Design of a Remediation Approach to Heavy Metals Contaminated Sediments in the Great Backa Canal (Serbia)

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Great Backa Canal (GBC)

- 118 km long and 25 m wide engineered canal built at turn of the 19th century.
- Integrated part of the large Danube-Tisa-Danube Hydro-system (DTD system).
- Main functions:
  - Drainage
  - Irrigation
  - Water supply for industrial users
  - Recipient of wastewaters
  - Navigation
  - Fishery and forestry
  - Tourism, sport and recreation

Site background

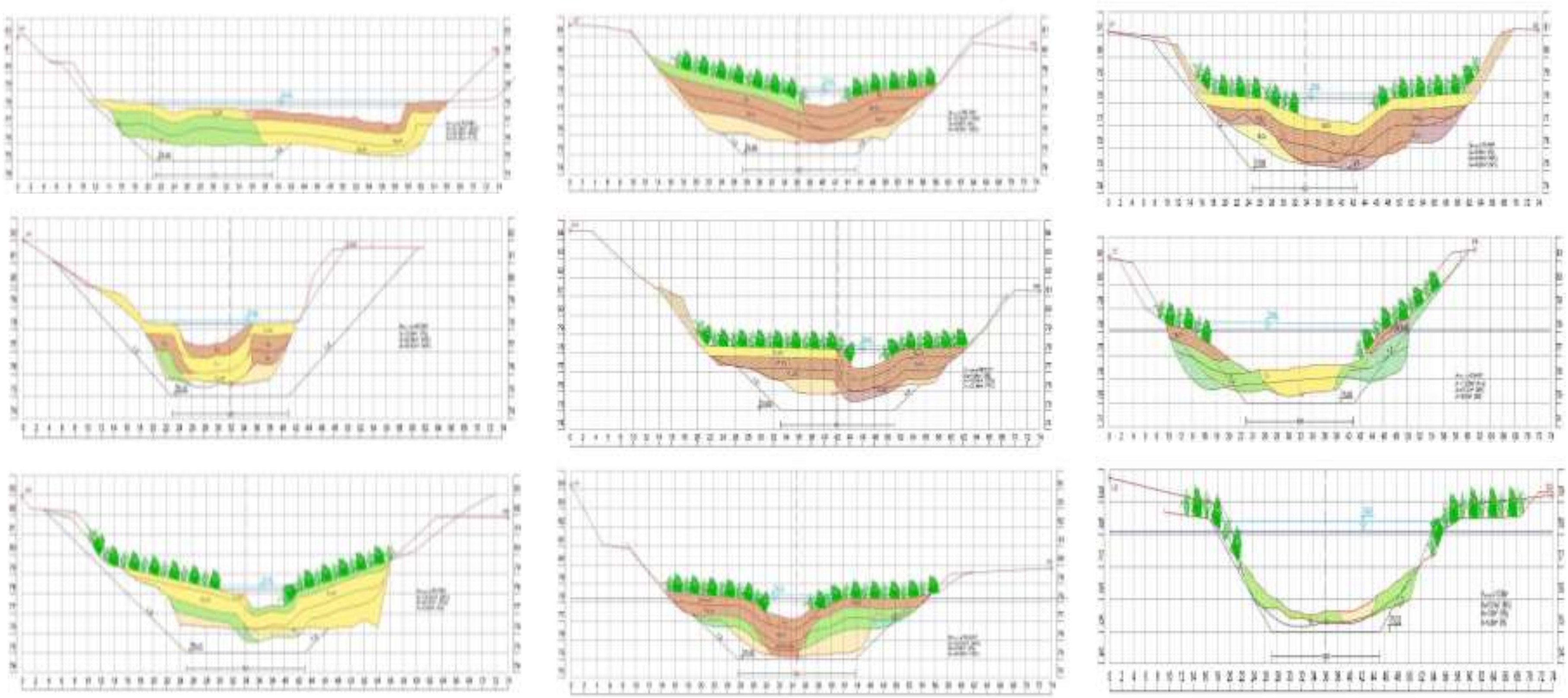
- Until 2010 11 large industrial plants discharged untreated or partially treated waters (mostly food – sugar, oil, meat

INDUSTRY	WWT
Food (meat processing)	Tertiary
Agriculture	Primary
Food	No treatment
Food (edible oil)	Secondary
Municipal	No treatment
Municipal	No treatment
Food	Secondary
Food (sugar)	Primary
Food (sugar)	Primary
Leather	No treatment
Metal	Primary
Food	Primary

17900 m^3 of WW/day
2820 kg BOD/day
8% compliance with ELV

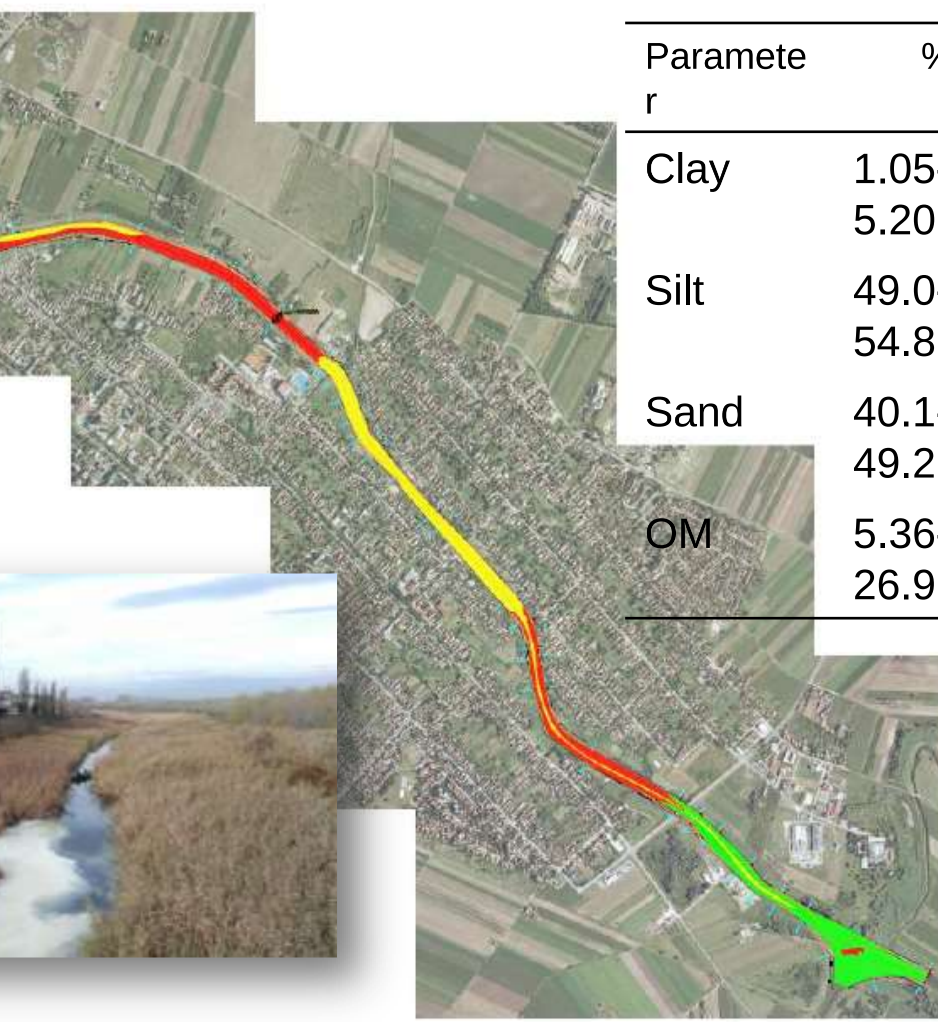
Problem #1: Sediment quantity

- Water depth at some points does not exceed 30-40 cm and 90% of canal bottom is covered with accumulated sediments – cca.



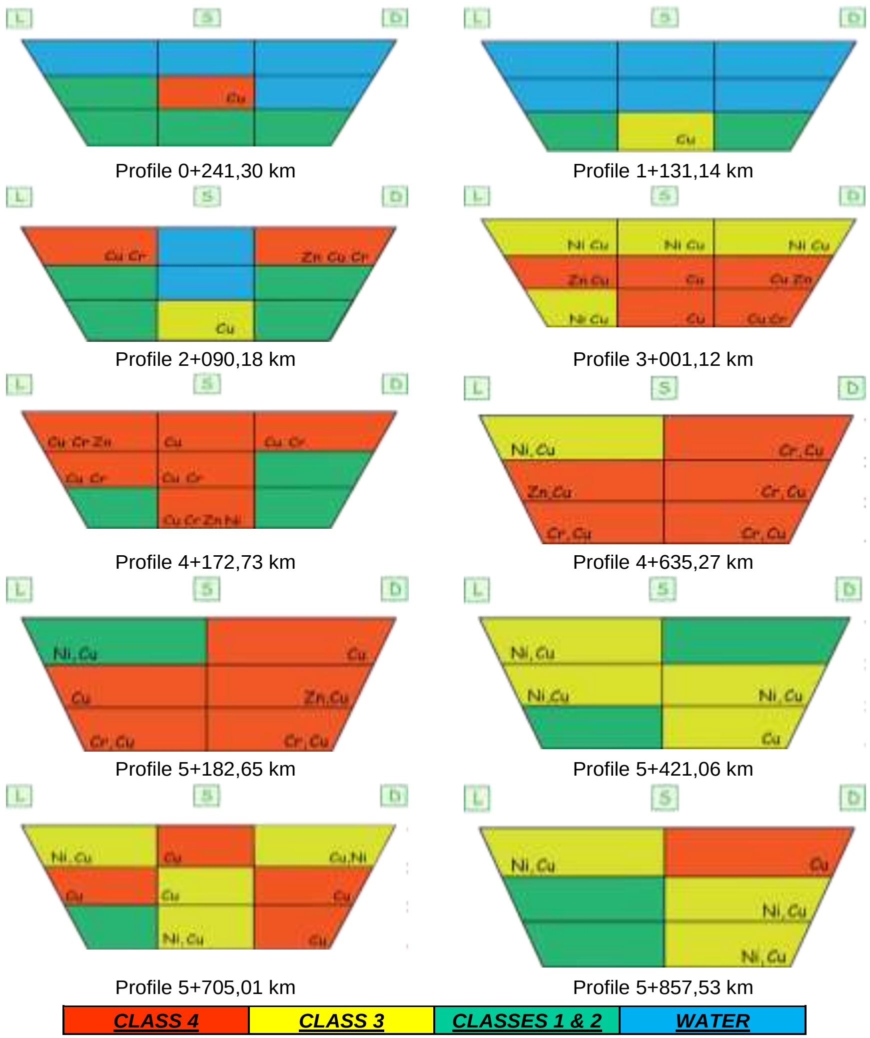
Problem #2: Sediment quality – Spatial distribution of pollution

- Main problem: heavy metals – Cu, Cr, Zn, Ni
- Organic pollutants are generally not present or present at low concentrations
- Microbiology: faecal coliforms



Parameter	%
Clay	1.05-5.20
Silt	49.0-54.8
Sand	40.1-49.2
OM	5.36-26.9

Problem #2: Sediment quality – Vertical distribution of pollution



Total quantity of sediment of 1 and 2 class:	~ 96 000 m^3
Total quantity of sediment of 3 class:	~ 94 000 m^3
Total quantity of sediment of 4 class:	~ 179 000 m^3
TOTAL	~ 369 000 m^3

Assessment of the sediment quality using a variety of criteria – 2012 campaign

Sampling site	Serbian national EQS	> PEL	SEM/AVS	RAC	CF > 6	PLI > 1	EF 10-25
0.000 t	4 (Cr, Cu)	Cr, Cu		Zn, Ni	Cr, Cu	+	
0.800 t	4 (Cu)	Cr, Cu, Pb			Cu, Pb	+	
0.800 m	3 (Cu, Ni)			Ni	Cu	+	
2.000 t	4 (Cr, Cu, Ni, Zn)	Cd, Cr, Cu, Ni, Zn, Pb		Zn	Cr, Cu, Pb, Ni, Zn	+	Cr, Cu, Ni, Zn
2.000 m	4 (Cu, Cr)	Cu, Cr		Zn, Ni	Cr, Cu	+	Cr, Cu
2.000 b	3 (Cu, Ni)	Cr		Zn, Ni	Cu, Ni, Zn	+	
2.900 t	4 (Cu, Ni, Zn)	Cu, Cr, Pb, Zn		Zn, Ni	Cu, Ni, Zn	+	Cu
2.900 m	4 (Cu, Ni, Zn)	Cd, Cr, Cu, Pb, Zn		Zn, Ni	Cu, Ni, Zn	+	Cu, Ni, Zn
4.000 t	4 (Cr, Cu, Ni, Zn, Pb)	Cd, Cr, Cu, Pb, Zn	+	Zn, Ni	Cu, Ni, Zn	+	Cr, Cu, Ni, Zn
4.000 m	4 (Cr, Cu, Ni, Zn)	Cd, Cr, Cu, Pb, Zn		Zn, Ni	Cr, Cu, Pb, Ni, Zn	+	Cr, Cu, Zn
4.000 b	4 (Cu, Cr, Zn)	Cr, Cu, Pb, Zn		Zn, Ni	Cr, Cu, Zn	+	Cr, Cu
4.900 t	4 (Cu, Ni, Zn)	Cd, Cr, Cu, Pb, Zn		Zn, Ni	Cr, Cu, Zn, Ni	+	Cu, Zn
4.900 m	4 (Cu, Ni, Zn)	Cd, Cr, Cu, Zn		Zn, Ni	Cr, Cu, Zn, Ni	+	Cu, Zn
4.900 b	4 (Cr, Cu)	Cr, Cu, Zn		Zn, Ni	Cu, Cr	+	Cr, Cu
5.800 t	4 (Cu)	Cr, Cu, Zn		Zn, Ni	Cu, Zn	+	Cu
5.800 m	3 (Cu, Ni)			Zn	Cu	+	

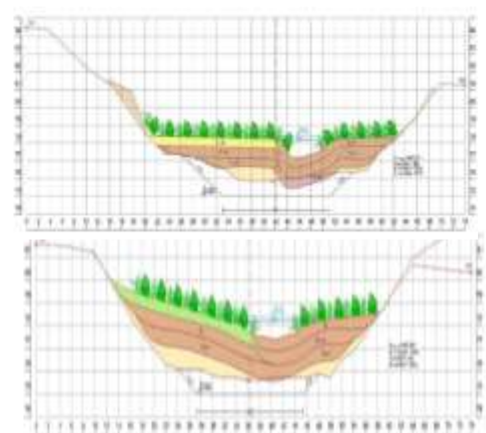
Krčmar et al. (2013) *Journal of Environmental Science and Health, Part A*, 48, [illegible]

Remediation of GBC

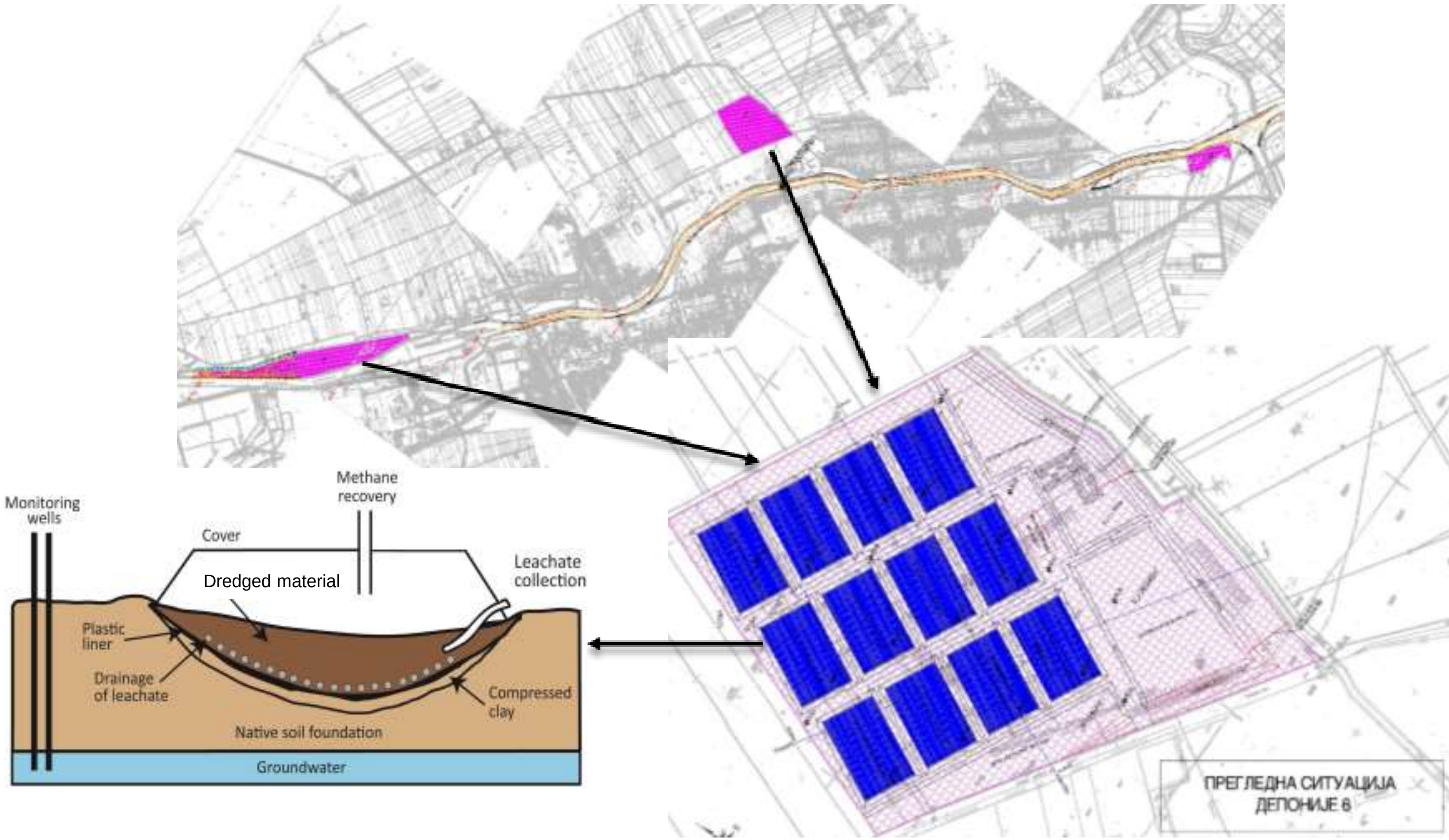
- The goal is to restore full function of canal which requires removal of contaminated and noncontaminated sediment from canal, its transport, treatment and disposal in environmentally safe way.
- Pre-feasibility study and General design propose technical solutions for:
  - sediment dredging;
  - sediment transport to landfills (3 sites are foreseen by Pre-Feasibility Study);
  - temporary storage and dewatering,
  - treatment of contaminated;
  - final disposal and/or beneficial use.

Sediment dredging

- Hydraulic dredging:
  - Favorable due to less sediment disturbances and impacts downstream
  - No road transport needed for dredged material
- Mechanical dredging:
  - Gives dredged material with less water – significantly shortens treatment cycle (ecpecially critical dewatering phase)

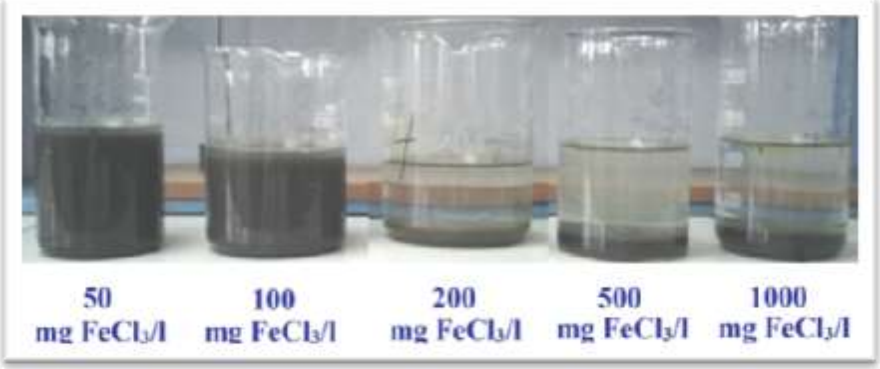


Dewatering and interim/final storage



Sanitary landfill leachate treatment

Metal	Coagulant dosage [mg $FeCl_3$/L], residence time 2 h						EQS 2nd class	EQS 3rd class
	0	50	100	200	500	1000		
	Metals [µg/L]							
Cu	68.8	10.14	6.58	5.65	1.43	2.29	40	500
Ni	19.38	3.46	3.08	3.7	16.87	17.61	20	20
Cr	17.11	2.33	1.49	0.69	0.86	1.08	50	100
Zn	173.77	14.28	14.66	24.55	5.52	27.35	1000	2000
Cd	0.48	0.06	0.08	0.13	0.03	0.05	0.45	0.6
As	19.39	20.3	13.05	10.4	10.9	16.82	10	50
Pb	20.5	1.96	2.2	0.57	0.43	0.5	7.2	7.2
Fe	6199	592.8	345.6	551.7	12684	28186	500	1000
Mn	173.5	88.39	146.9	360.6	962.3	1802	100	300



- 200 g $FeCl_3/m^3$
- 2 h residence time

Sediment remediation technology options

TABLE 3-1. INITIAL SCREENING BY CONTAMINANT GROUP

Contaminant group	Biological treatment	Dechlorination	Soil washing	Solvent extraction	Solidification/ stabilization	Incineration	Thermal desorption
Organics							
Halogenated volatiles	O	O	+	O	x	+	O
Nonhalogenated volatiles	O	x	+	O	x	+	O
Halogenated semivolatiles	+	+	O	O	x	+	O
Nonhalogenated semivolatiles	+	x	O	O	x	+	O
PCBs	O	+	O	+	O	+	+
Pesticides	O	O	O	O	O	O	O
Dioxins/furans	x	+	O	O	x	+	O
Organic corrosives	x	x	O	O	+	O	x
Organic cyanides	+	x	O	O	O	O	O
Inorganics							
Nonvolatile metals	x	x	O	x	+	x	x
Inorganic corrosives	x	x	O	x	+	x	x
Inorganic cyanides	O	x	O	x	+	O	x

Legend

+ Demonstrated effectiveness: Successful treatability test at some scale completed.
O Potential effectiveness but not demonstrated: Expert opinion that technology will work.
x No expected effectiveness
U Unspecified. Insufficient data available for adequate evaluation.

Source: Selecting Remediation Techniques For Contaminated Sediment, USEPA (1993)

Solidification/stabilization (S/S) treatment

- Local clay (C) was used as S/S agent and it was mixed with the dried sediment (40% of moisture) in the following proportions:
  - From 5:95 wt. - 90:10 wt.
- The mixtures were then homogenized on a milling machine using sieves with 3 mm pores.
- The compaction was performed according to ASTM D1557-00 (ASTM, 2000), providing a compactive force of 2700 kN m/m^3.

Krcmar, D., Dalmacija, M., Dalmacija, B., Prica, M., Trickovic, J., Karlovic, E. (2013) Evaluating the necessity for thermal treatment in clay-based metal immobilization techniques as an environmentally acceptable sediment remediation process. *Journal of Soils and Sediments* 13 (7), pp. 1318-1326.

Additional thermal treatment

- Carried out in an electrical furnace at a constant temperature of 1050±5^{0}C with variations in heating rate (4.6 ^{0}C/min from 25^{0}C to 300^{0}C, 1.7 ^{0}C/min from 300^{0}C to maximum T, 5h hold at max T).
- Samples were cured at 20°C in sealed sample bags for 28 days and then subjected to series of leachability tests for treatment efficiency.

Krcmar, D., Dalmacija, M., Dalmacija, B., Prica, M., Trickovic, J., Karlovic, E. (2013) Evaluating the necessity for thermal treatment in clay-based metal immobilization techniques as an environmentally acceptable sediment remediation process. *Journal of Soils and Sediments* 13 (7), pp. 1318-1326.

S/S treatment efficiency

ANS test - Mean leachability indices (LX)

Samples	Metals					
	Cr	Ni	Cu	Zn	Cd	Pb
S0	5.2	5.4	6.1	5.7	6	6.2
C5	10.6	12	13.4	12.7	13.3	13.4
C10	10.5	12	13.4	12.9	13.3	13.6
C20	9.8	12.1	13.5	13	13.3	13.6
C50	9.3	12.2	13.6	13	13.4	13.8
C80	9.3	12.4	13.7	13	13.6	13.8
C90	9.2	12.6	13.8	13.1	13.7	13.9
T5	11.4	14	14.3	14.2	14.3	14.4
T10	11.2	14.2	14.5	14.3	14.4	14.5
T20	11.3	14.2	14.5	14.4	14.4	14.6
T50	11.2	14.3	14.6	14.5	14.6	14.7
T80	11.2	14.4	14.7	14.5	14.6	14.8
T90	11	14.5	14.8	14.7	14.8	14.9

- Suitable for both beneficial use (LX > 9) or disposal at sanitary landfill (LX > 8).
- Thermal treatment is economically justified only if beneficial use of final S/S material is possible.

S0 – untreated sediment sample, C – non-thermally treated samples, T – thermally treated samples, numbers 5, 10, 20, 50, 80 and 90 in sediment samples stands for percentage (%) of clay present (wt.)

Option analysis

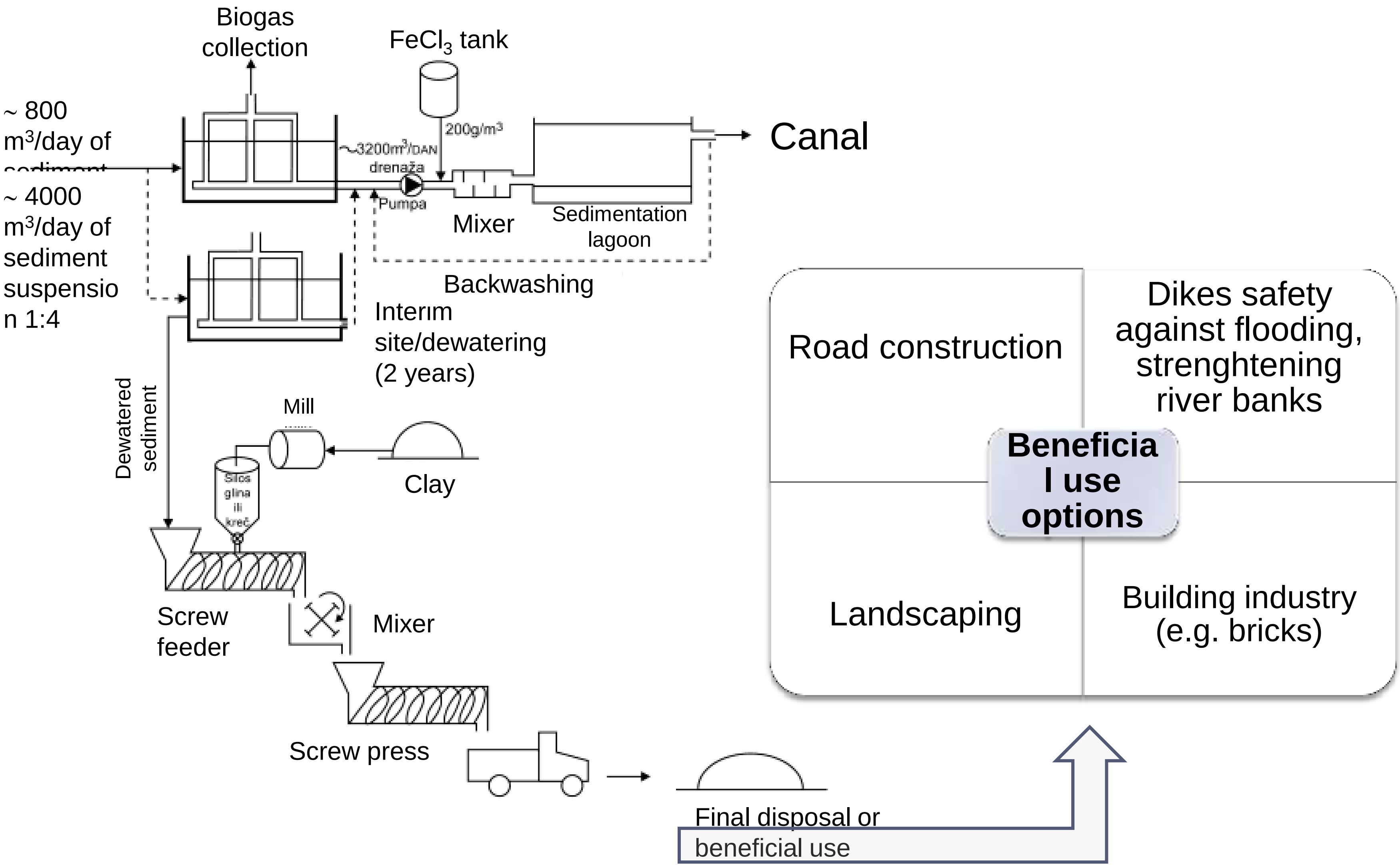
<table>
<tr><th colspan="5">OPTIONS</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>Hydraulic dredging</td><td>Hydraulic dredging and excavation</td><td>Hydraulic dredging</td><td>Hydraulic dredging and excavation</td><td>Hydraulic dredging (and excavation)</td></tr>
<tr><td colspan="2">Dewatering on temporary/interim sites (cassettes)</td><td colspan="2">Dewatering of the sludge with centrifuge</td><td>Dewatering of the sludge with centrifuge</td></tr>
<tr><td>S/S treatment of sediments – dynamics is determined by the speed of dewatering process</td><td colspan="3">S/S treatment of sediments by dredging dynamics</td><td>No treatment</td></tr>
<tr><td colspan="4">Permanent disposal in sanitary landfill and / or beneficial use of stabilized material</td><td>Permanent disposal on sanitary landfill w/o treatment</td></tr>
</table>

Socio-economic analysis (MCDM - Electre)

Criteria	Total investment	Total cost	Cost of sediment treatment	Total time for project completion	Duration of sediment treatment	Residual value of equipment	Environmental impact
Unit	EUR	EUR	EUR	Months	Months	EUR	/
Option 1	5,947,411	5,922,343	927,390	86	52	489,831	Good (3)
Option 2	9,550,033	5,179,573	618,099	25	10	4,527,458	Weak (1)
Option 3	8,286,349	4,247,431	991,677	22	7	4,557,966	Very good (4)
Option 4	8,266,515	4,326,172	960,081	22	7	6,666,864	Weak (1)
Option 5	4,694,199	4,642,758	0	322	/	0	Acceptable (2)
Goal	Min	Min	Min	Min	Min	Min	Max
Weight coefficients							
Alternative 1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Alternative 2	0.2	0.2	0.1	0.1	/	0.2	0.2
Alternative 3	0.3	0.2	/	/	0.1	0.2	0.2

- Alternative 1: Option 3 – excavation and transport of sediment through urban area
- Alternative 2: Option 1 – lenghty, but low investment cost and environmentally sound
- Alternative 3: Option 5 – the cheapest option, but public acceptance might be a problem

The most preferred option – Option 1



Preconditions and next steps

- Building sewarage network and connecting all polluters (communal, private, industrial) to the newly built municipal WWTP,
- Remediation of lateral GBCs D61 and D64 to avoid future re-pollution,
- No further “temporary” disposal of dredging material from lateral GBCs (assumed polluted),
- Cleaning of GBC up-stream of Vrbas lock to avoid future re-pollution.

Thank you for your attention!

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