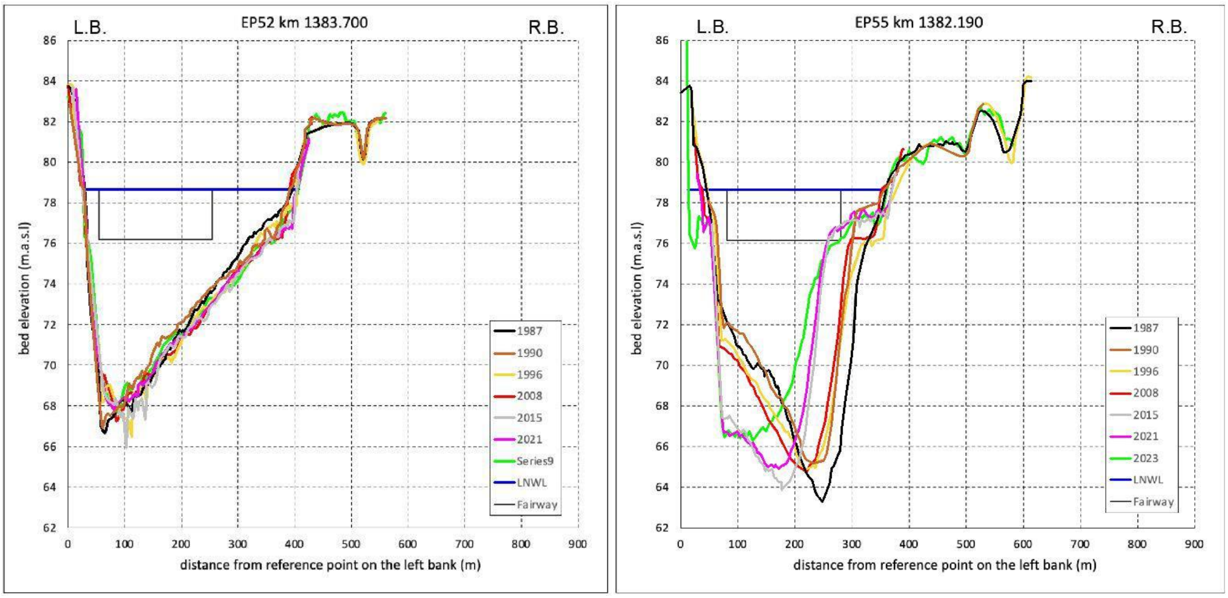


Figure 15 - EP 52 km 1383.700 and EP 55 1382.190 The chronology of changes

Deposited material suppresses the navigational fairway, and variations in the Danube and Drava discharges cause the sandbar to change its shape, thereby affecting navigation. Cross-section EP 52 demonstrates a high degree of stability over time, while EP 55 shows notable instability in the riverbed area, although the riverbanks remain stable and fixed. The list of activities related to the training works is provided in Table 5.

Table 5 - Drava Confluence - The list of the executed structures on a Right and Left riverbank

Left Riverbank					Right Riverbank				
r.b.	Station	Object type	Length (m)	Label	Station	Object type	Length (m)	Elevation (mnm)	Label
21	1388+640	Groyne	123.1	\					
22	1388+325	Groyne	63.37	\					
23	1387+910	Groyne	98.46	\					
					1382+557	Groyne	37.06	80.03	1382-D2

As shown in Table 5, the recorded activities in the past were not related to the confluence but to the upstream sector. It is interesting to note that the stability of EP 52 shows that the upstream groynes on km 1388 did a great job stabilising the riverbed. The location of the structures in the sector Drava confluence is shown in Figure 16 in red.

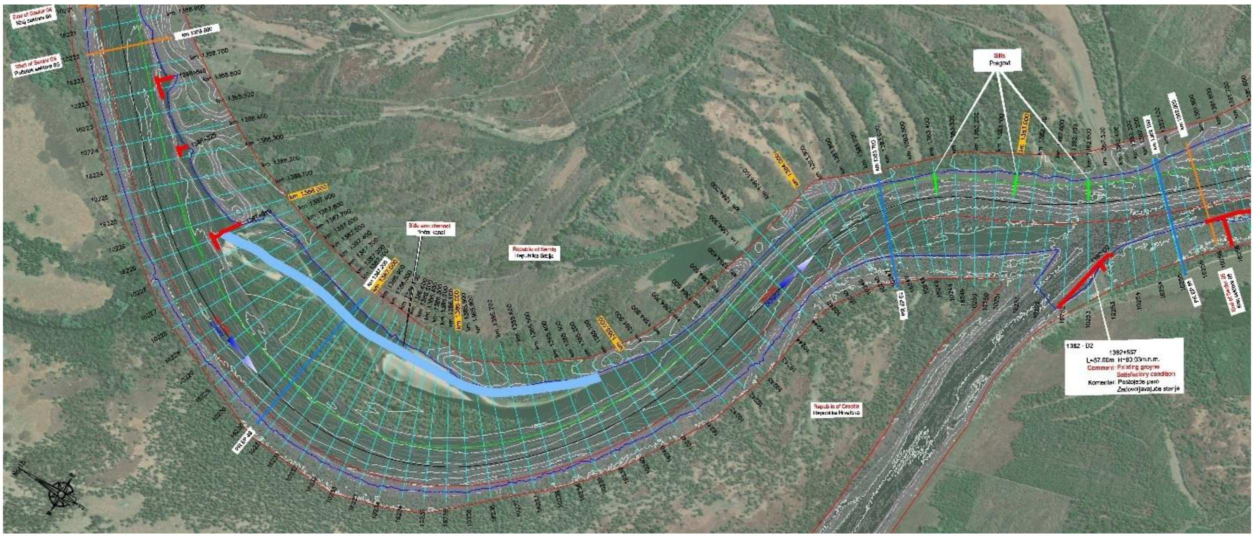


Figure 16 - Drava Confluence Map with existing training structures (red colour)

The sites proposed for intervention are located within protected areas (Figure 17 and 18) in both Serbia and Croatia, including the Gornje Podunavlje Special Nature Reserve, the Kopački Rit Nature Park, the Mura-Drava-Danube Transboundary Biosphere Reserve and the Natura 2000 site Dunav_Vukovar(HR2000372).

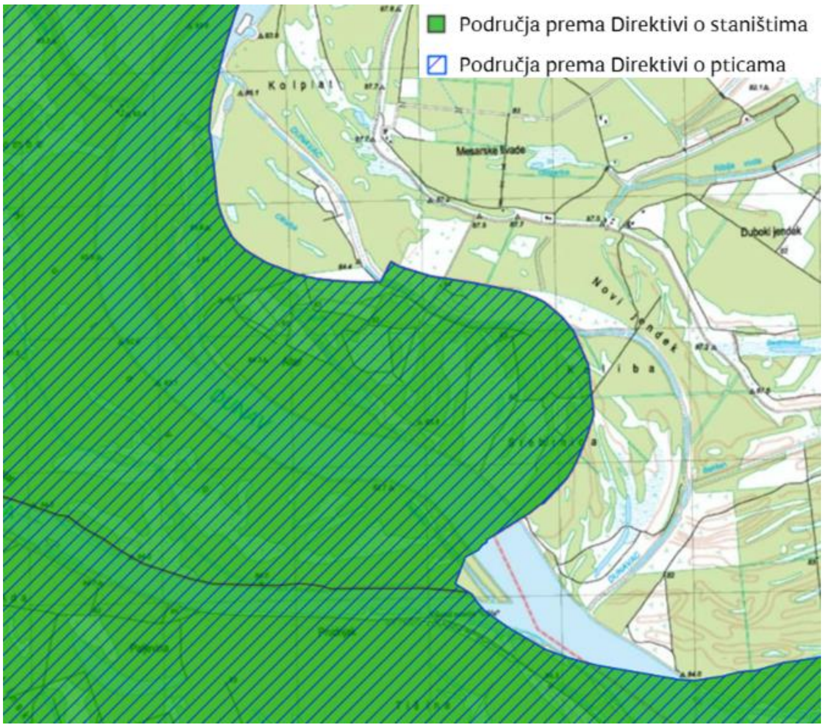


Figure 17 -Drava Confluence - Natura 2000 protected zones

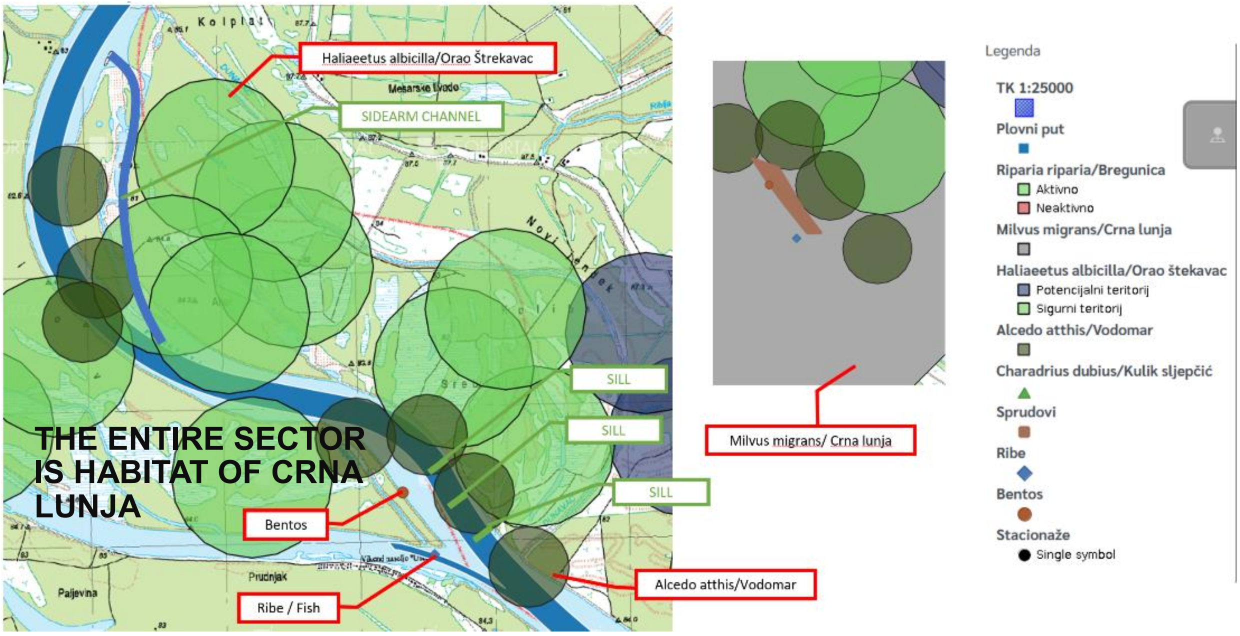


Figure 18 -Drava Confluence - Screenshot of the GIS map with results of the environmental screening

3.2.4 Staklar km 1376.8 to 1373.4 – Sector 6

Staklar is a sector characterised by a long, sharp curve. A navigation bottleneck occurs at the sector entrance, where a large sandbar has formed, restricting the fairway width and impacting navigation safety. The cross-sections in Figure 19 show the volatile nature of the riverbed in the zone before the deflection and the stable riverbed after.

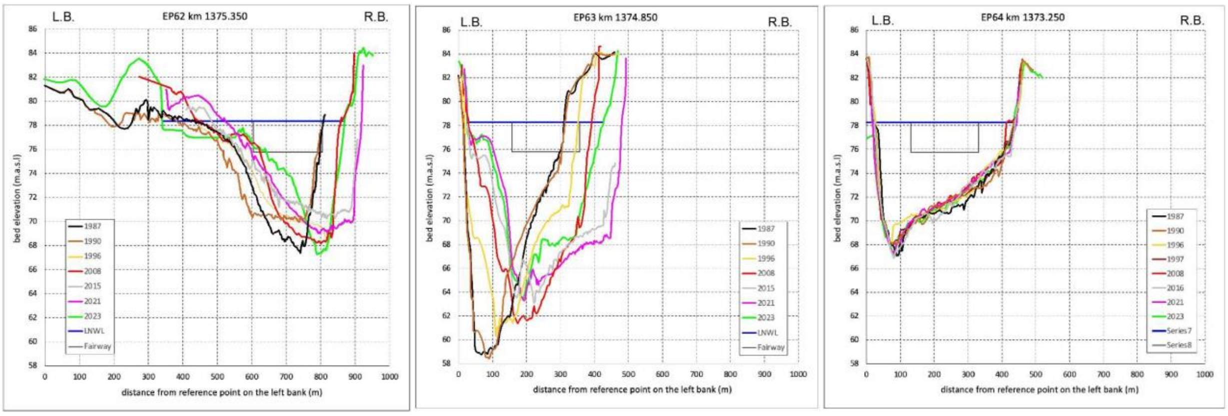


Figure 19 - EP 62 Km 1375.350, EP 63 Km 1374.850 and EP 64 Km 1373.250

The analysis of historical river structures (Table 6) and cross-section development confirms that the implemented sills have significantly contributed to downstream stability, effectively securing the riverbed over time. This positive impact serves as a foundation for the bottleneck resolution strategy.

Table 6 - Staklar - The list of the executed structures on a Right and Left riverbank

Left Riverbank				Right Riverbank			
r.b.	Station	Object type	Length (m)	Station	Object type	Length (m)	Height (mnm)
34	1374+200	Sills	70.50/63.8				
35	1373+980	Sills	46.50				
36	1373+890	Sills	56.00				
37	1373+790	Sills	34.50				
38	1373+700	Sills	46.5/18				

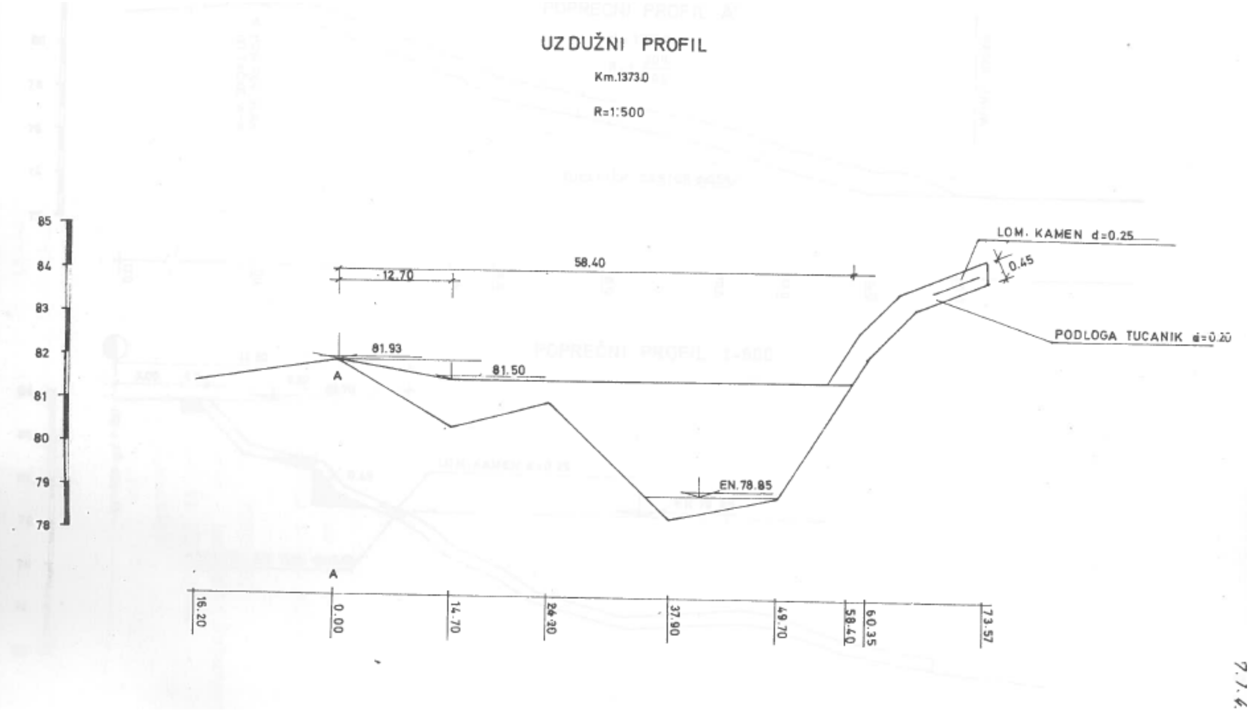


Figure 20 - Longitudinal cross-section of the submerged sill on the Staklar sector

The location of the sills is given on the sector map – Figure 21.

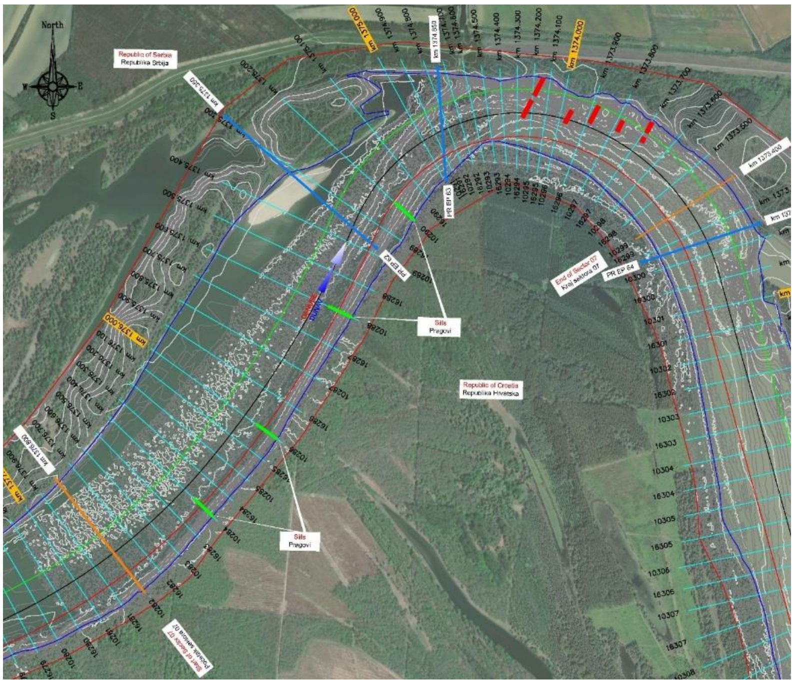


Figure 21 - Staklar – map of the sector with location of the sills

The site proposed for the structural measures is located within protected areas in Serbia and Croatia (Figure 22 and 23), including the Gornje Podunavlje Special Nature Reserve and the Natura 2000 site Dunav_Vukovar(HR2000372).

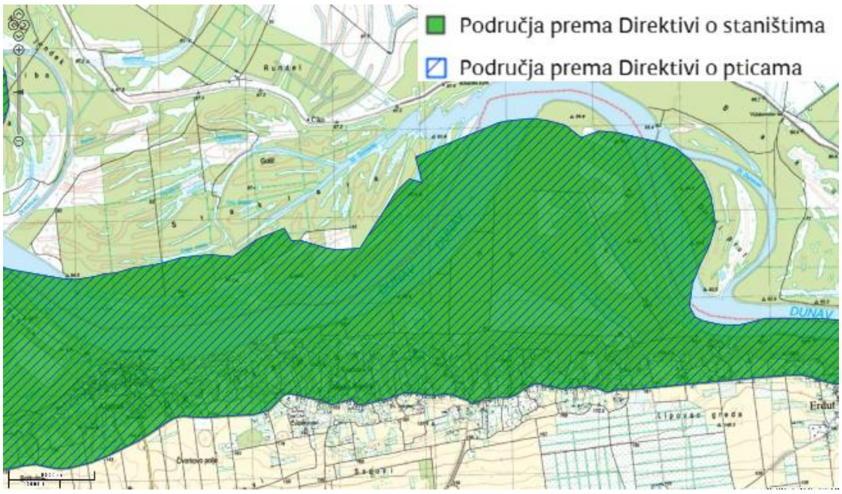


Figure 22 - Staklar – Natura 2000 protected zones

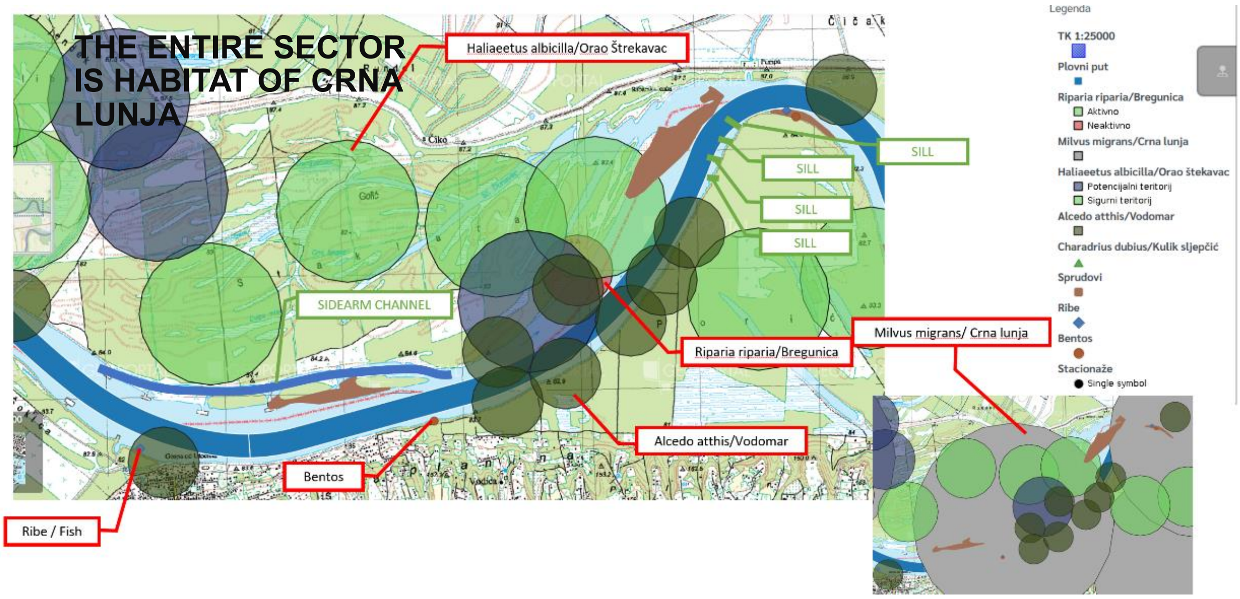


Figure 23 - Staklar - Screenshot of the GIS map with results of the environmental screening

4 PROPOSED RIVER TRAINING STRUCTURES WITHIN SCENARIOS

4.1 Description of suitable structures per location

4.1.1 Apatin km 1,408.2 – 1,400.0 – Sector 3

As detailed in a previous chapter, the Apatin sector presents two critical locations. The first features a restless, permanently active sandbar that periodically disrupts navigation. The second is a highly narrow stretch along the river band, characterized by a sandbar forming along the concave right riverbank. Both locations lie within sensitive, nature-protected areas and require carefully selected measures to improve flow conditions and sediment transportation, while minimizing adverse impacts on the natural environment.

Chapter 1.4 elaborates on the importance and distinctions between traditional and contemporary river training approaches. It also highlights the positive and adverse impacts of the nature-inclusive structures under consideration. Accordingly, the consultant presents a balanced assessment of the chosen measures, outlining their respective pros and cons regarding navigation and environmental performance.

For the sandbar between km 1405.4 and km 1403.0, the proposed structural intervention comprises a combination of two chevrons placed on the sandbar (see Figure 24). This nature-inclusive approach is favoured over traditional groynes, which are typically used in such situations.

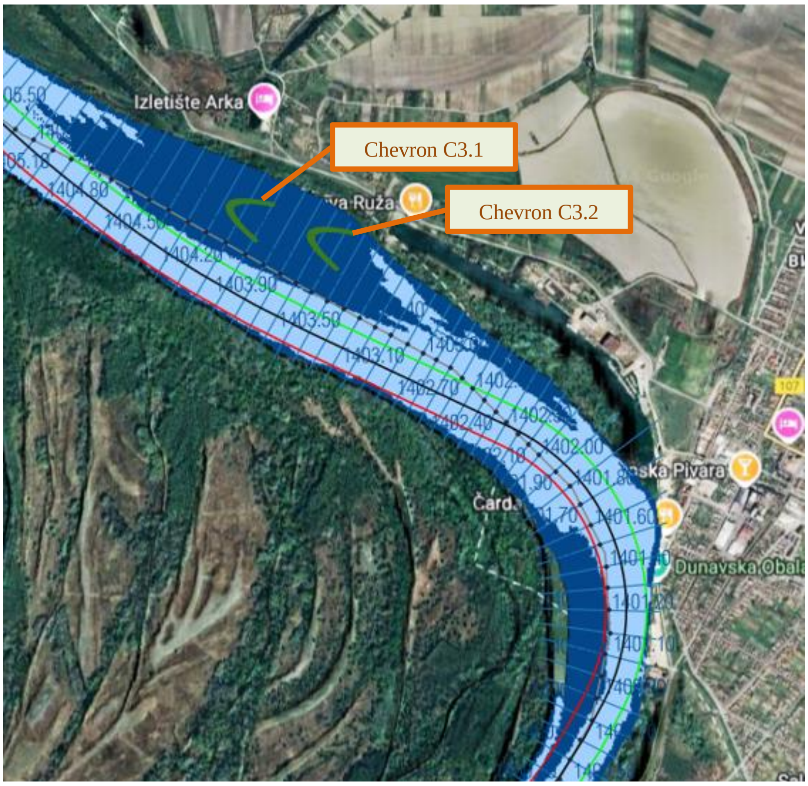


Figure 24 - Apatin km 1405.4 and km 1403.0 combination of two chevrons envisaged for stabilisation of the sandbar and improvement of navigational conditions

The chevron is a relatively new river training structure on the Danube. Over the past ten years, chevrons have been constructed on the Serbian stretch of the river; however, comprehensive studies evaluating their long-term efficiency and impact remain limited.

One of the most notable chevron structure was built near Futog between 2018 and 2019. Figure 25 presents a satellite view of this chevron, highlighting its layout and seamless integration into the river system.

Figure 25 - Chevron top view constructed in sector Futog, Serbia

Despite limited historical data, chevrons are emerging as a promising alternative thanks to their ability to:

- Influence flow patterns, thereby enhancing navigation conditions

- Promote beneficial sediment deposition behind the structure
- Reduce environmental impacts compared to traditional groins

Further monitoring and detailed modelling efforts will be essential to quantify their effectiveness and optimize their design and implementation in future river training projects.

The second critical location on the Apatin stretch is a sandbar positioned along the right riverbank. This sandbar, known as a Bentos zone, plays a crucial role for the microflora, fauna, and other organisms inhabiting the riverbed. To eliminate bottlenecks and ensure a stable fairway in this area, structural measures have been proposed. While dredging might provide optimal navigational conditions, it would significantly harm the benthic habitat. Therefore, the solution consists of installing a series of sills along the thalweg (the line of maximum depths) to facilitate sandbar transformation and widen the navigation channel.

Figure 26 illustrates the proposed positions for the sills.

The dredging route, if deemed necessary later on, will be determined after the sills have been in place for at least six months, allowing sufficient time to assess their impact. Given the sandbar's vulnerability and the sensitivity of the entire stretch, these measures must be carefully planned in collaboration with environmental experts.

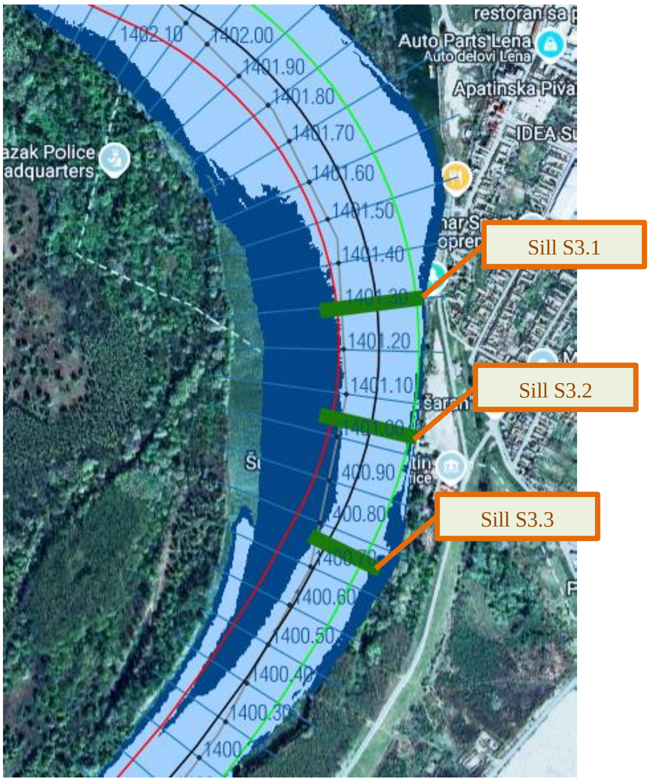


Figure 26 - Proposed position for three sills on an Apatin sector; Sill S3.1, S3.2 and S3.3

As previously mentioned, hydraulic modelling will determine the sills' final shape, its crest depth, and height from the river bed.

4.1.1.1 Chevron Structure – Design and Construction

The typical shape of a chevron resembles a horseshoe. This structure is primarily composed of crushed stone and has sizes ranging from 15 to 45 cm.

Technical Characteristics

Table 7 - Summary of the technical characteristics of the chevron

Crown Width:	Same as the groin (1m)
Slopes:	Upstream face slope: 1:2 Downstream face slope: 1:3
Height Considerations:	Similar to groins, the optimal height of a chevron is not mathematically determined. Traditionally, the height is based on experience rather than calculations, often aligning with a low navigation Water level +1m.

One key advantage of chevrons is that they are often constructed on sandbars. This reduces the amount of material required for construction compared to other river training structures.

Figure 27 illustrates the technical details of a typical chevron, including slope ratios, material composition, and layout within the river system.

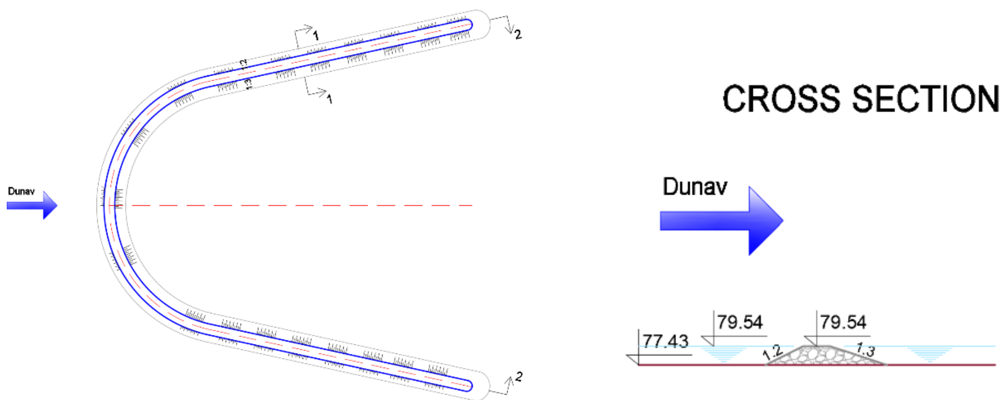


Figure 27 - Top view and typical cross-section; upward slope is 1:2 and downward slope is 1:3; the crown width is 1m

4.1.1.2 Sill Structure – Design and Construction

A sill is a submerged hydro-technical structure designed explicitly for river regulation. Depending on its intended function, a sill can serve a dual role. Traditionally, sills were used as barriers in shallow branches to hinder river flow at certain levels, thereby promoting distribution of flow through alternative channels. Additionally, they function to prevent deepening scours in the riverbed and to redistribute water across the channel. When placed in deeper sections, sills help prevent further erosion and adjust the shape of the cross-section in the affected zone. According to the literature, the application of sills increases water velocities locally, which can lead to lateral erosion and a widening of the riverbed, which is a desired morphological effect.

Because a sill is submerged, its height is not predetermined but rather calculated based on the requirements for water redistribution, the specific characteristics of the river system, and the desired hydraulic effects. Figure 28 illustrates the typical construction elements of a sill, including details on its design and positioning within the riverbed.

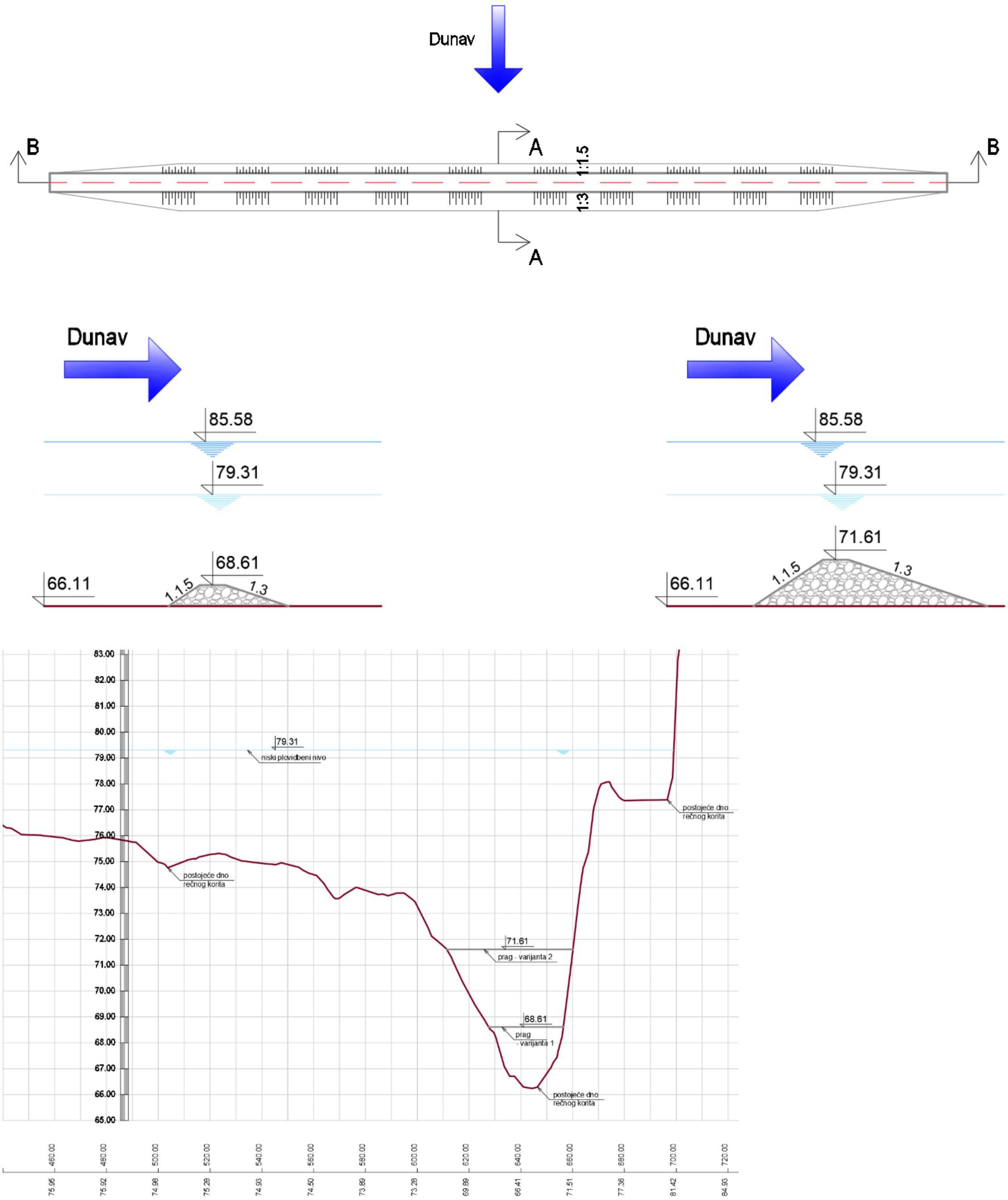


Figure 28 Top view and typical cross-section for two different variants; upstream slope is 1:2 and downstream slope is 1:3; the crown width is 1m

4.1.2 Civutski/Zidovski Rukavac (km 1397.2 – 1389.0) – Sector 4

As outlined in Chapter 3, Assessment of Current Issues, the Civutski/Zidovski rukavac stretch is characterized by a narrow riverbed and persistent sandbars that create navigation bottlenecks at four critical locations. From a river engineering perspective, this presents a complex challenge, further compounded by the environmental constraints inherent in a nature-protected area. Consequently, the proposed measures must simultaneously satisfy both navigational and ecological requirements. To address these challenges, the consultant has identified three possible engineering strategies to mitigate the bottlenecks:

- **Bedload Management:** Reducing suspended bedload from the upstream flow before it reaches the critical bottleneck zone.

- **Flow Concentration:** Constructing structural elements to concentrate the flow and consequently increase shear stress within the bottleneck area and,

- **Riverbed Widening:** Expanding the riverbed in the contraction zone to reduce local flow concentration (a standard measure under such conditions and objectives).

After thorough analysis and discussions with waterway administrations, it was decided to test a detached groyne in the river band where the water flow disperses. The current sediment transport balance has created four convenient locations for bedload deposition, which led the consultant to propose and prepare for modeling a detached groyne at km 1393.45, (see figure 29) specifically designed to facilitate bedload transport.

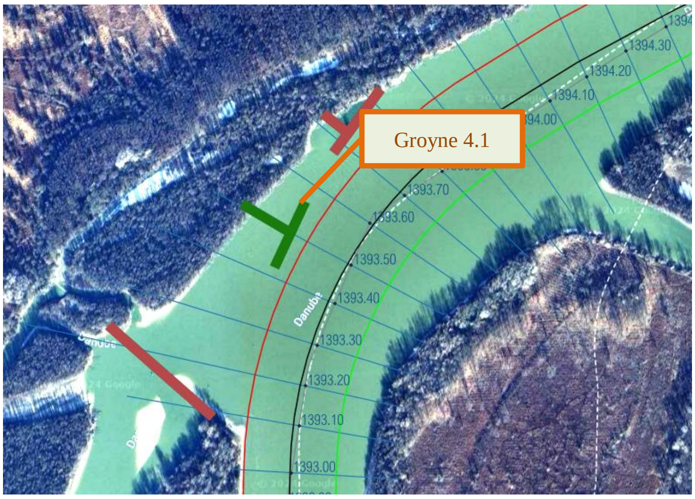


Figure 29 - The Danube River km 1393.5 – location of the newly proposed groyne (green) between two existing structures (red)

4.1.2.1 Detached Groyne Structure – Design and Construction

Groynes are the most used hydraulic structures on the Danube. When viewed from above, they are typically T-shaped, as shown in Figure 30.

Key characteristics of groins are that they are always constructed in groups of three or more. This arrangement maximises their functionality and the river's water, sediment, and ice transport capacity.

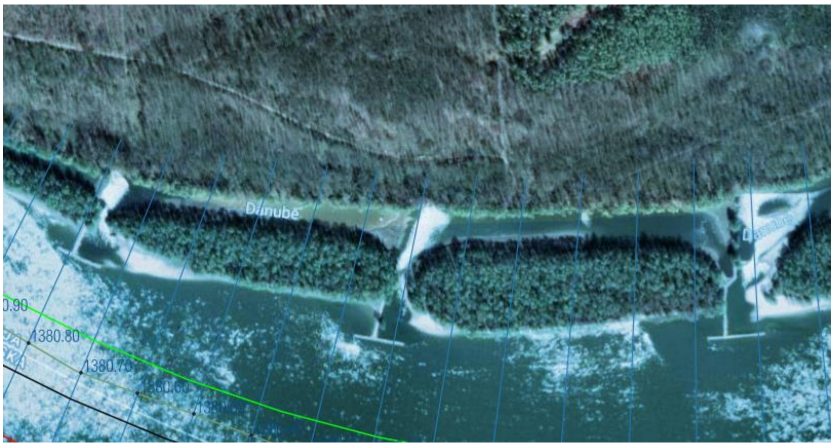


Figure 30 - Satellite image of the groyne field

To address rising ecological concerns, the engineers recently developed detached groynes, which are more nature-inclusive and eco-friendly. The trenched channel on the back of the groyne enables the genesis of small, connected ponds between the riverbank and sand deposits in the groyne fields. In this way, the barrier for aquatic organisms is removed, and new spawning and nursery habitats are created. Over time, the sedimented groyne fields will become a benthic zone for aquatic flora and fauna.

Technical Characteristics

Table 8 Summary of the technical characteristics of the detached groyne

Crown Width:	1m
Slopes:	Upstream face slope: 1:2 Downstream face slope: 1:3
Height Considerations:	Low Navigation Water Level (LNWL) +1m.

The structure's body is built using smaller stone fractions (15–45 cm), while the top layer is finished with stones up to 63 cm.

The height of groyns on the Danube corresponds to the Low Navigation Water Level (LNWL) + 1m. These measures are based on safety requirements which are prescribed for incised riverbeds. The height of the structures is related to their visibility during the periods when the water surface elevation is close to the LNWL.

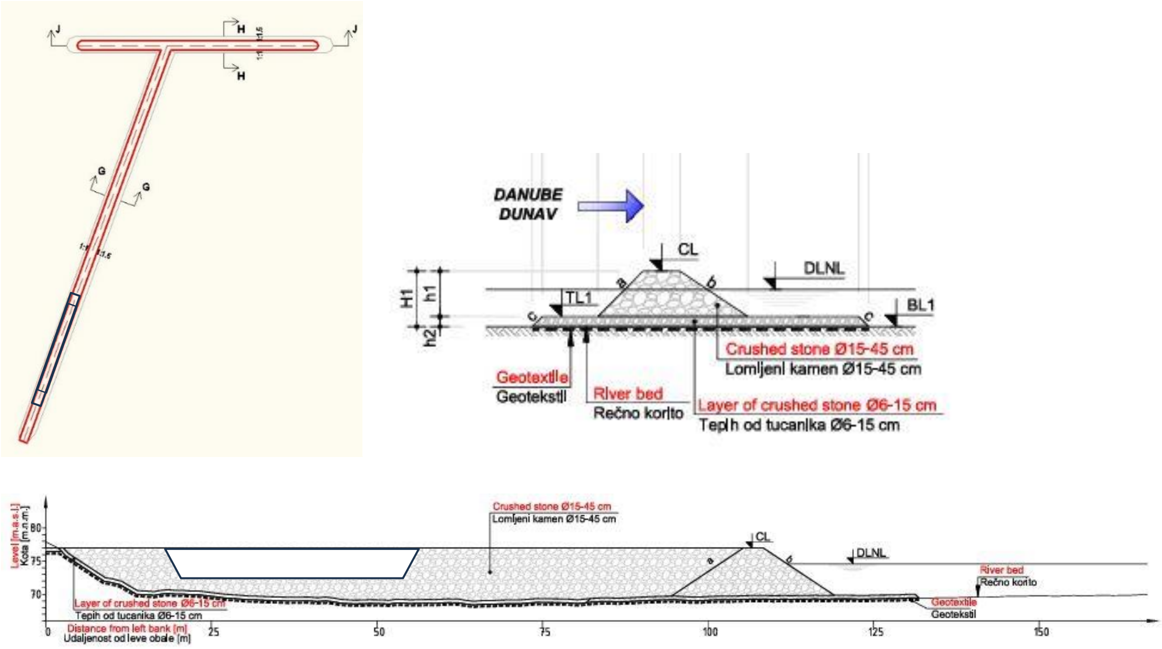


Figure 31 - The detached T-shaped groyne – characteristic top view, and two cross-sections

4.1.3 Drava Confluence (km 1388.8 – 1382.0) – Sector 5

The engineering strategies developed for Civutski/Zidovski Rukavac are also applicable to the Drava Confluence, although the hydraulic complexity at the confluence necessitates a combined approach.

The proposed solution integrates two measures addressing different physical mechanisms in bedload transportation. Figure 32 illustrates the recommended interventions for the Drava Confluence sector, which include a sidearm channel along the left riverbank (from km 1387.8 to km 1385.65) paired with the construction of three sills upstream of the confluence.

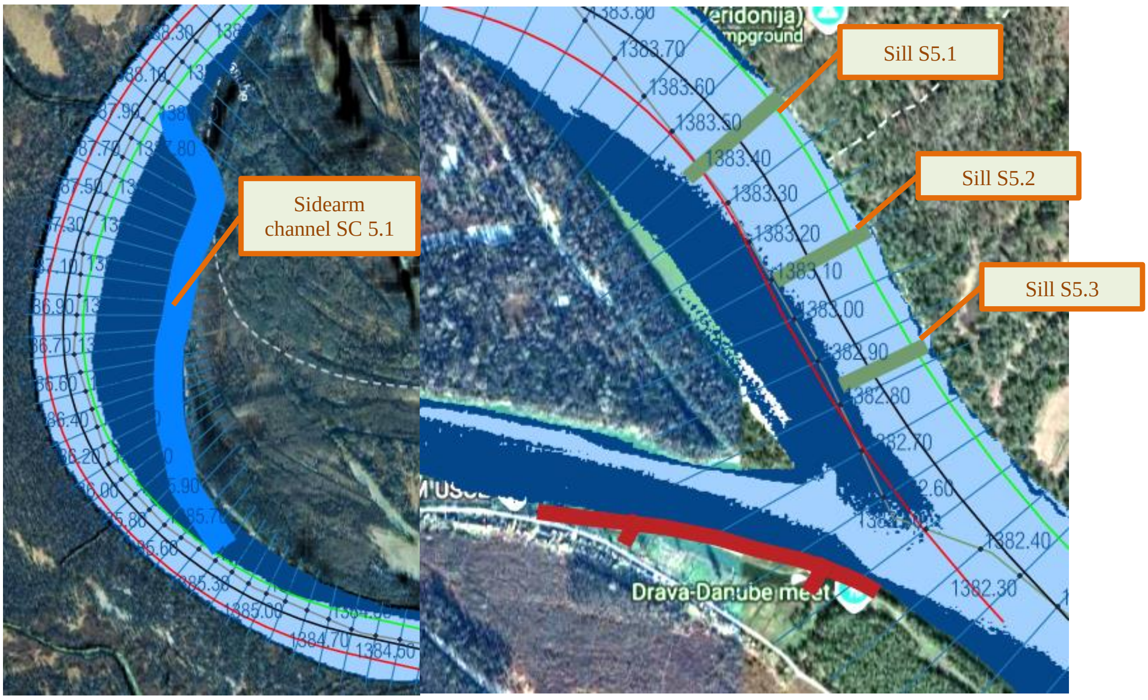


Figure 32 - The map of the structural measures envisaged for the Drava Confluence Sector – Sidearm channel 5.1 and Sills 5.1, 5.2 and 5.3

The details related to the sills are already presented in chapter 4.1.1.2, so it will not be repeated.

4.1.3.1 The sidearm channel – Design and Construction

The sidearm channel is one of the proposed restoration measures. At this level of the documentation development, it is known that the channel cross-section will be trapezoidal, with the slopes 1:1. The longitudinal slope of the channel will follow the slope of the riverbed in the main channel.

Technical Characteristics

Table 9 Summary of technical characteristics of the sidearm channel

Channel Width:	The model will calculate the channel width. 60m is the initial value
Channel Bank Slopes:	Lateral channel bank slope: 1:1
Channel slope	The channel slope will follow the slope of the main channel
Channel Bank Protection	The channel bank slopes will be protected by the stones, dominantly by the stones taken over from the groynes;

The slopes will be protected with stones excavated from the groynes' bodies. The channel bottom will be natural, partially covered by the surplus stones from the groynes.

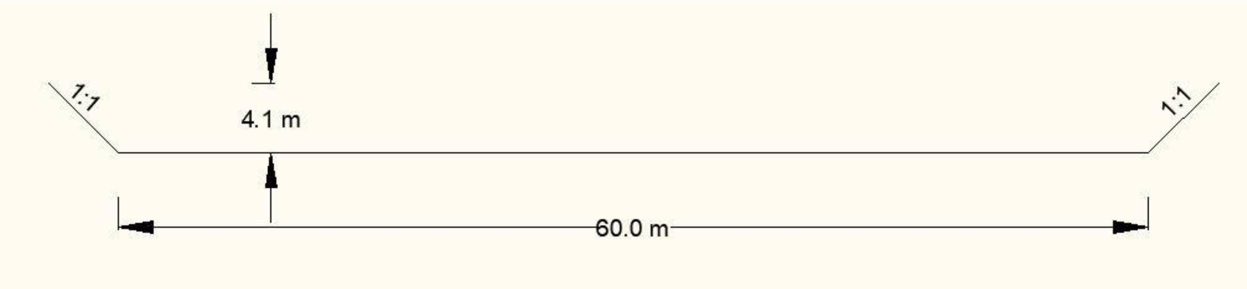


Figure 33 Typical cross-section of the envisaged channel

The channel width will be calculated using the model. The condition that must be satisfied is that the suspended load in the main channel should be deposited. Accordingly, to the first preliminary drawings, the total depth of the channel will be 4.1m.

The channel route for excavation is envisaged in the groyne field shown in Figure 34.

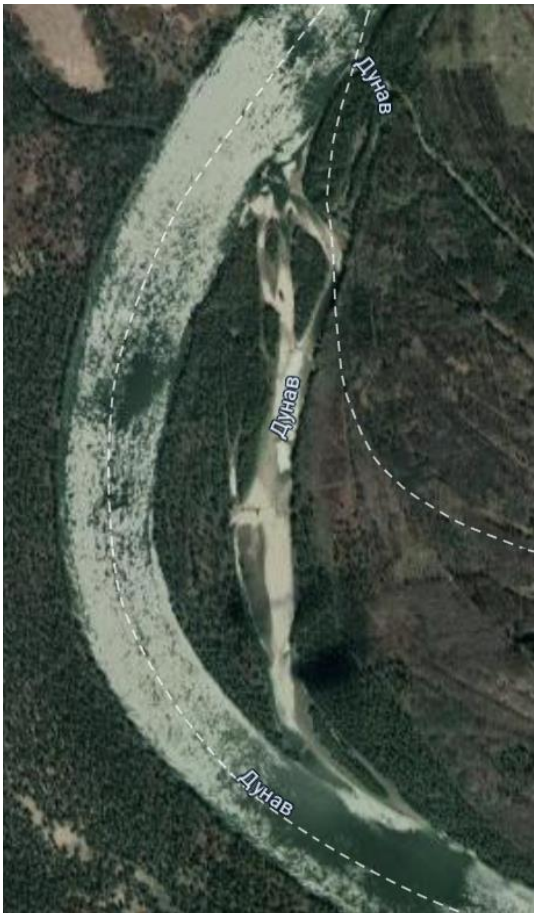
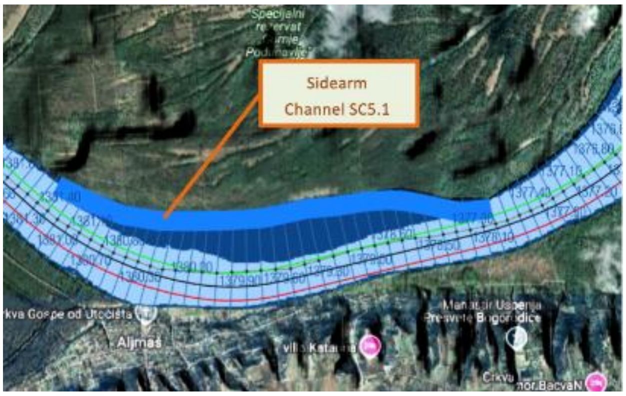


Figure 34 The Groyne field envisaged for restoration

4.1.4 Staklar km 1376.8 to 1373.4 – Sector 6

The historical analysis of river structures and the development of cross-sections confirm that the implemented sills have significantly contributed to downstream stability, effectively stabilizing the riverbed over time. This positive performance underpins the overall bottleneck resolution strategy.

In terms of bedload management, a sidearm channel trench has been designed for the Aljmas sector, while sills have been strategically placed at the Staklar band entrance to concentrate and redistribute water flow. The proposed measures, including the locations of the sidearm channel and the sills, are detailed in Figure 33.



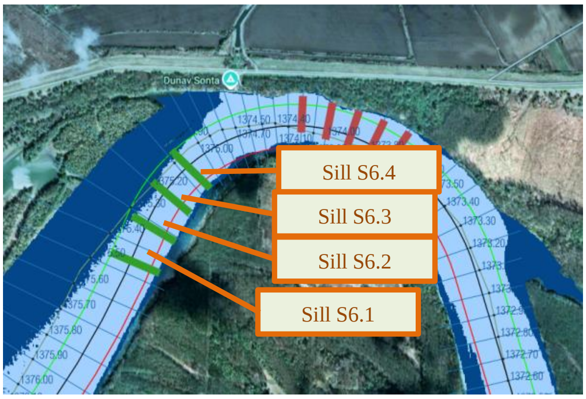


Figure 35 - The locations envisaged for the sidearm channel trenching and construction of the sills on the Staklar section

The details related to the channel and sills are already presented in chapters 4.1.3.1 and 4.1.1.2, so it will not be repeated.

4.2 Justification for each measure (environmental, morphological)

4.2.1 Apatin km 1,408.2 – 1,400.0 – Sector 3

The purpose of the envisaged chevrons is to smoothly redirect water into the main channel and stabilise the sandbar. Concurrently, part of the water flow will be directed towards the riverbank, making a river branch.

The expected result of this structural intervention from the navigational perspective are:

- Widening of the main channel where is the navigational fairway;
- Stabilisation of the sandbar and preventing further alternations.

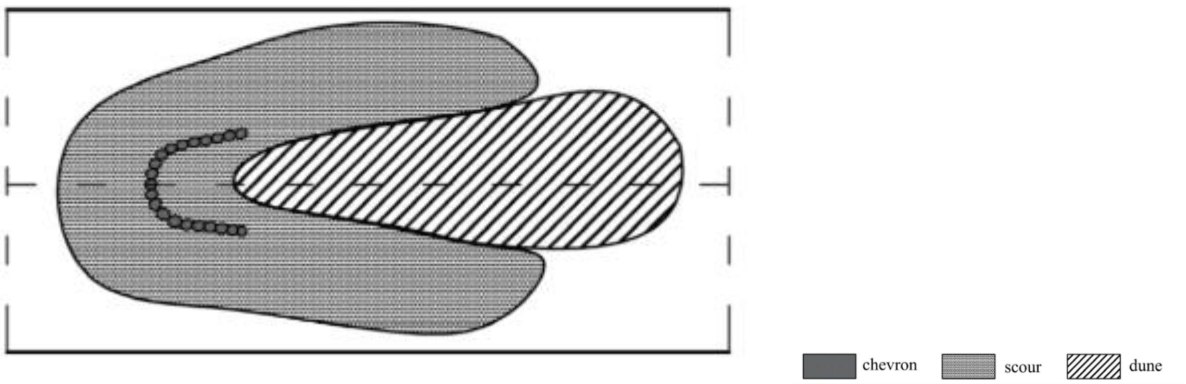


Figure 36 - The expected effects of placing the chevron in the riverbed with a riverbed composed of the material which is mixture of the silt and fine sand

From an environmental perspective, the primary goal of the proposed measures is to minimize habitat destruction. This approach aims to sustain natural sediment dynamics that foster spawning and nursery habitats, as well as safe refuge zones.

In the long term, constructing chevrons may promote the formation of new river islands and shelters, thereby creating diverse habitats that benefit species such as herons, cormorants, and other waterfowl. These new hydraulic features could present both challenges and opportunities for aquatic biota. For example, fish species—including *Aspius aspius*, *Barbus barbus*, *Chondrostoma nasus*, and *Squalius cephalus*—often rely on varying flow conditions for spawning and feeding. The increased flow heterogeneity provided by well-designed chevrons and sills may create additional microhabitats that support different life stages of fish.

Moreover, ecological considerations are integrated into the design by ensuring riverine connectivity, maintaining shallow water zones, and avoiding uniform channelization. These measures not only support improved navigation but also promote long-term ecological health. It is essential to also restrict construction activities during the spawning season of protected and strictly protected species such as Aspius aspius, Gymnocephalus balonii, Leuciscus idus, and Squalius cephalus, to prevent undue disturbances.

4.2.2 Civutski/Zidovski Rukavac (km 1397.2 – 1389.0) – Sector 4

From an engineering perspective, the proposed detached groyne is intended to reshape the sediment transportation balance and generate additional shear forces. Its primary goal is to address the bottlenecks at km 1390.9 by increasing pressure on the sandbars in that zone, thereby improving navigational conditions. While the exact outcome of this intervention remains uncertain, the Civutski/Zidovski rukavac sector has experienced numerous navigational challenges, and the navigation authorities would welcome any effective measure to alleviate these issues.

From an environmental standpoint, the area targeted for the detached groyne is identified as a critical fish habitat (see Figure 37). This designation underscores the need for careful ecological consideration throughout the design and implementation process to ensure that any intervention does not adversely affect the local aquatic biodiversity.

Figure 37 - The fragment from the GIS prepared by the Croatian consortia related to the Civutski/Zidovski rukavac and habitats of the wild spices, which are captured in this zone

The planned construction of an additional groyne on the right bank of the Čivutski Rukavac section, situated between two existing structures, is aimed at improving local navigation conditions by stabilizing the riverbank and optimizing the water flow. This area holds high ecological value—it serves as an important wintering site for diverse waterfowl and functions as a breeding area for various bird species, similar to the upstream sector. However, the construction activities, as well as the temporary disturbance they cause, could potentially impact the local bird populations. To mitigate these short-term effects, it is advisable to schedule construction outside the breeding season and the main winter months, while also maintaining undisturbed zones in close proximity to the work area.

From an ichthyological perspective, the sector's unique hydromorphological characteristics support both rheophilic (current-loving) and limnophilic (stillwater-preferring) fish species. The installation of the groyne is expected to modify local hydraulic conditions by increasing flow velocity in its immediate vicinity and creating zones of lower flow within the groyne field. This hydrodynamic variability can enhance habitat diversity and support different life stages of fish—from spawning to juvenile development. For rheophilic species, improved flow velocity can enhance oxygenation and the availability of spawning substrates, while limnophilic species may benefit from the calmer, shallow waters provided by the groyne field as refuges or nursery areas.

To ensure that the new groyne contributes positively to both navigation and biodiversity, ecological considerations should be integrated into the design. This includes accounting for sediment deposition patterns to promote the formation of natural islands and shallow habitats. Additionally, continuous monitoring of bird and fish populations both before and after construction will be essential for adaptive management, ensuring that any environmental impacts are identified and mitigated promptly to maintain the ecological integrity of this sensitive and valuable section of the Danube River.

4.2.3 Drava Confluence (km 1388.8 – 1382.0) – Sector 5

The proposed sidearm channel is designed to split the water course into two streams. The existing riverbed becomes the main channel, which remains the same size, but the sidearm channel takes over the amount of water and decreases the discharge and velocities in the main riverbed. This action reduces the discharge and velocities in the main channel and consequently stimulates bedload sedimentation. The negative consequences of this measure might be the sidearm siltation, particularly in the zones of the channel mouth and its confluence to the main channel. The generated sediment thresholds may severely affect the channel function and envisaged siltation mechanism.

The reduction in suspended load enhances the water's ability to erode downstream deposits, which is the primary objective of this measure. To support this process, three additional sills have been designed to redistribute the flow in the main channel and reshape the sandbar along the right riverbank.

While mixing of the two water flows at the channel confluence generates turbulence and continuous riverbed morphology changes, these effects are common in most confluences. However, hydraulic modelling remains essential to assess the impacts on:

- Flow patterns
- Sediment transport
- Riverbed morphology changes

From an environmental perspective, the sidearm channel trenching is considered a restoration measure that benefits both navigation and the ecosystem. The intervention, which involves breaching existing groynes (Figure 34) to reopen the side channel upstream of the Drava estuary combined with the installation of new sills on the left bank, aims to improve navigation through enhanced flow distribution and fairway stability.

Ecologically, reopening the side channel can reestablish the lateral connection between the main river and its tributaries, improving habitat diversity. This connectivity is particularly beneficial for fish species such as Rutilus virgo, Chondrostoma nasus, Squalius cephalus, and Cobitis elongatoides, which depend on side channels for spawning, feeding, or refuge during high water levels. Restoring natural flow in these channels may also reduce stagnation and enhance water quality, thereby supporting aquatic invertebrates and macrophytes that form the base of the food web.

Nevertheless, the modification of existing groynes and addition of sills could temporarily alter local hydraulic conditions, sediment transport, and flow regimes. Such changes might impact habitats used by certain fish species and waterbirds, especially if construction occurs during sensitive periods such as spawning or breeding seasons. By incorporating ecological considerations during planning—such as preserving shallow water zones, ensuring gentle gradients, and maintaining continuous flow paths—the structures can be designed to promote both improved navigation and biodiversity. In the long term, these measures may create new microhabitats and establish better conditions for both rheophilic and limnophilic species, contributing to a dynamic and resilient river ecosystem.

4.2.4 Staklar km 1376.8 to 1373.4 – Sector 6

The issues related to the Staklar band and sandbar located along the left riverbank are already described and envisaged measures proposed, so the expected effects of this measures and its pros and cons will be elaborated in this chapter.

Since submerged sills have proven effective in downstream areas, the approach will be extended by constructing four additional sills. The idea behind this is to increase sandbar shear stress and enhance the curve entrance's transport capacity. Additionally, on the Aljmas sector, km 1382.3 to km 1376.8, one more sidearm channel is designed as an upstream intervention with the goal of reducing bedload availability, and minimising sedimentation along the sandbar, and lowering the demand for transport capacity. The effectiveness of these measures will be assessed after the modelling.

The expected effects on the surrounding nature are considered and analysed. In order to improve navigation conditions in the Danube section near Aljmaš, the proposed measures focus on non-structural interventions— in particular the partial removal of existing groynes and the reactivation of a side arm channel. In contrast to the construction of new structures, these measures aim to restore more natural hydromorphological dynamics by improving the flow distribution and restoring the lateral connection between the main channel and its floodplain.

From an ecological point of view, these measures can have a particularly positive impact on the local wildlife. The opening of the side arm channel can improve the diversity of aquatic habitats and provide valuable spawning, feeding and refuge areas for various fish species, including both rheophilic (*Alburnus sava, Aspius aspius*) and limnophilic species (*Esox lucius, Cobitis elongata*). Increased water exchange and greater current variability can improve water quality and oxygen levels, promoting a richer benthic community and healthier fish populations. The reconnected side channel can also attract bird species, particularly waterfowl and waders, as it provides undisturbed shallow water zones ideal for foraging and resting.

In addition, the removal or modification of existing groynes can help to reduce current stagnation and sediment accumulation in certain areas, creating more dynamic habitat conditions that benefit a wider range of aquatic organisms. As these interventions are consistent with the principles of natural river restoration, they offer a rare opportunity to improve navigation while enhancing ecological functions — provided that implementation is carefully planned and timed to avoid sensitive periods such as fish spawning and bird breeding seasons.

At the Staklar site, which is located in the uppermost part of a pronounced bend in the Danube, a series of four sills have already been constructed along the left bank to improve navigation by stabilising the navigation channel and controlling sediment transport. As an additional measure, the construction of three more sills is proposed on the right bank, directly upstream of the bend, is proposed. It is expected that these measures will optimise the concentration of the current and the alignment of the navigation channel, which is essential for safe and efficient navigation in this dynamic section of the river.

From an ecological perspective, the sills will not benefit a local biota, particularly. The sills present a local discontinuity for the fish swimming upstream in its migration. We assume that this discontinuity will affect some fish species and that they will easily adapt to the new modified habitat. Also, the sill creates a shallow water zones and pools on the upstream side (backwater effect) and a zone with intensive turbidity in the downstream zone that will be used by fish species for wintering habitats and feeding as well. On the other hand, the local turbulence will affect the benthic aquatic organisms, mostly aquatic insect larvae, while other representatives will recover in some extent. The birds and other biodiversity elements would not be affected by this measure.

5 SCENARIO DEVELOPMENT AND COMPARISON

5.1 Scenario 1: Baseline ("Do Nothing")

This scenario is the benchmark for evaluating the effectiveness of all other scenarios. The “do nothing” scenario will show how morphological changes develop starting from the current state without any activities. It will be modelled as all other scenarios to understand the future trajectory of the observed stretch without modifications. The results will offer insights into the section's potential "improvement" or deterioration over time. Figure 38 illustrates the flow patterns gained by the 2D modelling and the results of the modelling. Detailed analysis of the results achieved by the modelling will be presented in the next book, which will present the results of the modelling and Multi-Criteria Analysis.

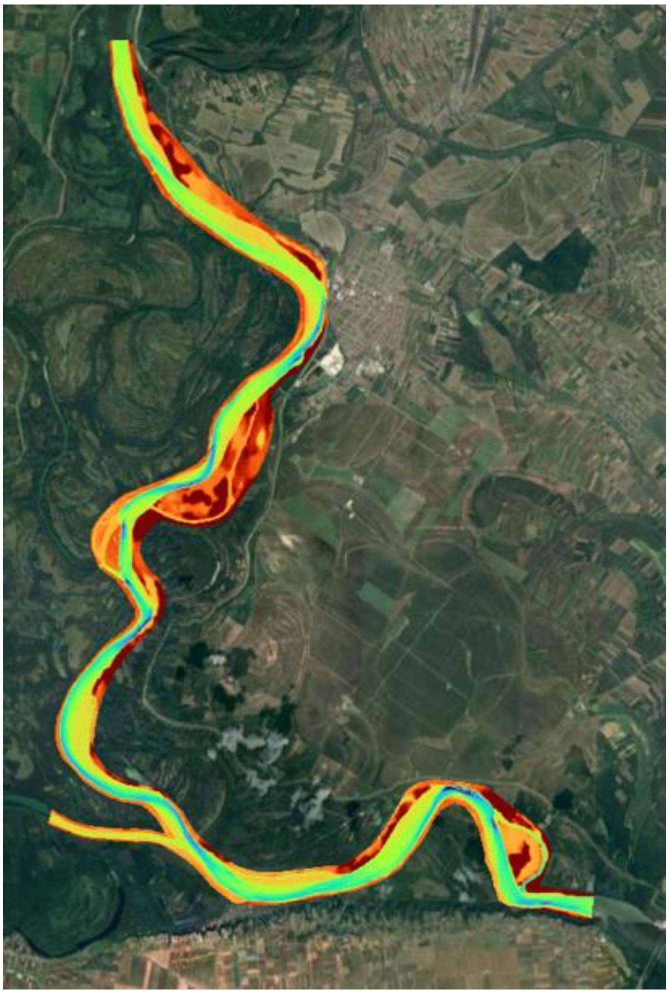


Figure 38 - The overview of the model results for the "Do Nothing" scenario

5.2 Scenario 2: structural and revitalisation measures

This scenario focuses on the non-traditional structural measures to address the bottlenecks in key sectors like Apatin and Drava Confluence. This scenario considers non-traditional structural measures that place equal focus on improving indicators related to navigation and environmental protection criteria. The measures in Scenario 2 will be analysed using the following codification system to understand better and track the proposed solutions:

- C for Chevron
- S for Sill
- SC for Sidearm trenching
- G for Groyne

The sector number and structure number will follow the codification. For example, C3.1 refers to Chevron (C) in sector 3 (Apatin), structure number 1.

Figure 39 illustrates the sectors affected by the structural measures and the type of structural measure.

Figure 39 - Map of the locations and proposed nature-inclusive measures

Table 10 summarises the proposed measures per sector.

Table 10 - List of the proposed structures in Scenario 2

Apatin	
Chevrons	C3.1
	C3.2
Sills	S3.1
	S3.1
	S3.1
Civutski/Zidovski rukavac	
Sidearm dredging	SC 4.1
Aljmas	
Sidearm dredging	SC5.1

Within Scenario 2—Structural and revitalisation measures, the consultant has developed two separate sub-scenarios aiming to optimise proposed measures and present to the investors a comprehensive analysis of structure variants encompassed by Scenario 2.

Sub-scenario 1 of Scenario 2 is a flow analysis of the sector Apatin with only one chevron, where the second chevron is removed.

Sub-scenario 2 of Scenario 2 is designed to explore flow and sediment transportation conditions when the height of the sills is varied.

The definitive version of the scenario used in MCA is the optimal version selected among all sub-scenarios.

5.3 Scenario 3: Navigational fairway realignment (minimal intervention approach)

Scenario 1 - "Do Nothing" is designed as a benchmark scenario without intervention. Scenario 3 is envisioned as a business-as-usual scenario, comprising adjustments in the fairway over time. This scenario aims to optimize fairway without large-scale physical interventions.

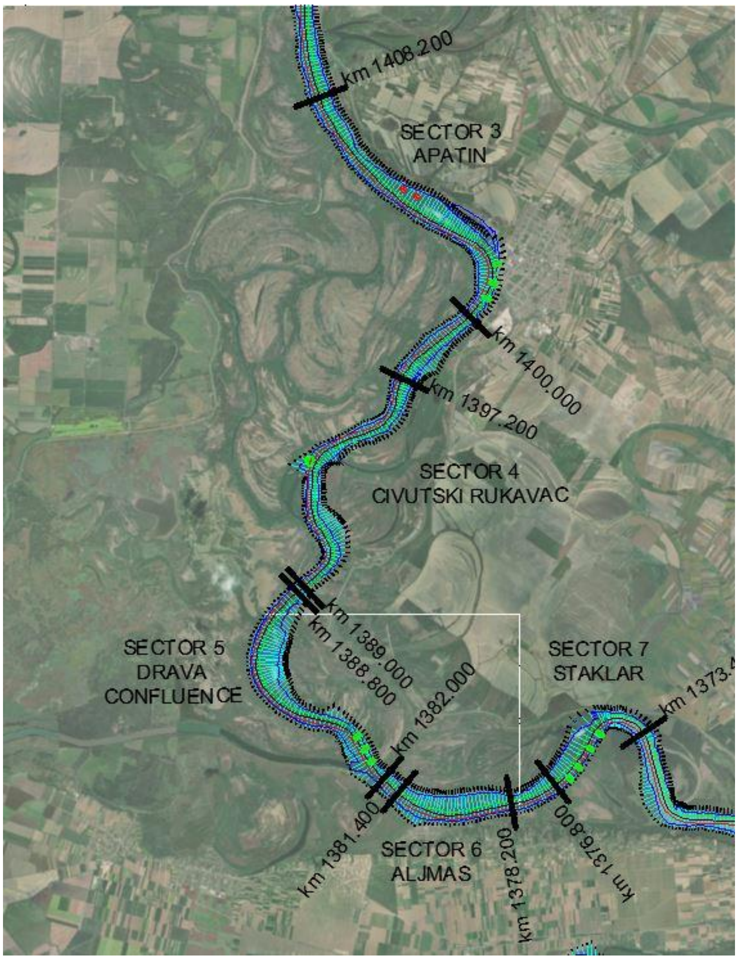
5.4 Scenario 4: Full structural intervention (comprehensive measures)

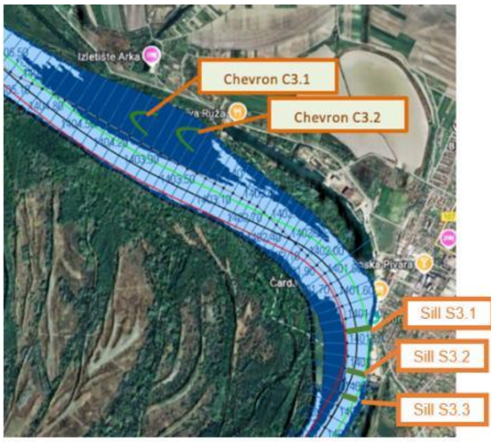
This scenario includes only structural measures. It will consider more traditional structural measures combined with the nature-inclusive measures proposed in Scenario 2. This scenario contains the structural measures envisioned for Civutski/Zidovski rukavac and for sector Staklar. Table 11 contains a breakdown of Scenario 4 proposed measures.

Table 11 - The list of training structures envisaged for model testing in Scenario 4

Apatin	
Chevrons	C3.1
	C3.2
Sills	S3.1
	S3.1
	S3.1
	S3.1
Civutski/Zidovski rukavac	
Groin	G4.1

Staklar	
Sills	S6.1
	S6.2
	S6.3
	S6.4





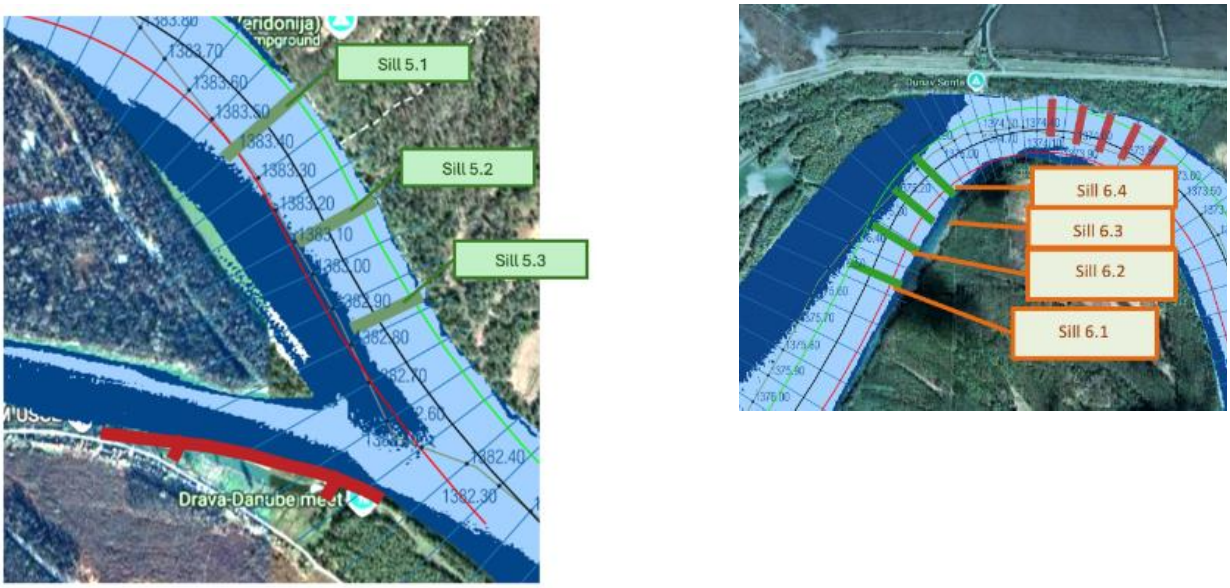


Figure 40 - Scenario 4 – overview of the proposed structural measures on the a) Apatin , B) Civutski / Zidovski rukavac, C) Drava Confluence and D) Staklar

Since Scenario 4 consists of 11 training structures, six sub-scenarios for system optimisation are planned. Two of them are repeated sub-scenarios developed on the Apatin sector, and the remaining four are linked to the variants of the groyne on the Civutski rukavac. They include the typical rooted groyne with wings, detached groyne with wings, rooted groyne without wings, and detached groyne without wings (Table 12).

Table 12 - Breakdown of the planned sub-scenarios

Sub-scenario I	Apatin sector – Upstream chevron remains, downstream chevron is removed from the modell calculation;
Sub-scenario II	Apatin sector - The height of the sills is raised 2m;
Sub-scenario III	Civutski/Zidovski rukavac – rooted T-shaped groyne
Sub-scenario IV	Civutski/Zidovski rukavac – detached T-shaped groyne
Sub-scenario V	Civutski/Zidovski rukavac – rooted groyne (without wings)
Sub-scenario VI	Civutski/Zidovski rukavac – detached groyne (without wings)

6 CONCLUSION

In conclusion, this study has comprehensively assessed the critical navigational bottlenecks along the joint Serbian-Croatian stretch of the Danube River, integrating both engineering and environmental perspectives. The analysis identified key problematic areas where sediment accumulation and unstable channel morphology compromise the required 200-meter fairway. A suite of nature-inclusive structures—such as chevrons, detached groynes, sills, and sidearm channels—was proposed to restore flow dynamics while preserving ecological integrity. Preliminary evaluations indicate that these measures can enhance navigational efficiency, minimize maintenance costs, and minimise environmental impact and even create beneficial microhabitats for aquatic and riparian species. The study's multi-scenario approach, detailed in Table 13, presents a baseline "Do Nothing" scenario alongside scenarios for structural and revitalisation measures, fairway realignment, and full structural intervention.

Table 13 - Summary all four scenarios and training structures envisaged for analysis

Scenario	Apatin	Čivutski rukavac	Drava Confluence	Aljmaš	Staklar
Scenario 1 (S1) – Do nothing	-	-	-	-	-
Scenario 2 (S2) – Structural and revitalisation measures	2 Chevrons, 3 sills	-	Sidearm channel	Sidearm channel	-
Scenario 3 (S3) – Fairway realignment	-	-	-	-	-
Scenario 4 (S4) – Only structural measures	2 Chevrons, 3 sills	1 Groyne	3 sills	-	4 sills

These scenarios encapsulate a range of interventions aimed at optimally balancing sediment management with ecological preservation through targeted hydraulic modifications. Robust hydraulic modeling, using both 1D and 2D techniques, will be essential to further test these hypotheses and assess their long-term performance.

Continuous monitoring and adaptive management will help ensure that potential short-term ecological disturbances are minimized and that the implemented solutions remain effective over time. The integration of stakeholder input and environmental regulations shall support the credibility and practical relevance of the proposed measures. Ultimately, by reconciling navigational requirements with sustainable environmental practices, the project paves the way for a resilient and dynamic river system that supports both safe navigation and rich biodiversity.

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