

Lot 1: Hydraulic and morphological modelling of the SRB-CRO common stretch of the Danube River

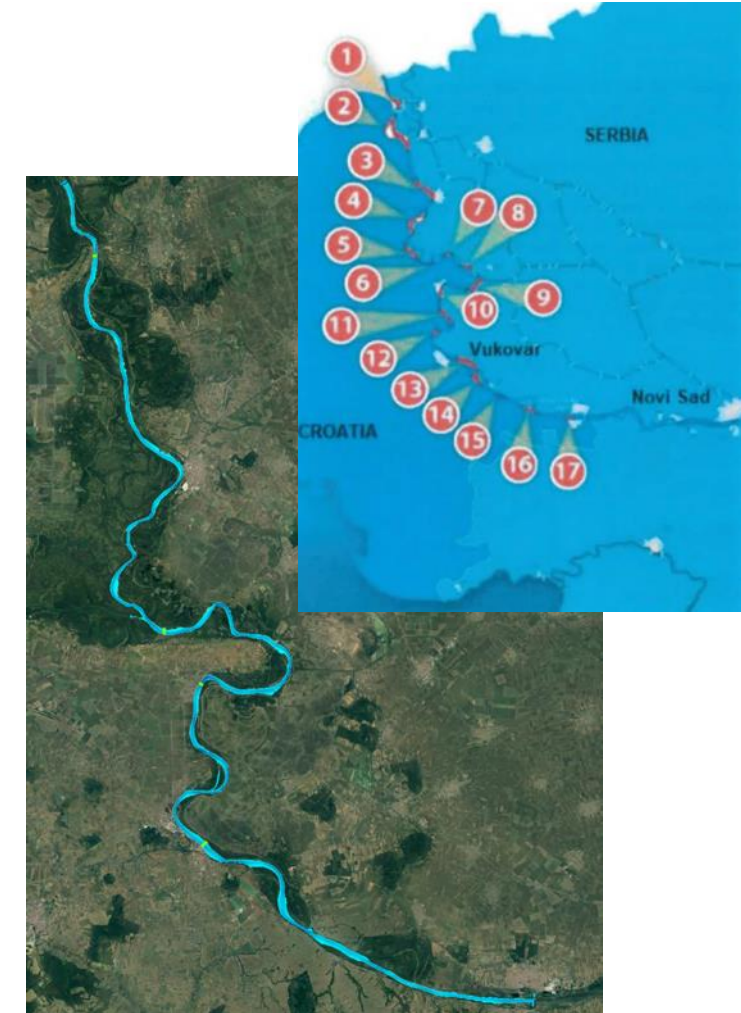
Hydraulic modelling and multi-criteria analysis

Stakeholders' Forum Meeting 10 (SFHM 10)

28/10/2024

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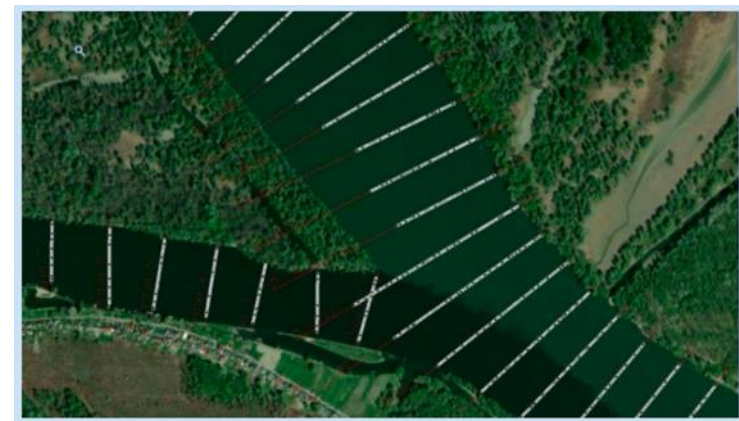
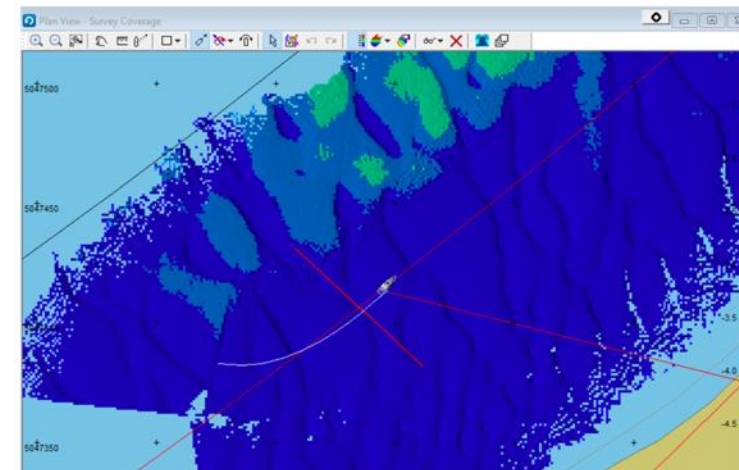
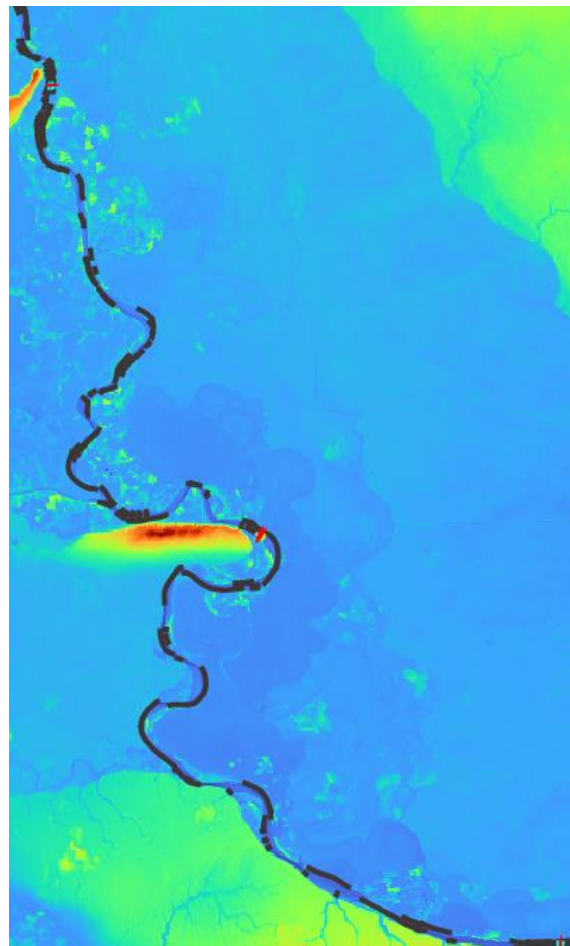
- 1D (2D) Hydraulic Modelling
 - Input data checked
- Redefinition and Prioritization of Navigational Bottlenecks
 - Update of bottlenecks catalogue
 - Prioritization of bottlenecks
- Multi-criteria analysis
 - MCA definition
 - Numerical Example



A1: 1D (2D) Modeling

Input data for geometry data

- Input data checked
- Riverbed elevations are valid in the old vertical coordinate system



Calibration results

- Rating curves valid in the old vertical CRS => Calculated WSE valid in the old CRS

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

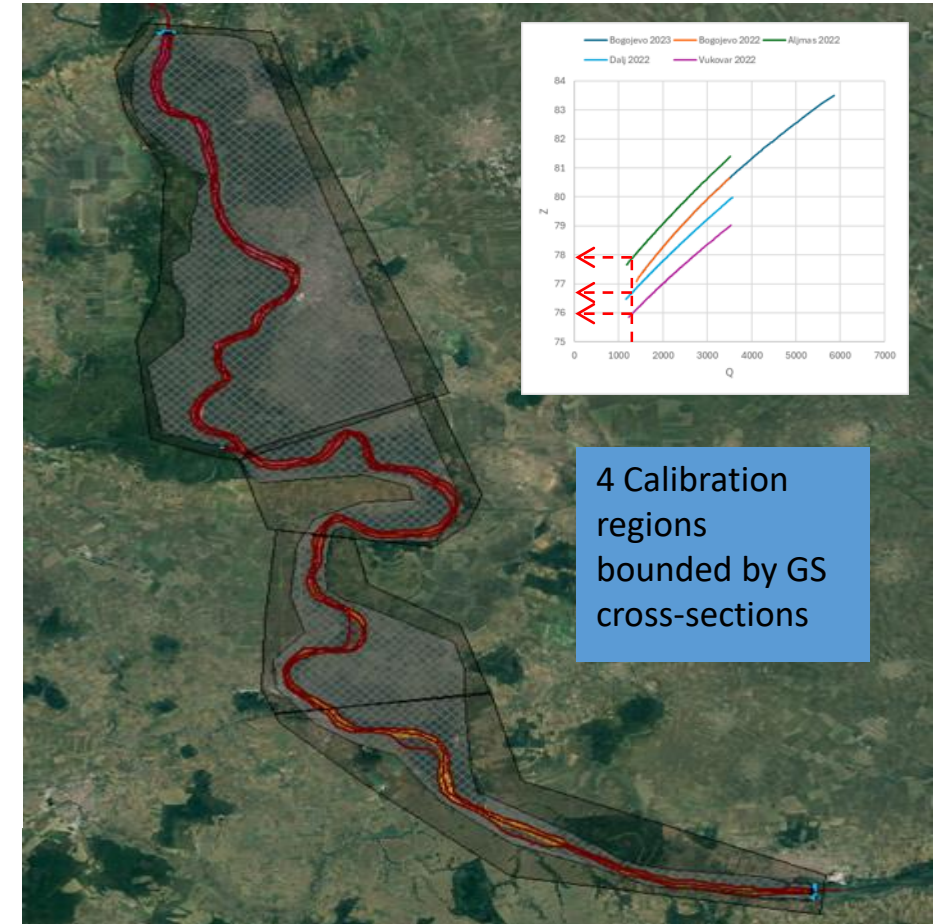
Q_{94%}

1st iteration	Vukovar	Dalj	Aljmaš	Batina
Z _{DHMZ} [masl]	76.60	77.36	78.60	80.61
Z _{HECRAS} [masl]	76.73	77.51	78.70	80.77
n [m ^{-1/3} s]	0.0290	0.0300	0.0295	0.0325

↓ Calibration

Q_{94%}

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]	0.0270	0.0285	0.0290	0.0305

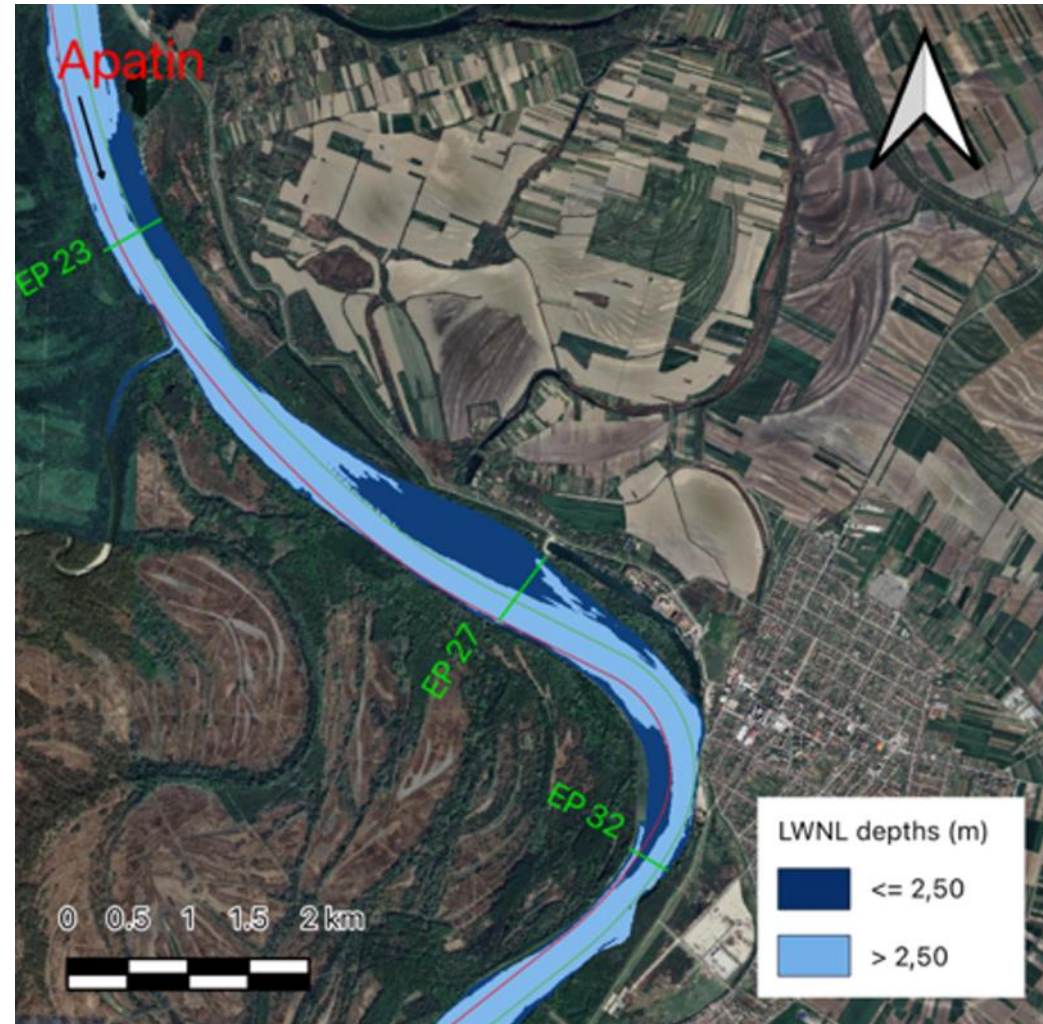


4 Calibration regions bounded by GS cross-sections

A2: Redefinition and Prioritization of Navigational Bottlenecks

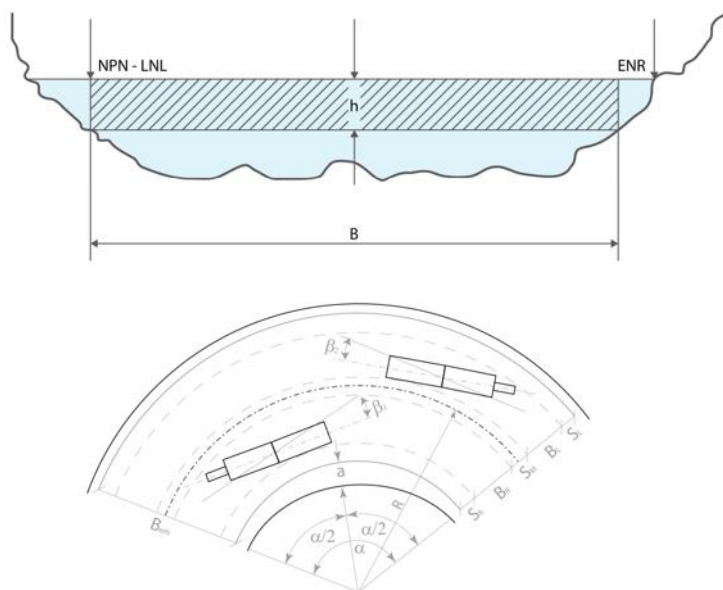
LWNLs calculation

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



Updated Bottlenecks Catalogue

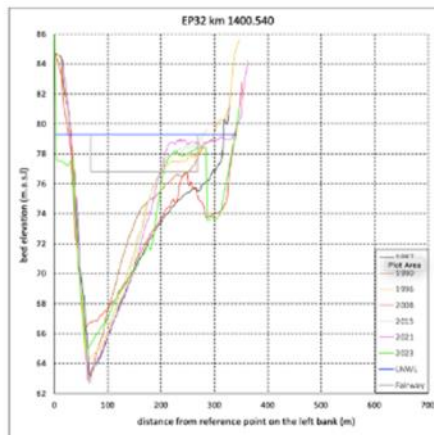
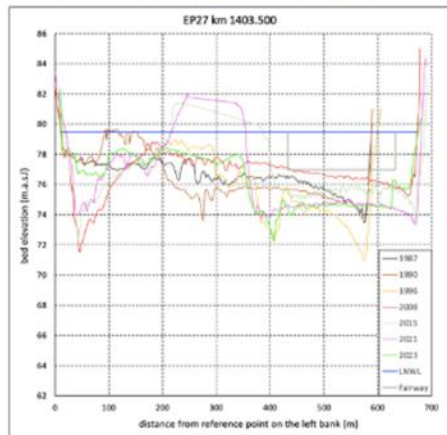
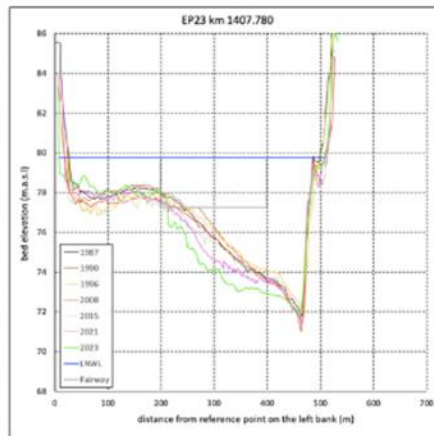
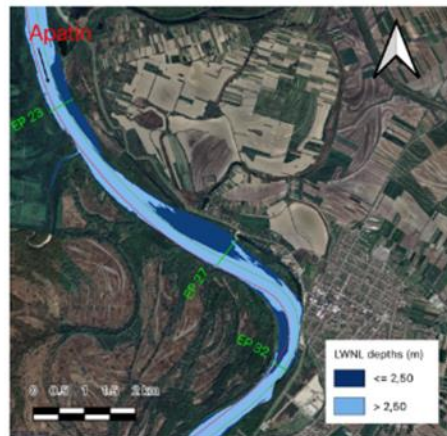
- DC criteria for existing fairway axis
- 13 critical sectors
- 4 sectors excluded in updated catalogue



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
1	Bezdan	1,429.0 – 1,425.0	0	0	0	4,745
2	Siga Kazuk	1,424.2 – 1,414.4	0	0	0	1,106
3	Apatin	1,408.2 – 1,400.0	7,035	14,635	26,821	54,311
4	Civutski Rukavac	1,397.2 – 1,389.0	343	1,494	8,164	52,977
5	Drava Confluence	1,388.8 – 1,382.0	0	441	4,221	22,013
6	Aljmas	1,381.4 – 1,378.2	0	0	0	0
7	Staklar	1,376.8 – 1,373.4	733	1,571	3,823	14,781
8	Erdut	1,371.4 – 1,366.4	0	0	0	0
9	Bogojevo	1,366.2 – 1,361.4	0	0	0	330
10	Dalj	1,357.0 – 1,351.0	0	0	0	344
11	Borovo 1	1,348.6 – 1,343.6	0	415	5,431	26,555
12	Borovo 2	1,340.6 – 1,338.0	0	346	6,863	40,353
13	Vukovar	1,332.0 – 1,325.0	0	0	0	2
14	Sotin	1,324.0 – 1,320.0	0	0	0	85
15	Opatovac	1,315.4 – 1,314.6	0	0	0	37
16	Mohovo	1,311.4 – 1,307.6	93	177	368	748
17	Ilok	1,302.0 – 1,300.0	0	0	0	0

Bottlenecks Catalogue (Plovput Cross-sections)

Basic location info			
Name of the bottleneck	Apatin	Alternative name	N/A
Waterway	Danube River	Waterway class (AGN)	VI
From (km upstream)	1,408.20	To (km downstream)	1,400.00
Total length (km)	8,20	River bed	sand
Left bank	SRB	Right bank	HRV



Basic information on the navigation obstacle(s)

<input checked="" type="checkbox"/> depth	<input checked="" type="checkbox"/> width	<input type="checkbox"/> radius	<input type="checkbox"/> height
<input type="checkbox"/> other (to be specified if selected)			

Historical information

<input checked="" type="checkbox"/> The location is known as the navigation bottleneck from before	<input type="checkbox"/> The location is newly identified navigation bottleneck
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Basic ecological information

Overall ecological status of the water body (WFD reference)

<input type="checkbox"/> high	<input type="checkbox"/> good	<input checked="" type="checkbox"/> moderate	<input type="checkbox"/> poor	<input type="checkbox"/> bad
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Protected areas information:

- The Transboundary Biosphere Reserve Mura-Drava-Danube
- Special Nature Resort Gornje Podunavlje
- Kopacki Rit Nature Park

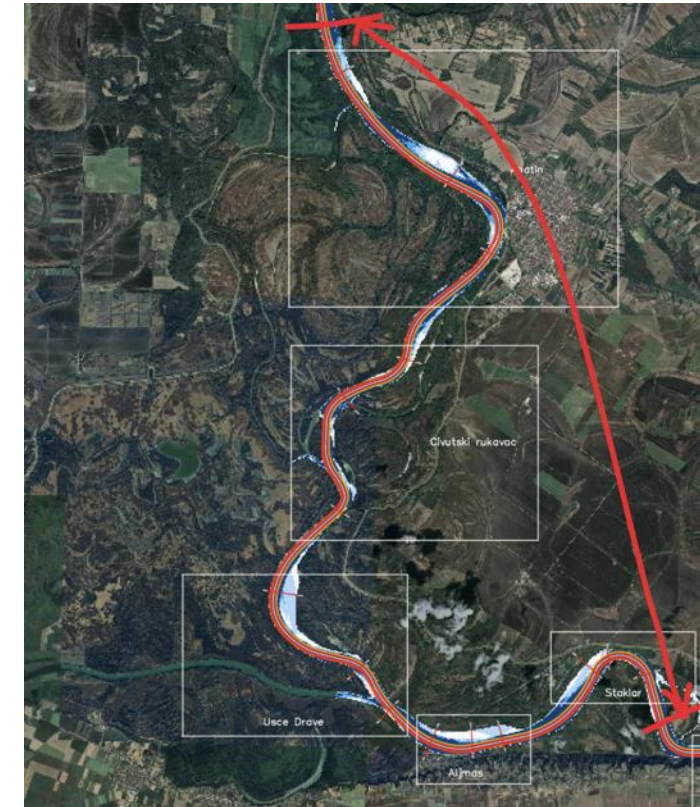
Basic hydrological information

Name of the reference gauging station	Apatin			
Year of the establishment of the gauging station	1876			
Location of the gauging station	km 1.401,90			
Distance to the (center of the) bottleneck	2.20 km			
Period for the calculation of the reference levels	1981-2010			
ENR (LNWL)	79.31 m.a.s.l.	47 cm	LNQ	1.180 m ³ /s
HNWL	85.58 m.a.s.l.	674 cm	HNQ	5.280 m ³ /s
Period for the calculation of the reference levels	1994-2023			
ENR (LNWL)	N/A	N/A	LNQ	N/A
HNWL	N/A	N/A	HNQ	N/A

Prioritization of the critical sectors

- Required dredging works according existing fairway widths
- The level of service approach
- Five consecutive sectors to be analyzed in the following activities

No.	Sector	Chainage (from km to km)	Quantity of sediment within the fairway of 2.5m depth &			
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A3: MCA Definition

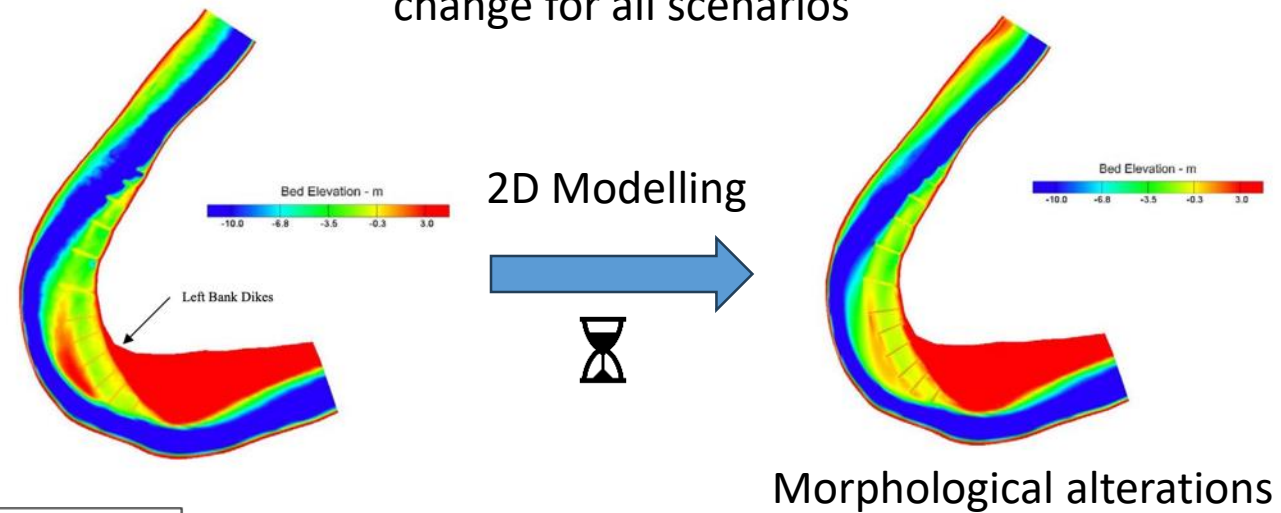
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Purpose of Multi Criteria Analysis

- Evaluation of solutions whose impact is considered over time (scenarios)
- „Do nothing” is base solution (zero alternative)
- 2D Sediment transport model for morphological changes prediction (effects of solutions compared)
- Expert judgment

Do nothing – scenario without measures (even operational or maintenance measures not included)

Numerical simulations of morphological change for all scenarios



MCA



	Group score for navigation	Group score for environment	Group score for feasibility	Total Score
"Do nothing"	1.00	1.00	1.00	1.00
Groyne system	1.07	0.81	1.04	0.90
Fairway realignment	1.05	1.00	1.06	1.12

Methodology

- Weighted product model
- 3 groups of criteria
- Qualitative and quantitative indicators
- Scores for groups of subcriteria
- Reference score 1.0
(relates to Doing nothing scenario)

Code	Criteria	Code	Criteria	Code	Criteria
N ₁	DC requirements	E ₁	Hydro-morphology	F ₁	Technical aspects
N ₂	Maneuverability	E ₂	Sediment and water quality	F ₂	Financial aspects
N ₃	Safety (can deteriorate)	E ₃	Bird population		
		E ₄	Fish population		
		E ₅	Flora		
		E ₆	Climate change vulnerability		

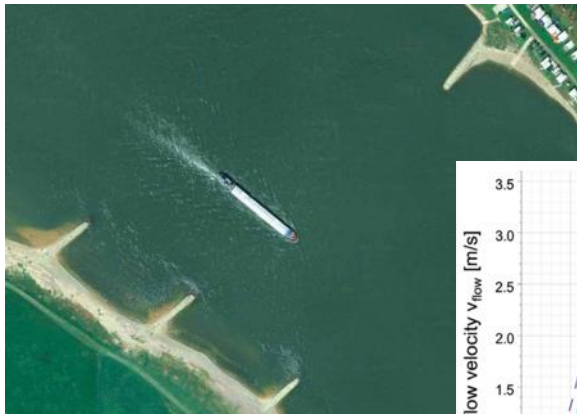
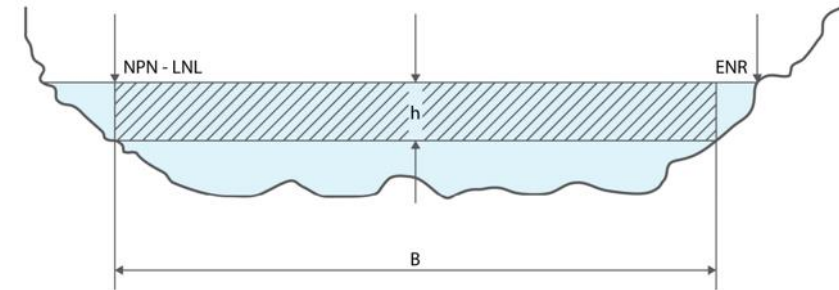
$$Total\ score = N_1^{0.20} \cdot N_2^{0.10} \cdot N_3^{0.10} \cdot E_1^{0.10} \cdot E_2^{0.05} \cdot E_3^{0.05} \cdot E_4^{0.10} \cdot E_5^{0.05} \cdot E_6^{0.05} \cdot F_1^{0.05} \cdot F_2^{0.15}$$

Navigation group of criteria

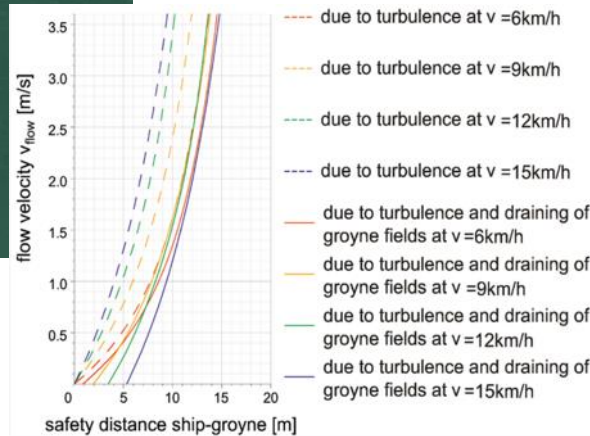
Code	Criteria	Indicators	Acceptable Score	Weighting coefficient
N ₁	DC requirements	<u>Quantitative</u> - Water depth ratio, Top width ratio, Curve radius ratio	1.5 - 2	0.20
N ₂	Maneuverability	<u>Quantitative</u> - Velocity ratio <u>Qualitative</u> - Hindrance	0.25 - 2	0.10
N ₃	Safety (can deteriorate)	<u>Qualitative</u> - Visibility of the structures	0.25 - 2	0.10

Navigation group of criteria (DC Requirements)

- DC Requirements
- Maneuverability
- Safety



BAW Karlsruhe, 2016



By © Steffen Schmitz (Carschten) / Wikimedia Commons

Environment group of criteria

Code	Criteria	Indicators	Acceptable Score	Weighting coefficient
E ₁	Hydro-morphology	<u>Quantitative</u> - Riverbed volume ratio, SHDi ratio, Length of low flow channels ratio, Bankfull discharge water level difference, Lateral connectivity ratio	0.25 - 2	0.10
E ₂	Sediment and water quality	<u>Quantitative</u> - Dredging volume <u>Qualitative</u> - Effects on physical, chemical and biological parameters of water quality	0.25 - 2	0.05
E ₃	Bird population	<u>Qualitative</u> - Aspects of nesting and wintering	1 - 2	0.05
E ₄	Fish population	<u>Qualitative</u> - Aspects of spawning, migration, growing and living	1 - 2	0.10
E ₅	Flora	<u>Qualitative</u> - Creation of new areas for distribution	1 - 2	0.05
E ₆	Climate change vulnerability	<u>Qualitative</u> - Aspects of climate change sensitivity and adaptivity	0.25 - 2	0.05

Environment group of criteria (Subcriteria)

- Hydro-morphology
- Sediment and water quality
- Bird population
- Fish population
- Flora
- Climate change

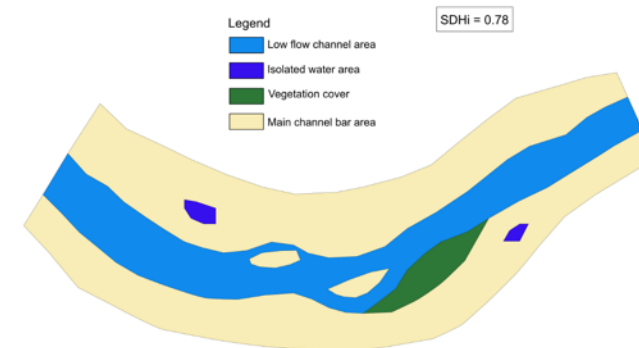
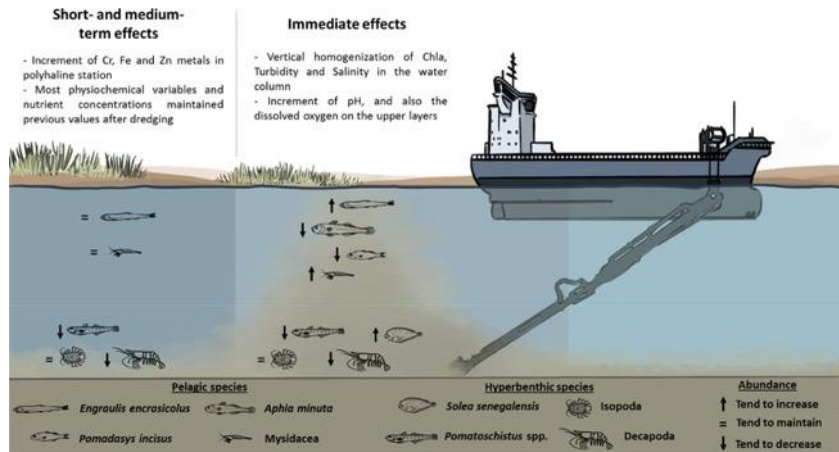


Figure 3: Characteristic areas after 2D sediment transport simulation for channel forming discharge (fictitious "Do nothing" scenario)

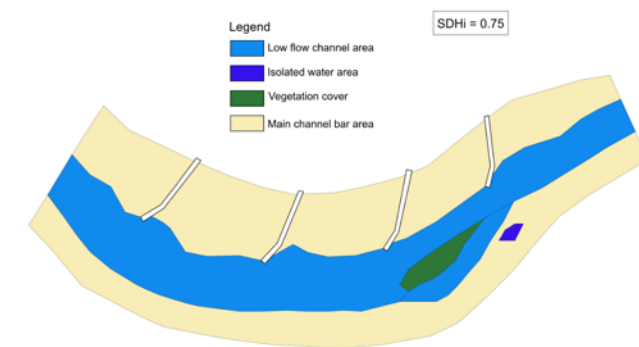


Figure 4: Characteristic areas after 2D sediment transport simulation for channel forming discharge (fictitious alternative solution with groyynes)

Environment group of criteria (Hydro-morphology)

- Riverbed volume
- SHDi
- Length of low flow channels
- Water stage elevation difference for bankfull discharge
- Lateral connectivity

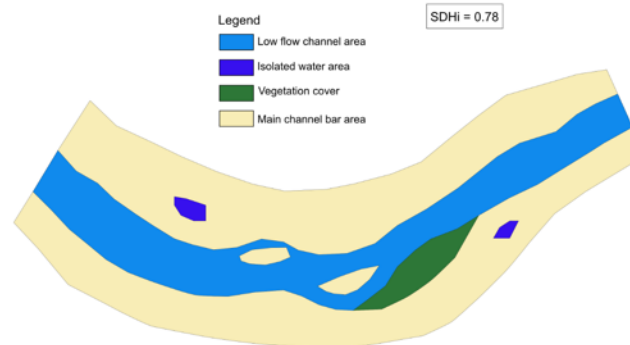


Figure 3: Characteristic areas after 2D sediment transport simulation for channel forming discharge (fictitious "Do nothing" scenario)

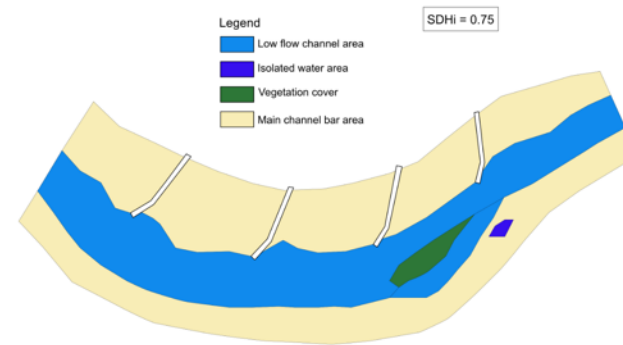


Figure 4: Characteristic areas after 2D sediment transport simulation for channel forming discharge (fictitious alternative solution with groynes)

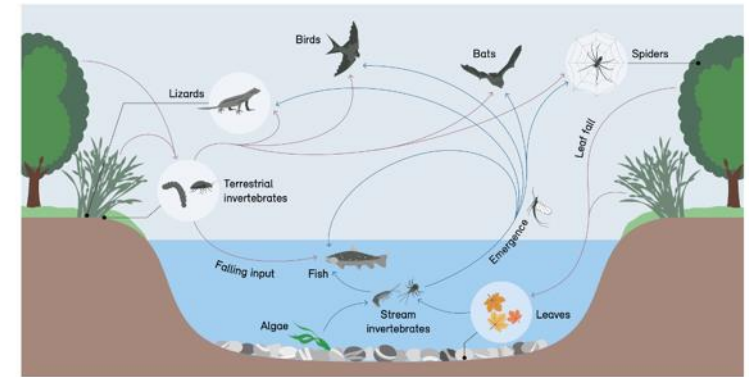
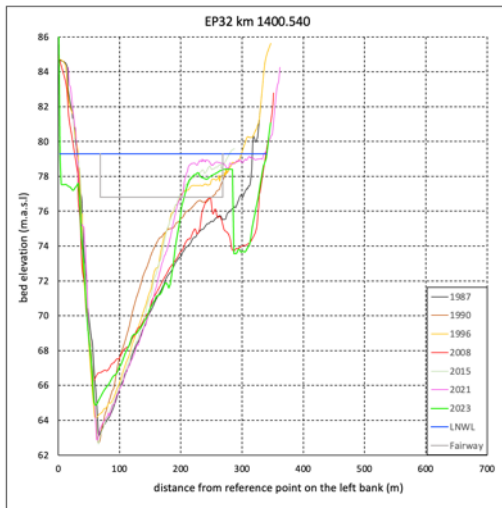


Figure 5: Illustration for aquatic-terrestrial fluxes (Baxter, Fausch and Saunders 2005)

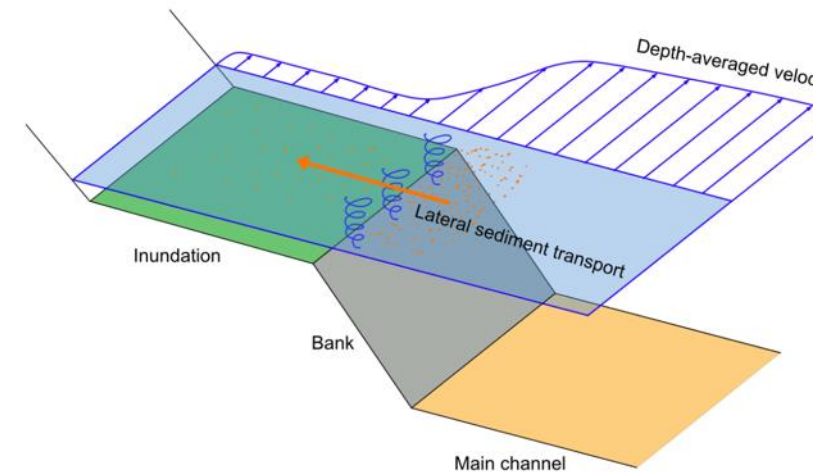


Figure 6: Lateral sediment exchange between main channel and inundation

Riverbed volume change (Basin scale)

- Morphological alteration along SRB-CRO Danube stretch (DanubeSediment, SMS -> DRBMP)

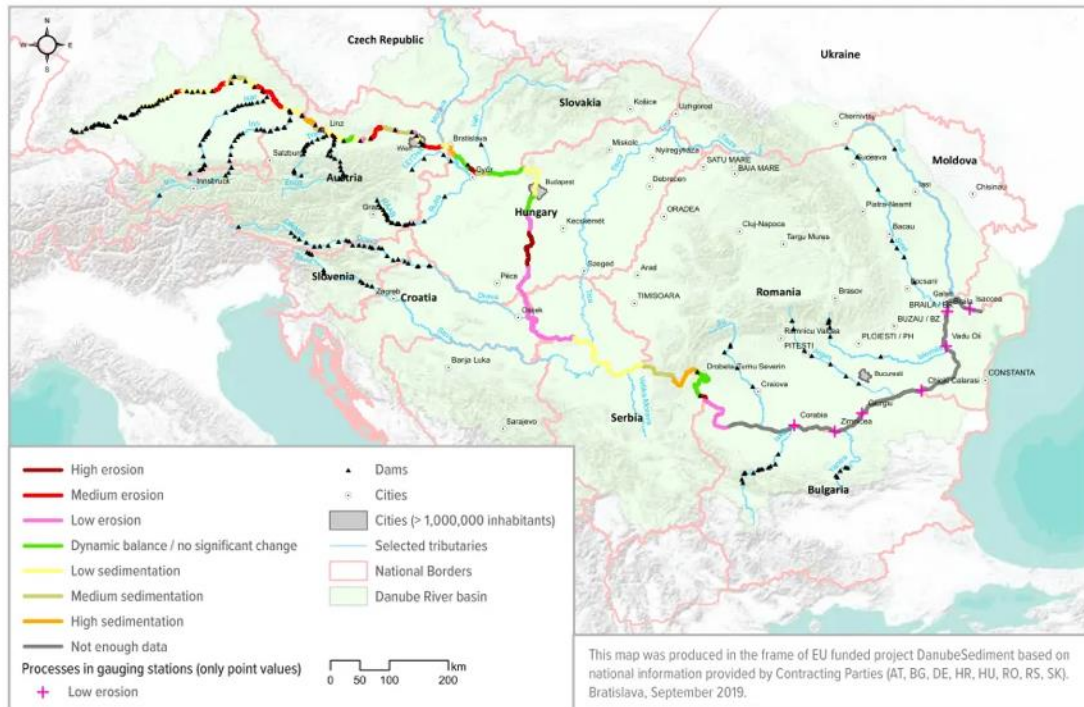


Figure 24: Reaches at the Upper, Middle and Lower Danube showing sedimentation and erosion (from the DanubeSediment report "Long-term Morphological Development of the Danube in Relation to the Sediment Balance")

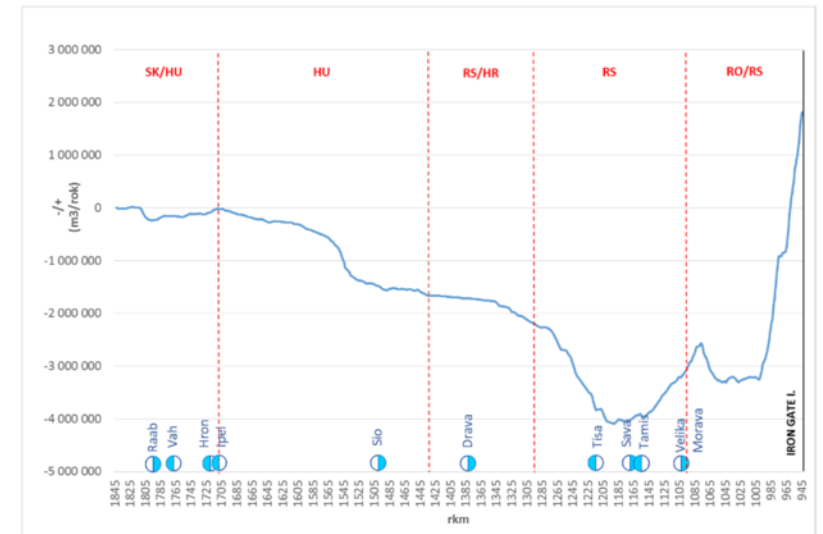
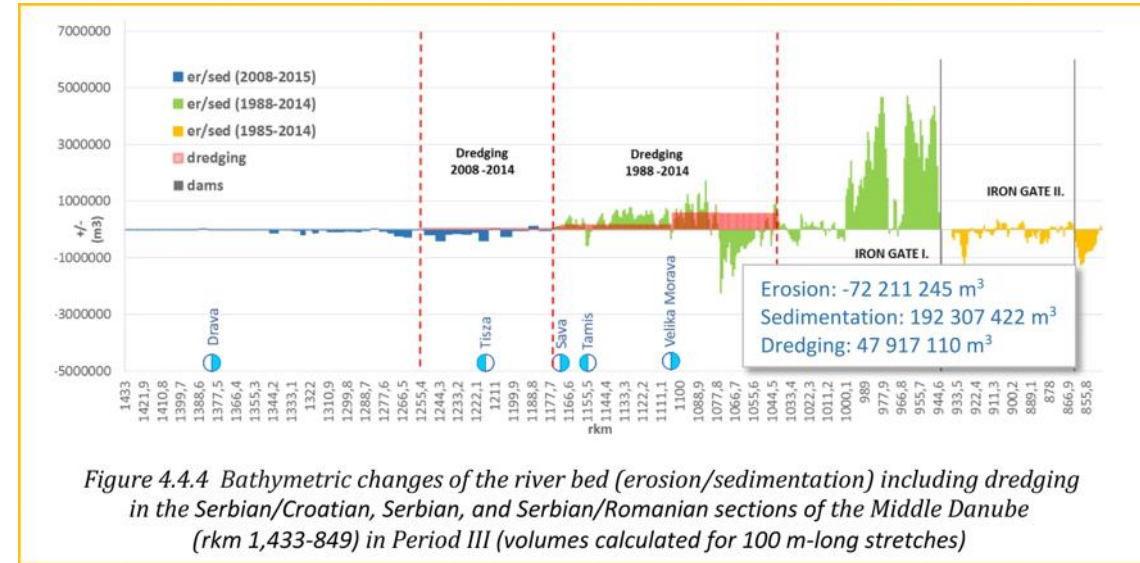


Figure 5.3.2 Cumulative erosion/sedimentation volume curve

Bird populaton

- Nesting
- Wintering



Photo: Martin Čech

Table 4: Selected bird species for MCA in terms of nesting

	Nesting
Waterfowls	Anseriformes (Aythya ferina, Aythya fuligula, Anas crecca, Tadorna tadorna, Branta leucopsis, Cygnus Cygnus)
	Ciconiformes fam. Ardeidae (Ardea cinere, Ardea alba, Arde purpurea)
	Gruiformes fam. Ralidae
	Charadriformes fam. Charadriidae (Charadrius dubius), Sternidae
Roller, bee-eater and kingfisher	Coraciformes (Alcedo atis)
Birds of prey	Falconiformes (Haliaeetus albicilla, Milvus migrans)

Table 5: Selected bird species for MCA in terms of wintering

	Wintering
Waterfowls	Anseriformes
Birds of prey	Falconiformes (Haliaeetus albicilla)

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Fish populaton

- Spawning
- Migration
- Growing
- Living

Table 6: Selected fish species for MCA
(Legend: (R) – rheophils; (Li) – lithophils; (L&Ph) - Limnophils & phytophils)

Species name	Latin name	Status (IUCN)	Status (SRB)	Status (HR)	EU Habitat Directive
Asp (R)	<i>Aspius aspius</i>	LC	P	LC	Annex II, V
Common barbel (R)	<i>Barbus barbus</i>	LC	P	LC	Annex V
Balkan loach (L&Ph)	<i>Cobitis elongata</i>	LC	SP	VU	Annex II
Loach (L&Ph)	<i>Cobitis elongatoides</i>		P	VU	Annex II
Danube bleak (R)	<i>Alburnus sava</i>	LC	SP	LC	
Balon's ruffe (L)	<i>Gymnocephalus baloni</i>	LC	SP	VU	Annex II, IV
Schraetzer (L)	<i>Gymnocephalus schraetser</i>	LC	P	CR	Annex II, V
Ide (L&Ph)	<i>Leuciscus idus</i>	LC	P	VU	
Common chub (R)	<i>Squalius cephalus</i>	LC	P	VU	
Cactus roach (R)	<i>Rutilus virgo</i>	LC	P	NT	Annex II, V

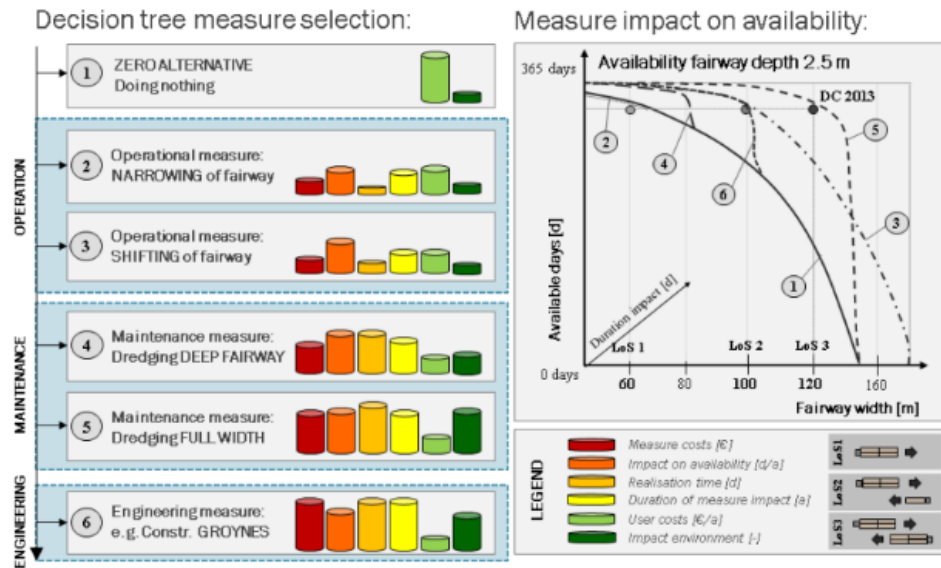
Flora

Registered species of the flora that will be analysed along critical sectors are:

- 91E0* Alluvial forests - *Alnus glutinosa* and *Fraxinus excelsior* (Alno-Padion, Alnion incanae, Salicion albae) - *Populus alba*, *Populus nigra*, *Salix alba*, *Rubus caesius*, *Carex elata*, *Carex remota*, *Carex riparia*, *Galium palust*, *Polygonum hydropiper*, *Rumex sanguineus*;
- 3130 Oligotrophic to mesotrophic standing waters with vegetation - *Lindernia dubia*, *Eleocharis acicularis*, *Cyperus michelianus*, *Lythrum portula*;
- 3150 Natural eutrophic lakes with Hydrocharition or Magnopotamion type vegetation - *Lemna* spp., *Spirodela polyrhiza*, *Utricularia vulgaris*, *Azolla filiculoides*, *Salvinia natans* (emerged plants);
- 3270 Rivers with muddy banks - *Bidens frondosa*, *Bidens tripartitus*, *Polygonum hydropiper*, *Potentilla supina*.

Feasibility group of criteria

Code	Criteria	Indicators	Acceptable Score	Weighting coefficient
F ₁	Technical aspects	<u>Quantitative</u> - Response time and execution of works	0.25 - 1	0.05
F ₂	Financial aspects	<u>Quantitative</u> - CBA (Investment and maintenance costs/avoided users costs as benefit)	0.25 - 2	0.15



Numerical example (1)

Navigation group of criteria

Scenario Indicators - Subcriteria	"Do-nothing" (Reference values/state)	Groyne system (Indicators -> Score)	Fairway realignment (Explanation -> Score)
Water depth	ref. value: $\bar{H} = 2.45$ m <i>Comment: DC recommendation is not met</i>	<i>ratio</i> = 1.08 ($\bar{H} = 2.65$ m)	<i>ratio</i> = 1.04 ($\bar{H} = 2.55$ m)
Top width	ref. value: $\bar{B} = 170$ m <i>Comment: DC recommendation is not met</i>	<i>ratio</i> = 1.10 ($\bar{B} = 187$ m)	<i>ratio</i> = 1.07 ($\bar{B} = 182$ m)
Curve radius	ref. value: $\bar{R} = 1300$ m	<i>ratio</i> = 1.00 ($\bar{R} = 1300$ m)	<i>ratio</i> = 0.95 ($\bar{R} = 1240$ m)
N₁ - DC Requirements	1.0	2.0	1.5
Velocity	ref. value: $\bar{V}_{max} = 1.70$ m/s	<i>ratio</i> = 1.03 ($\bar{V}_{max} = 1.75$ m/s)	<i>ratio</i> = 1.00 ($\bar{V}_{max} = 1.70$ m/s)
Hindrance	ref. state: No sudden change in flow pattern	proj. state: No sudden change in flow pattern	proj. state: Moderate changes in flow pattern
N₂ - Maneuverability	1.0	1.0	0.5
Visibility of the structures	ref. state: There are four groynes on the sector with same crest level = DLNL + 1m	proj. state: Additional four groynes with crest level = DLNL + 1m (slightly increased risk of accidents)	New marking works will be conducted
N₃ - Safety	1.0	0.5	1.5

Numerical example (2)

Feasibility group of criteria

Scenario	"Do-nothing" (Reference values/state)	Groyne system (Indicators -> Score)	Fairway realignment (Explanation -> Score)
Indicators - Subcriteria			
Response time ref. value/ratio	<i>no response time</i>	<i>long period</i>	<i>short period</i>
Execution of works	without execution works	moderate difficulty	improving marking system (simple implementation)
F ₁ - Technical aspects	1.0	0.25	1.0
CBA ref. value/ratio	<0	<i>significantly higher B-C</i>	<i>higher B-C</i>
F ₂ - Financial aspects	1.0	2.0	1.5

Total score

	Group score for navigation	Group score for environment	Group score for feasibility	Total Score
"Do nothing"	1.00	1.00	1.00	1.00
Groyne system	1.07	0.81	1.04	0.90
Fairway realignment	1.05	1.00	1.06	1.12

Environment group of criteria

Scenario	"Do-nothing" (Reference values/state)	Groyne system on convex side of the bend (Indicators -> Score)	Fairway realignment (Explanation -> Score)
River bed volume	ref. value: $V = -88500 \text{ m}^3$	$\text{diff.} = -7000 \text{ m}^3$ $(V = -95500 \text{ m}^3)$	$\text{diff.} = 0$ $(V = -88500 \text{ m}^3)$
SHDi	ref. value: $SHDi = 0.78$	$\text{ratio} = 0.96$ $(SHDi = 0.75)$ Negative impact on biodiversity (living organisms negatively affected)	$\text{ratio} = 1.0$ $(SHDi = 0.78)$
Length of LF channels ref. value/ratio	ref. value: $L_{lf} = 250 \text{ m}$	$\text{ratio} = 0.84$ $(L_{lf} = 210 \text{ m})$	$\text{ratio} = 1.0$ $(L_{lf} = 250 \text{ m})$
Z(Q _{bankfull})	ref. value: Z = 90.00 m.a.s.l.	$\text{diff.} = 1 \text{ cm}$ $(Z = 90.01 \text{ m.a.s.l.})$	$\text{diff.} = 0 \text{ m}$ $(Z = 90.00 \text{ m.a.s.l.})$
Lateral connectivity	ref. value: $V_b = 1.4 \text{ m/s}$	$\text{ratio} = 0.64$ $(V_b = 0.9 \text{ m/s})$ aquatic-terrestrial fluxes disturbed	$\text{ratio} = 1.0$ $(V_b = 1.4 \text{ m/s})$
E ₁ - Hydro-morphology	1.0	0.25	1.0
Dredging volume	n.a.	n.a.	n.a.
Water quality parameters	n.a.	slightly negative effects since local stagnant water introduced	n.a.
E ₂ - Sediment and Water quality	1.0	0.5	1.0
Nesting	ref. state	no changes if groyne system is proposed along shallow banks/ negative effect for steep banks	<i>no changes</i>
wintering	ref. state	n.a.	<i>no changes</i>
E ₃ - Birds	1	1 / 0	1
Spawning	ref. state	n.a.	<i>no changes</i>
Migration	ref. state	n.a.	<i>no changes</i>
Growing	ref. state	sheltered	<i>no changes</i>
Living	ref. state	negative due to siltation	<i>no changes</i>
E ₄ - Fish	1.0	1.0	1.0
Creation of new areas for distribution	ref. state	no significant change	<i>no changes</i>
E ₅ - Flora	1.0	1.0	1.0
Climate change sensitivity	ref. state	<i>moderate sensitivity</i>	<i>no changes regarding reference state</i>
Climate change adaptivity	ref. state	<i>moderate adaptivity</i>	<i>no changes regarding reference state</i>
E ₆ - Climate change vulnerability	1.0	0.5	1.0

Lot 1: Hydraulic and morphological modelling of the
SRB-CRO common stretch of the Danube River
Hydraulic modelling and multi-criteria analysis

Thank you for your kind attention

28/10/2024, Belgrade