Co-financed by the Connecting Europe
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Lot 1: Hydraulic and morphological modelling of the
SRB-CRO common stretch of the Danube River

Hydraulic modelling and multi-criteria analysis

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Preparing FAIRway2 works in the Rhine Danube Corridor (2019-EU-TM-0262-S and 2019-HR-TMC-0263-S)

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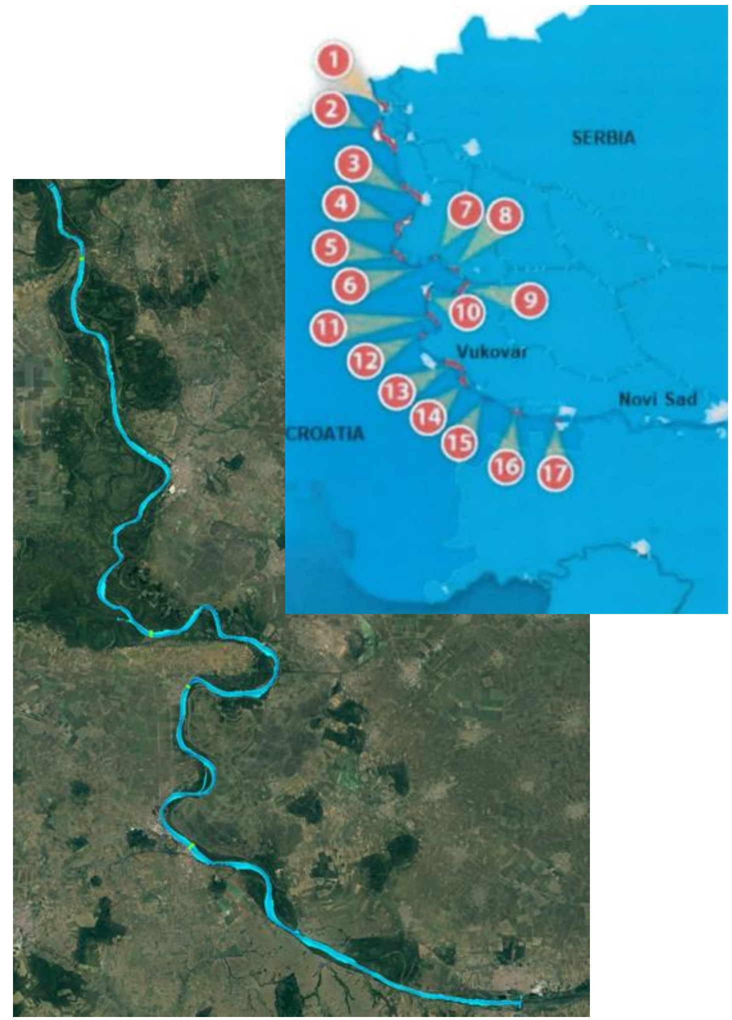
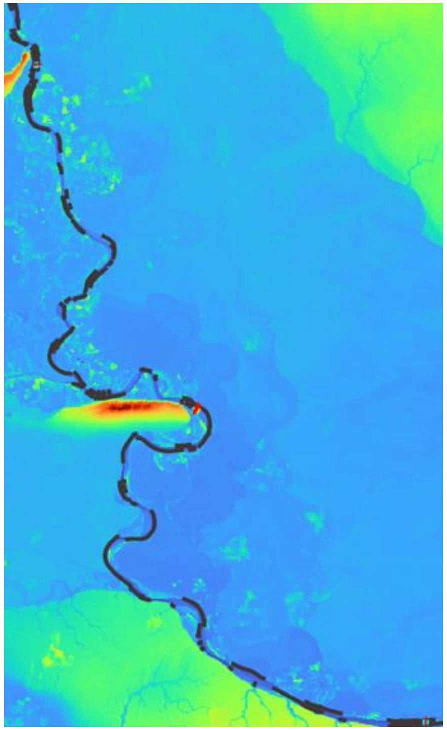
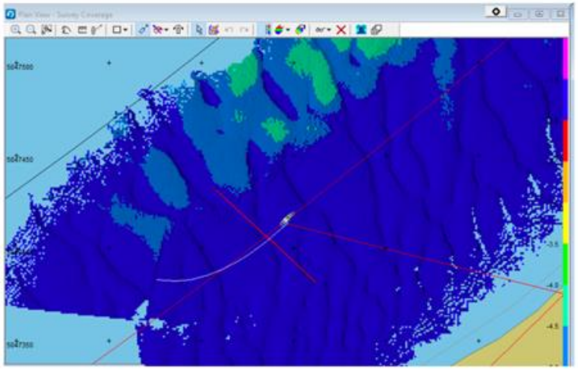


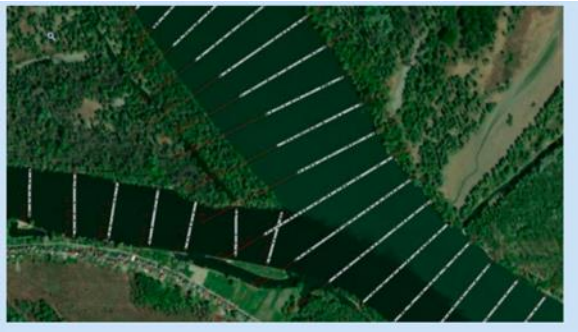
A1: 1D (2D) Modeling

Input data for geometry data

- Single-beam survey data
- Multi-beam survey data
- Lidar survey data (1m and 5m)
- Global DEM (FABDEM)
- Training structures (shp files)
- Bridges (dwg files)





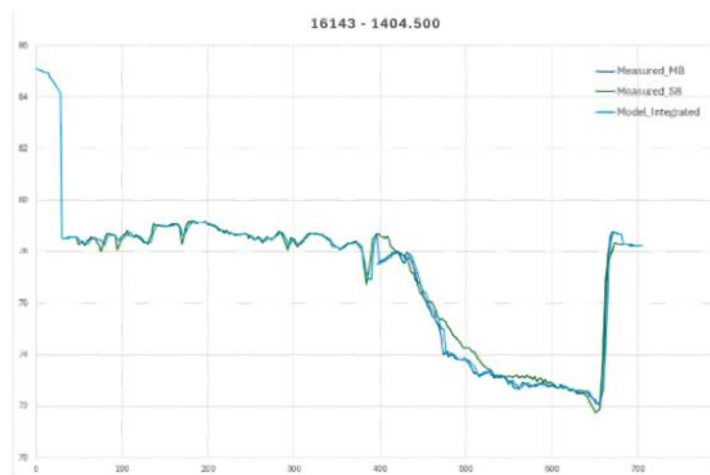


Hybrid geometry model

- Single vs Multi beam
- Missing data ("filling gaps")
- Lidar and Global DEM

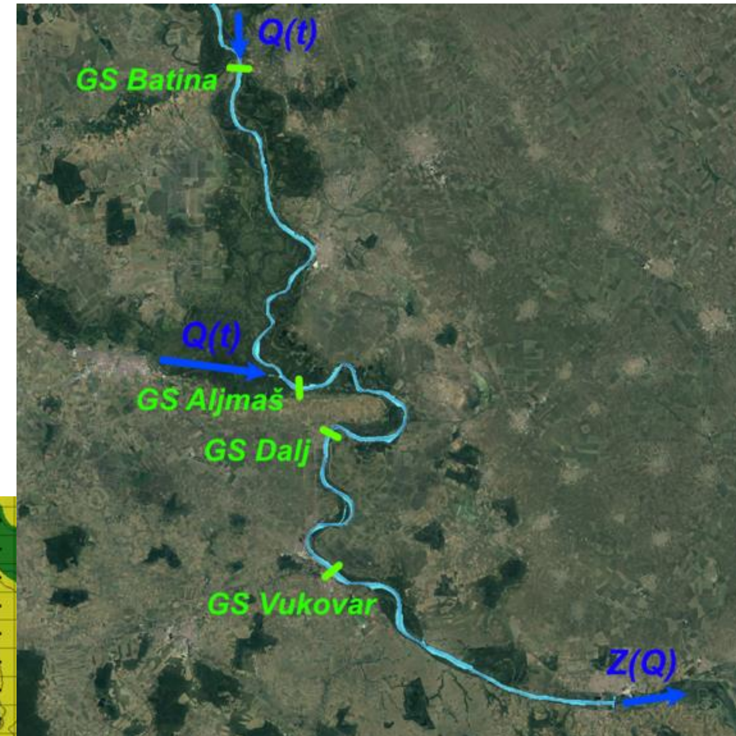
– Orange (darker) is the area that consecutive single-beam measurements cover. The coverage area is generated by connecting the endpoints of the charted cross-sections.

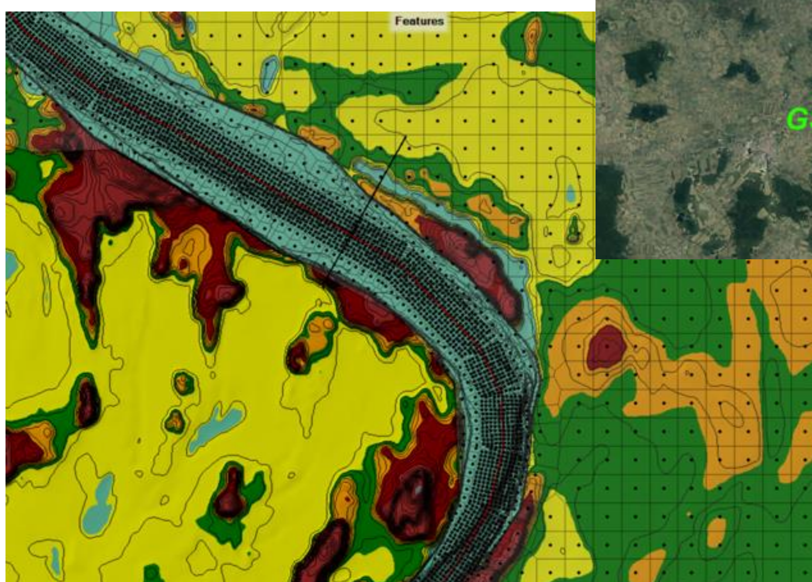
– Orange (gradient) is the area covered by the multi-beam measurement. The borderline is generated manually.



HECRAS 2D model

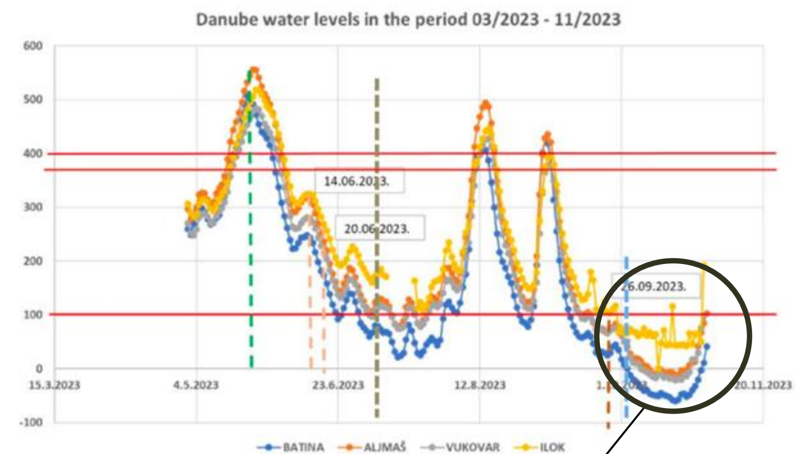
- Computational grid DX,DY ≈ 30 m ✅
  (Grid refined where needed)
- Boundary conditions ✅
- Feasible numerical simulations ✅
- Model calibration ✅
- Verification ✅
- Simulation for $Q_{94\%}$ ✅

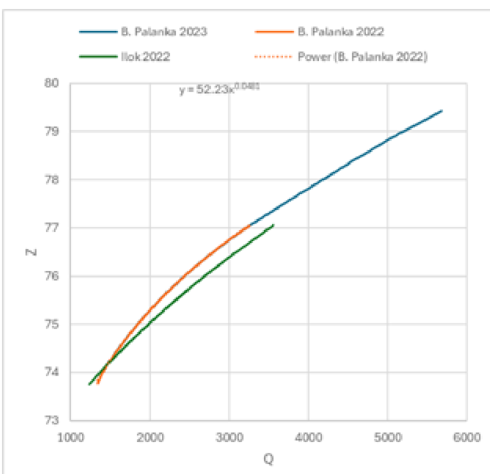




Calibration

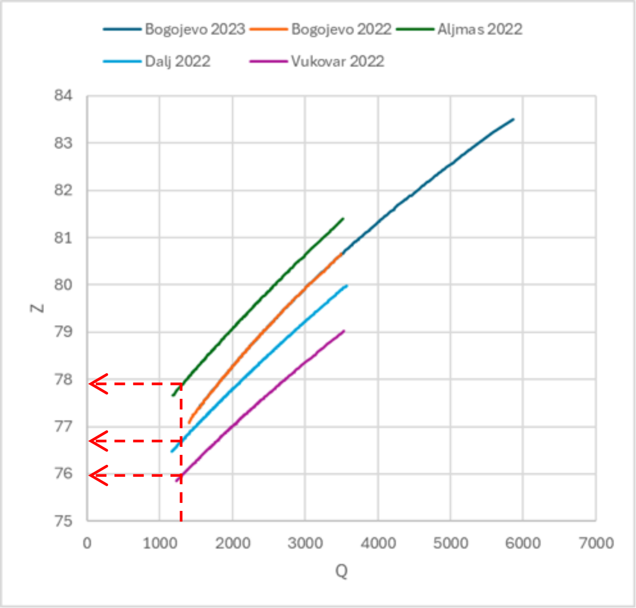
- 1D (2D) Hydraulic Modelling
- **Manning coefficient**
- Data for calibration❓
  - Stage hydrograph at HS ILOK (non-filtered data) ❎
  - Rating curves RHMZ/DHMZ ✅





Calibration results

- Rating curves from DHMZ
- Calculated WSE
- 950 m³/s (Danube - Bezdan) + 350 m³/s (Drava)



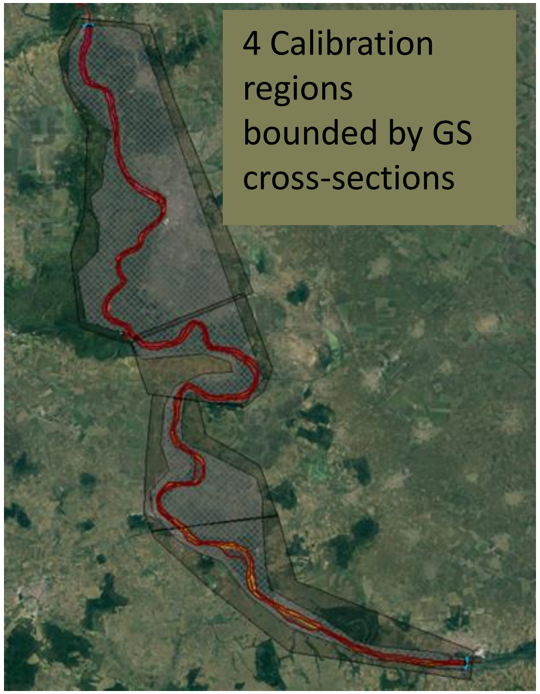
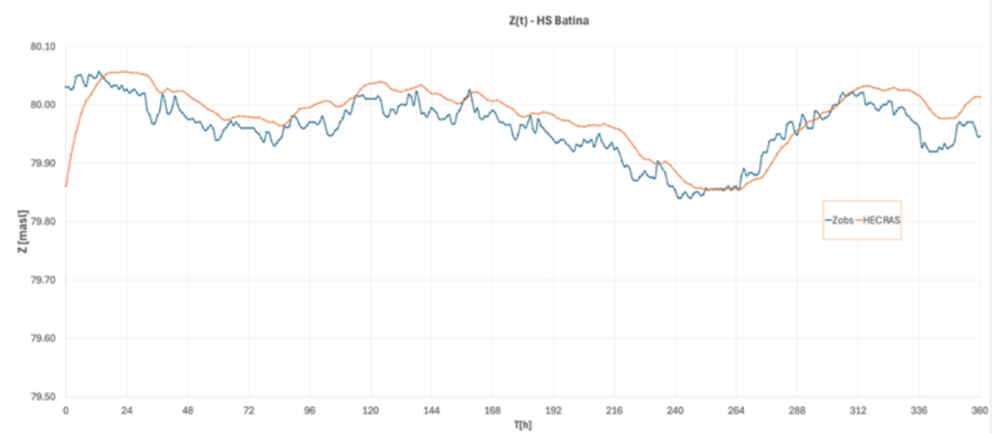


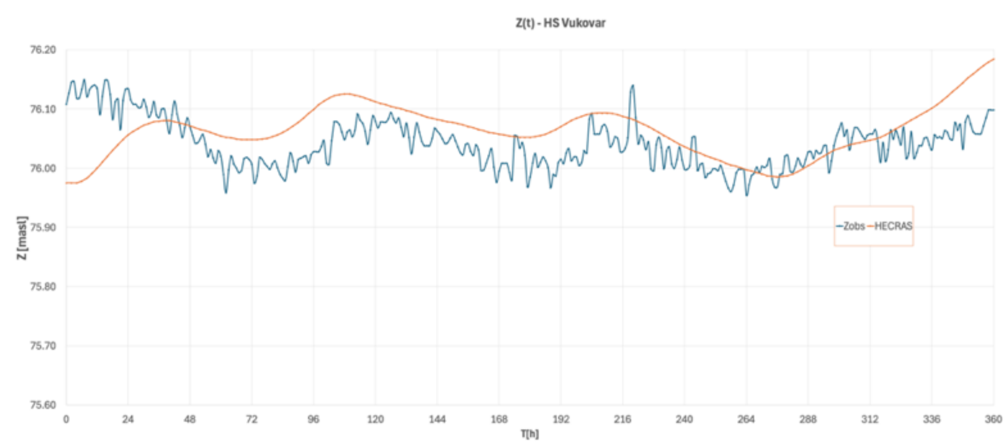
Table 3: Comparison of observed (Z_{DHMZ}) and calculated (Z_{HECRAS}) elevations for adopted Manning's coefficients

	Vukovar	Dalj	Aljmas	Batina
Z_{DHMZ} [masl]	75.96	76.70	77.88	79.86
Z_{HECRAS} [masl]	75.98	76.69	77.88	79.85
n [$m^{-1/3}s$]	0.0290	0.0300	0.0295	0.0325

Verification

- Hydrographs for HS Batina (Danube) and HS Belišće (Drava)
- Time series from 10.10.2023 to 15.10.2023
- Two issues:
  1. Initial conditions
  2. Hydrograph for the Drava confluence
- Calculated vs observed WSE (gauging stations along the sector)
- Max. difference = 10 cm

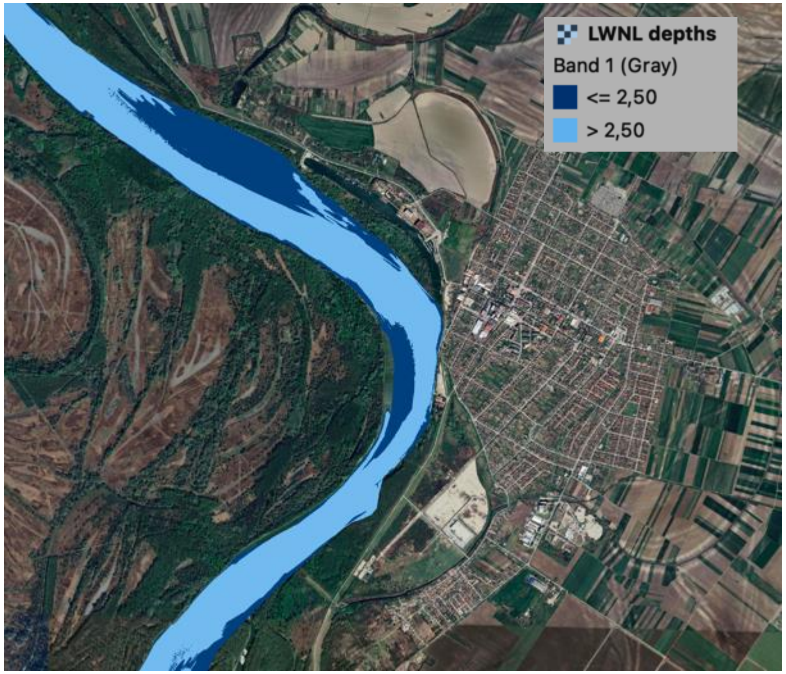




A2: Redefinition and Prioritization of Navigational Bottlenecks

LNLs calculation

- Steady state solution
  $Q_{94\%}$ (HS Batina) and $Q_{94\%}$ (HS Aljmaš)
- Additional calibration
- ENR calculation →
  Maps for fairway depths
- Bottlenecks catalogue update



Q94% 1st iteration	Vukovar	Dalj	Aljmaš	Batina
Z_{DHMZ} [masl]	76.60	77.36	78.60	80.61
Z_{HECRAS} [masl]	76.73	77.51	78.7	80.77
n [$m^{-1/3}s$]	0.0290	0.0300	0.0295	0.0325

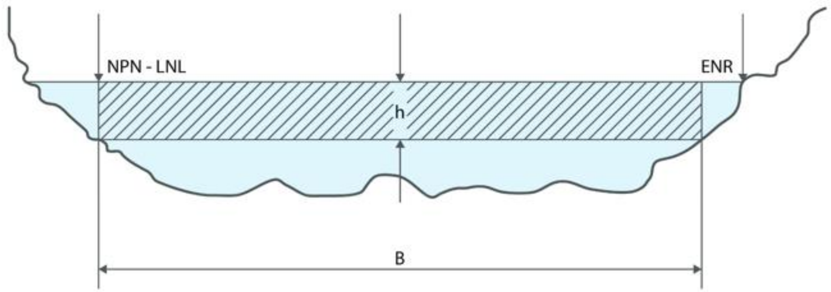
Calibration

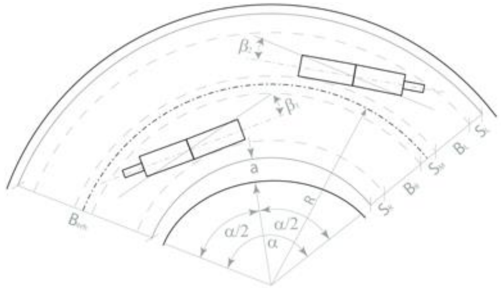
Q94% 5th iteration	Vukovar	Dalj	Aljmaš	Batina
Z_{DHMZ} [masl]	76.60	77.36	78.60	80.61
Z_{HECRAS} [masl]	76.59	77.36	78.60	80.61
n [$m^{-1/3}s$]	0.02700	0.02850	0.02900	0.0305

Station	Q94% (m^3/s)	
	Before adjustment	After adjustment
Bezdan	**1344**	–
Aljmas	1735	**1719**
Bogojevo	1707	–
Dalj	1791	1768
Vukovar	1774	1769
Ilok	1821	1813
Backa Palanka	1897	1778

Bottlenecks indentification

- Criteria for Fairway dimensions
  (Danube Commission -
  Minimal fairway depth, width and curvature)



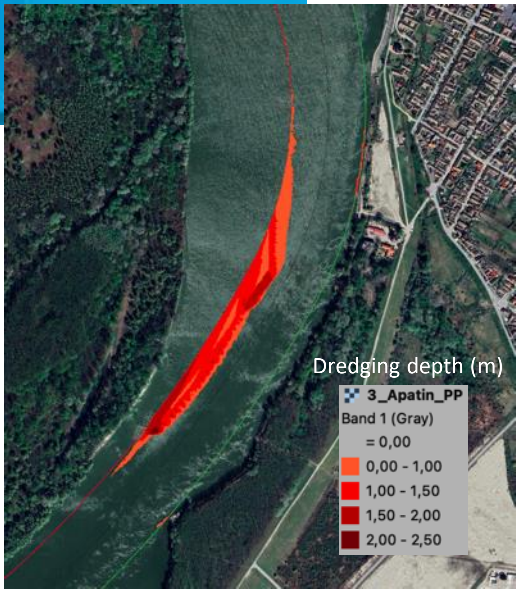


Update of bottlenecks catalogue

- No additional critical sectors
- Some sectors were not identified as critical ❓

Table. Dredging volume for fairway depth of 2.5 m

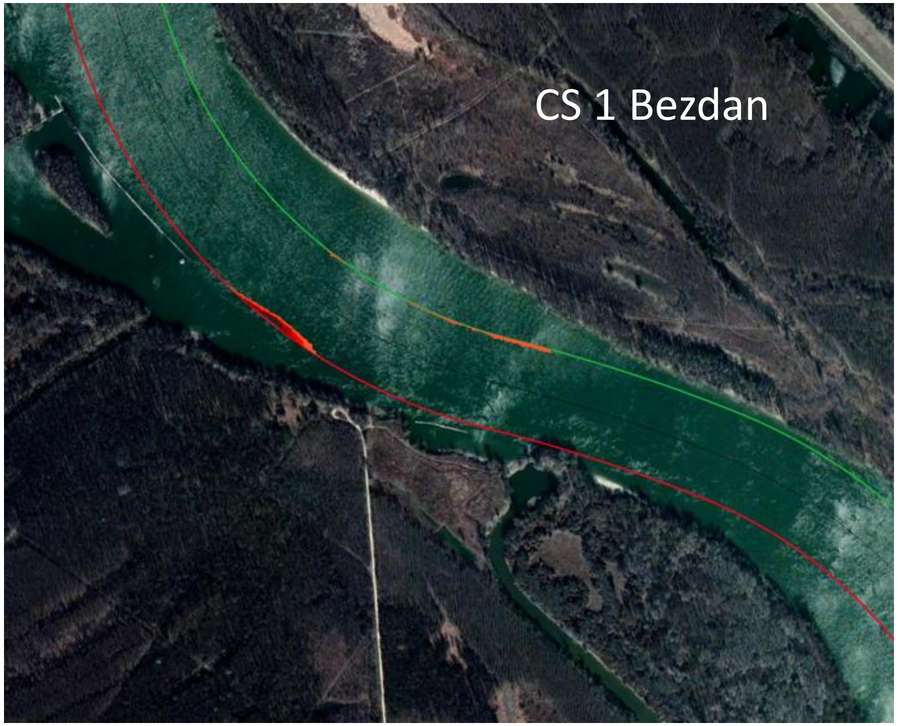
No	Sector	Chainage [rkm]	"Dredging" [m3]
1	Bezdan	1429.0 - 1425.0	4745
2	Siga Kazuk	1424.2 - 1414.4	1016
3	Apatin	1408.2-1400.0	54311
4	Židovski rukavac	1397.2-1389.0	52977
5	Drava confluence	1388.8-1382.0	22013
6	Aljmaš	1381.4-1378.2	0
7	Staklar	1376.8-1373.4	14781
8	Erdut	1371.4-1366.4	0
9	Bogojevo	1366.2-1361.4	330
10	Dalj	1357.0-1351.0	244
11	Borovo 1	1348.6-1343.6	26555
12	Borovo 2	1340.6-1338.0	40353
13	Vukovar	1332.0-1325.0	2
14	Sotin	1324.0-1320.0	85
15	Opatovac	1315.4-1314.6	37
16	Mohovo	1311.4-1307.6	748
17	Ilok	1302.0-1300.0	0

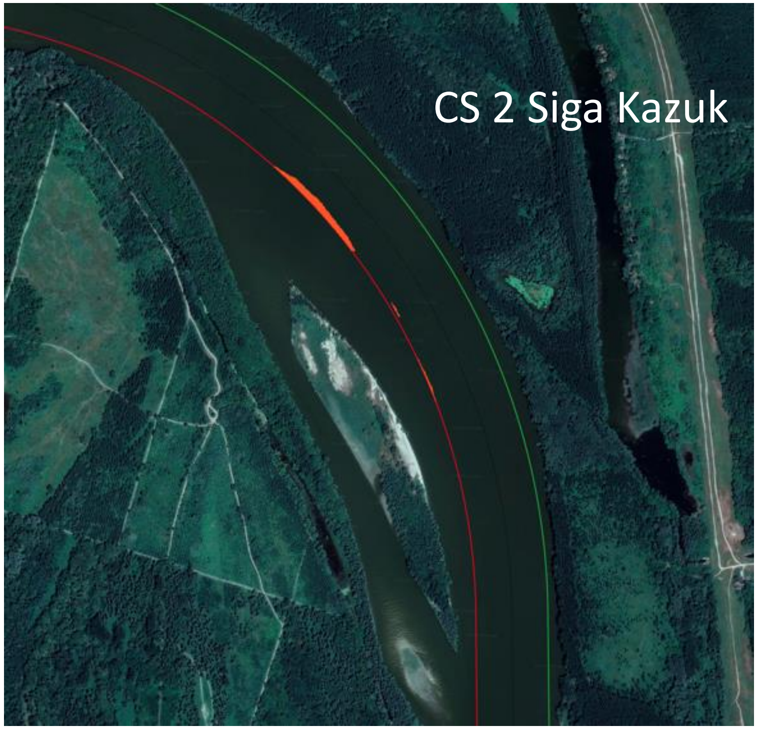


“Dredging” volume by sectors (1)

Dredging depth (m)

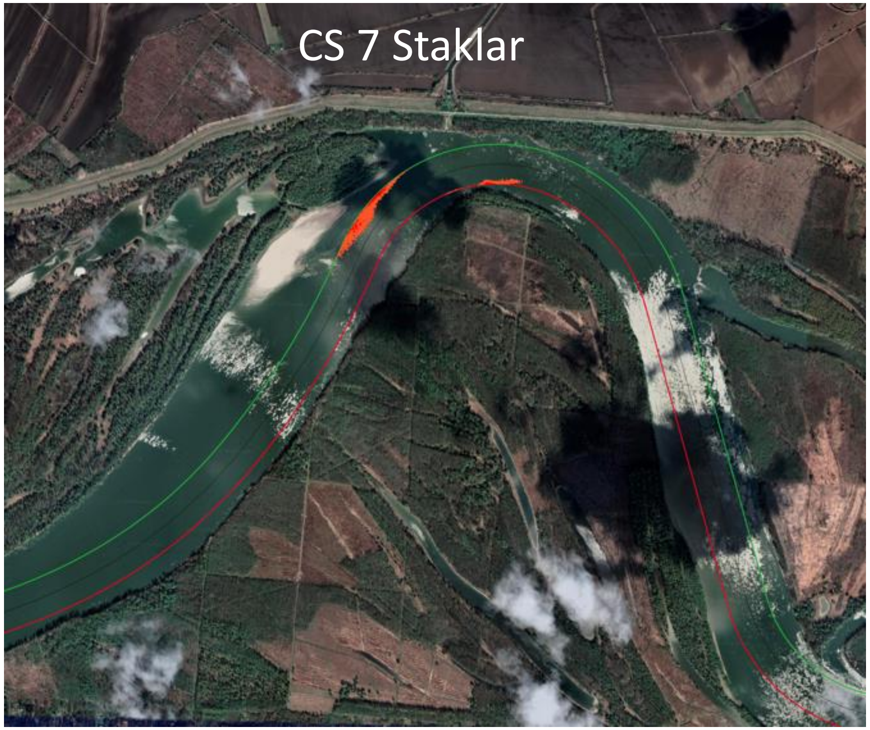
- 0,00 - 1,00
- 1,00 - 1,50
- 1,50 - 2,00
- 2,00 - 2,50





“Dredging” volume by sectors (2)

"Dredging" volume by sectors (3)



“Dredging” volume by sectors (4)

Prioritization of the critical sectors

- Required dredging works according
  to different fairway widths + minimal water elevation for fairway width reduction
  (adopted Methodology for prioritizing critical sectors on the common sector, 2014)

Table. Dredging volume in cubic meters for different level of service

	Sector	Chainage [rkm]	B[m] 100	B[m] 120	B[m] 150	B[m] 200
1	Bezdan	1429.0 - 1425.0	0	0	0	4745
2	Siga Kazuk	1424.2 - 1414.4	0	0	0	1016
3	**Apatin**	**1408.2-1400.0**	**7035**	**14635**	**26821**	**54311**
4	**Židovski rukavac**	**1397.2-1389.0**	**343**	**1494**	**8164**	**52977**
5	**Drava_Confluence**	**1388.8-1382.0**	**0**	**441**	**4221**	**22013**
6	Aljmaš	1381.4-1378.2	0	0	0	0
7	**Staklar**	**1376.8-1373.4**	**733**	**1571**	**3823**	**14781**
8	Erdut	1371.4-1366.4	0	0	0	0
9	Bogojevo	1366.2-1361.4	0	0	0	330
10	Dalj	1357.0-1351.0	0	0	0	244
11	**Borovo 1**	**1348.6-1343.6**	**0**	**415**	**5431**	**26555**
12	**Borovo 2**	**1340.6-1338.0**	**0**	**346**	**6863**	**40353**
13	Vukovar	1332.0-1325.0	0	0	0	2
14	Sotin	1324.0-1320.0	0	0	0	85
15	Opatovac	1315.4-1314.6	0	0	0	37
16	Mohovo	1311.4-1307.6	93	177	368	748
17	Ilok	1302.0-1300.0	0	0	0	0

A3: MCA Definition

Model development

- Available data
- Methodology
- Criteria
- Stakeholders forum

$$P(A_K) = \prod_{j=1}^{n} (a_{Kj})^{w_j}, \text{ for } K = 1, 2, 3, \ldots, m.$$

$$P(A_1/A_2) = (25/10)^{0.20} \times (20/30)^{0.15} \times (15/20)^{0.40} \times (30/30)^{0.25} = 1.007 > 1$$

$$P(A_1/A_3) = 1.067 > 1, \text{ and } P(A_2/A_3) = 1.059 > 1.$$

$$A_1 > A_2 > A_3$$

Table1. Navigation group of criteria

Criteria	Indicators	Score	Weighting coefficient
Navigability	Water depth ratio, Top width ratio, Curve radius ratio, Velocity ratio, Hindrance ratio	From 1 to 3	0.2
Safety	Visibility of the structures	From 0 to 1	0.2

Table 2. Environment group of criteria

Criteria	Indicators	Score	Weighting coefficient
Hydro-morphology	SHDi ratio, Length of low flow channels ratio, Bankfull discharge water level difference, Mean grain size ratio, lateral connectivity ratio	From 0 to 3	0.1
Sediment and Water quality	Dredging volume ratio, Water depths ratio	From 0 to 3	0.05
Bird population	Habitat suitability area ratio (aspects of nesting and wintering)	From 1 to 3	0.05
Fish population	Habitat suitability area ratio (aspects of spawning, migration, growing and living taken into account)	From 1 to 3	0.1
Flora	Habitat suitability area ratio	From 1 to 3	0.05
Climate change vulnerability	Climate change sensitivity ratio, Climate change adaptivity ratio	From 0 to 3	0.05

Table 3. Feasibility group of criteria

Criteria	Indicators	Score	Weighting coefficient
Technical aspects	Construction time, execution of the works (level of difficulty and safety), sustainability	From 0 to 1	0.05
Financial feasibility	Cost ratio (Investment, Maintenance)	From 0 to 3	0.15

Technical note

- Questions from Stakeholders
- „Do-nothing“ scenario
- Scoring for Environment group of criteria

Figure 11

Habitat suitability for adult brown trout (Salmo trutta) at river discharge rates (Q) of (a) 1.15 $m^3 s^{-1}$ and (b) 3.95 $m^3 s^{-1}$. Vermigliana creek, Vermiglio (IT).

Source: Courtesy of Prof. G. Zolezzi (DICAM, University of Trento, Italy)

$$\delta A_f = \sum_{i=1}^{N} \frac{A_{if,as} - A_{if,0}}{A_{if,0}} \cdot 100\% \cdot w_{if}$$

A_{if} - area suitable for the i-th type of fish; w_{if} - weighting coefficient for i-th type of fish ($\sum_{i=1}^{N} w_{if} = 1$).

Example: Indicator for Hydro-Morhology

- Geomorphic diversity
- Qchf

$$SHDi = -\sum_{i=1}^{4} p_i \ln p_i$$

$$\delta SHDi = \frac{SHDi_{as} - SHDi_0}{SHDi_0} \cdot 100\%$$

Where:

$SHDi_{as}$ - Shannon diversity index for alternative solution

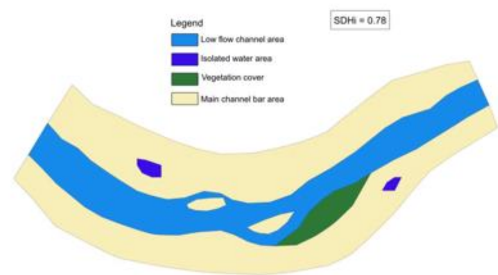
$SHDi_{as}$ - Shannon diversity index for "Do nothing" scenario

Scoring

0.0 if $\delta SHDi$ *for alternative solution* is **≤-10%**

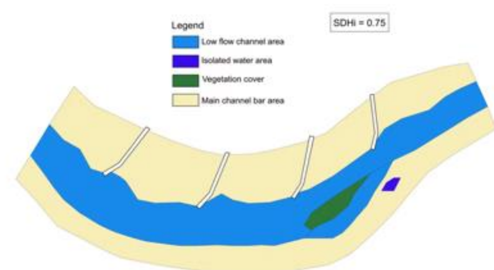
3.0 if $\delta SHDi$ *for alternative solution* is **≥20%**

Characteristic areas after 2D sediment transport simulation for Qcf - "Do nothing scenario"



River planform after river bed deformation simulation for do-nothing solution (Simulation for "Channel forming discharge")

Characteristic areas after 2D sediment transport simulation for Qcf - Alternative solution



Do nothing scenario:

$p_1 = 0.29$ (proportion of "Low flow channel area")

$p_2 = 0.01$ (proportion of "Isolated water area")

$p_3 = 0.03$ (proportion of "Vegetation cover")

$p_4 = 0.67$ (proportion of "Main channel bar area")

$SHDi_0 = 0.78$

Alternative solution:

$p_1 = 0.36$ (proportion of "Low flow channel area")

$p_2 = 0.00$ (proportion of "Isolated water area")

$p_3 = 0.02$ (proportion of "Vegetation cover")

$p_4 = 0.61$ (proportion of "Main channel bar area")

$SHDi_{as} = 0.75$

$\delta SHDi = -3.63\%$

Score for Alternative solution 0.64

In MCA product sum model term related to geomorphic conditons is $0.64^{0.05} = 0.98$ (this value decreases total product value)

The channel-forming discharge concept is based on the idea that for a given alluvial channel geometry, there exists a single steady discharge that given enough time would produce channel dimensions equivalent to those shaped by the natural long-term hydrograph. (ASCE)

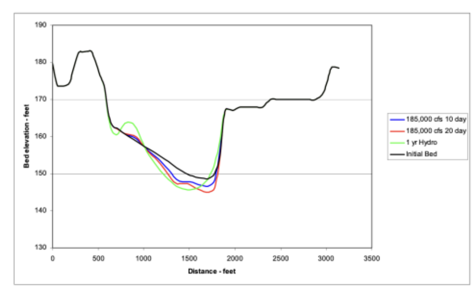
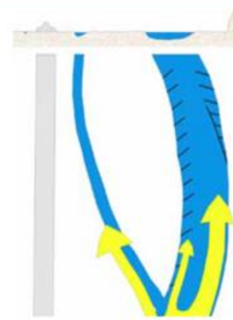
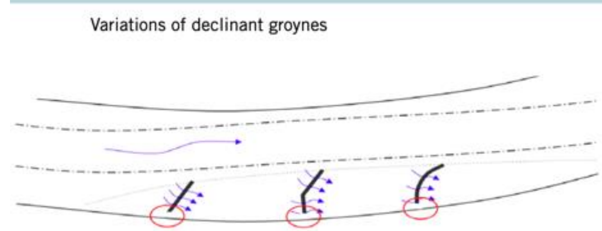


Figure 14. Change in thalweg elevation for the bank full discharge and one year hydrograph simulations – Section 43.6

Good practice examples

- Ecologial river engineering in waterways (Platina)
  - Balance between ecological and navigational „requirements“ (Win-Win solutions ❓)





Thank you for your kind attention