
Multi-Stage Treatment
System for Removal of
Heavy Metal Contaminants


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Al Mattes
Nature Works
Doug Gould
CANMET
Bill Duncan
Teck Cominco

Presentation Outline

- Describe design and construction details
- Discuss microbial reactions
- Describe testing protocols and assays
- Summarize results
  - Flow rates
  - pH and dissolved oxygen
  - Metals removed
  - Bacterial activity
  - Role of plants

Construction Details

- Initial phase constructed in 1997 as three gravel bed free-surface flow wetlands treatment cells
- Bench scale testing showed need for pre-treatment to reduce metals
- Anaerobic bioreactor added in 1998
- Second anaerobic bioreactor added in 2000
- System winterized in 2000
- Sand Filter added in 2001

System Layout

Anaerobic Bioreactor

Anaerobic Bioreactor

Plant Cell Research

Plant Cell Grasses

Typha latifolia

Holding Pond


HITACHI

Anaerobic Cell Design

- Two formulas used to size cells based on metal loading.
- Volume (*rule of thumb*) based on removal of 0.3 mol /m^3 of biosolid
- Volume = (155 mol/d)/((0.3 mol/m^3d))
- Area (*rule of thumb*) 10 – 20 m^2min/L; pH dependent with higher pH requiring lower loading
- Area = ((20m^2min/L)X 13.9 L/min)

Microbiological Chemistry

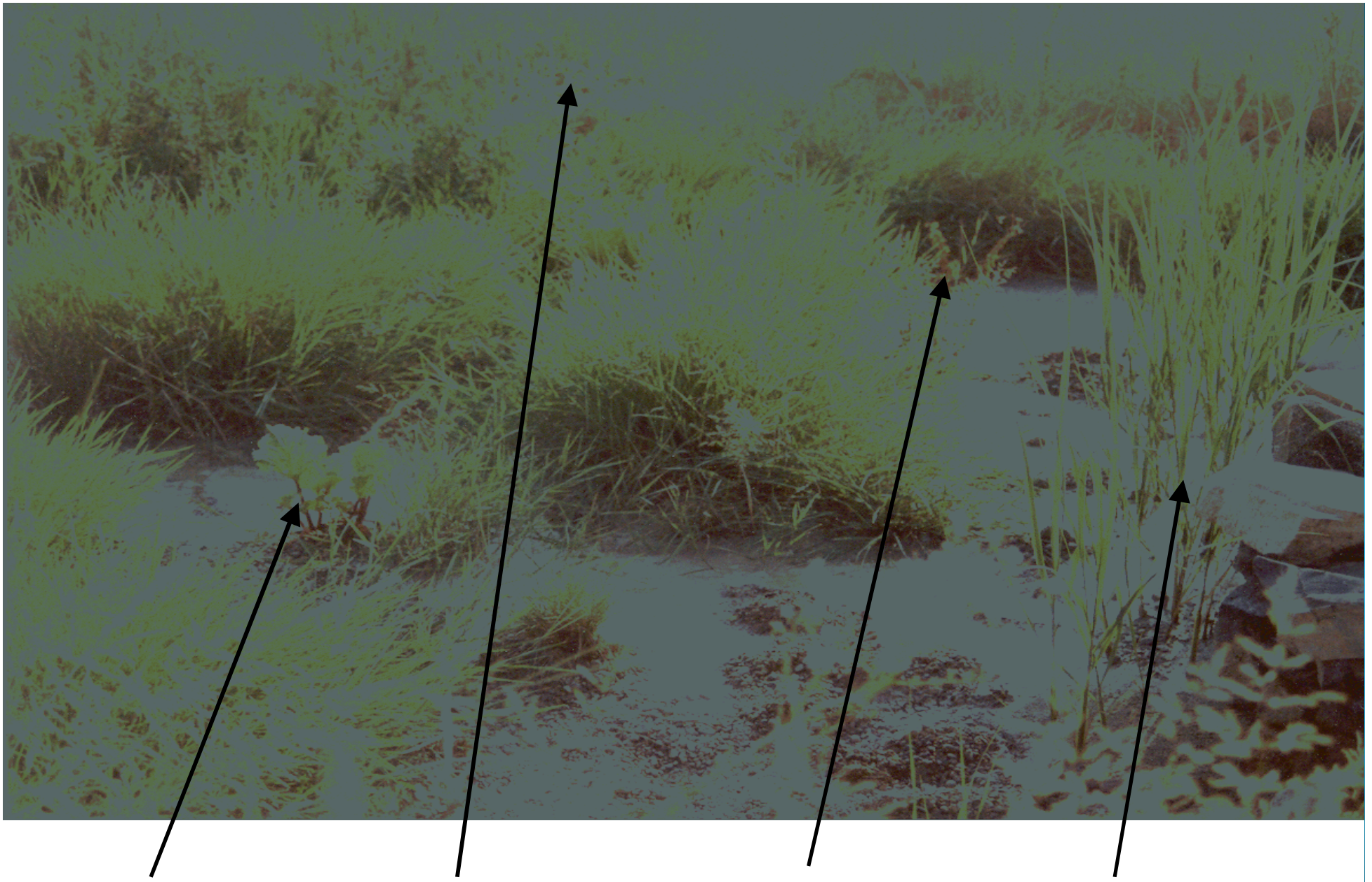
- Sulphate-reducing bacteria (SRBs) using carbon as a substrate can reduce metal sulphates to metal sulphides by:

- $2CHO + SO_4^{=} + 2\ H^{+} \rightarrow H_2S + 2HCO_3^{-}$

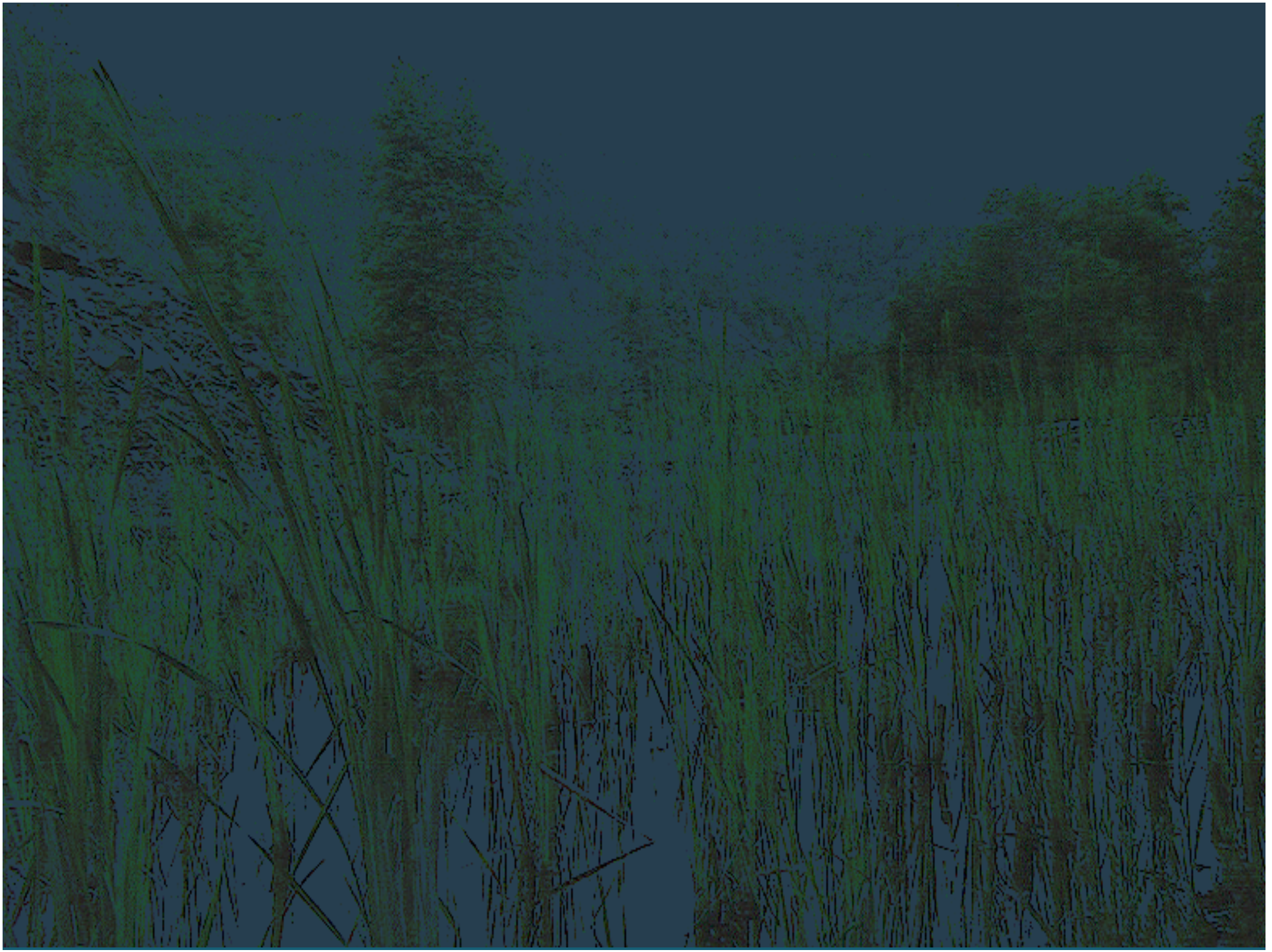
- $Zn^{2+} + H_2S \longrightarrow ZnS + 2H^{+}$

Testing Protocols & Assays

- Accumulating flow meter gives daily and total flow to system; System flow through set manually
- Thrice weekly assays of water at 8 points for metal content (Zn, Cd, As)
- pH and dissolved oxygen completed for each sample
- Labelled plants sampled monthly (June – Sept.) for metal content
- Anaerobic samples of bioreactors taken twice/year
- Rainfall, temperature and evaporation rate monitored



Late Summer (*Epilobium* has seeded)




Results
8/2/2002

Flow Rates

Time Period	Total Summer Flow	Mean Daily Flow	Total Evaporated	Winter Flow	Year's Total
07/06/00 to 20/01/01	2,354,209	16,348	556,619	486,000	2,840,209
01/05/01 to 20/01/02	2,615,612	15,327	570,876	486,000	3,101,612

Mean pH and D.O. levels

Period	Parameter	Input	Anaerobic one	Anaerobic two	1st Plant	2nd Plant	*Typha*
07/06/2000 – 20/01/2001 (n = 74)							
	pH	5.13	6.76	6.94	6.86	6.78	6.83
	D.O.	6.24	3.0	2.10	1.82	1.85	2.99
01/05/2001 – 08/08/2001 * (n = 55)	*Data given only to Aug 8th, pH adjustment began to fail.*						
	pH	5.52	6.80	7.12	7.04	7.12	7.28
	D.O.	3.88	2.44	3.06	1.40	1.80	3.65

Mean Metal Removal
07/05/00 – 20/01/01 (n = 56)

Assay Point	Arsenic Level (ppm)	% Reduction	Cadmium Level (ppm)	% Reduction	Zinc Level (ppm)	% Reduction
Input	39.4		5.3		395.9	
Anaerobic 1	9.2	76.5	1.9	63.2	226.3	42.9
Anaerobic 2	10.5	+ 13.6	0.3	83.2	102.6	54.7
Cell 1	8.4	19.8	0.2	21.2	63.8	37.8
Cell 2	8.3	1.3	0.2	23.1	53.6	16.1
Cell 3	1.9	76.8	0.03	85.0	14.2	73.4
Final Pond	1.6	15	0.02	33.4	11.4	19.9
Total %		95.80		99.50		97.10

Mean Metal Removal 14/05/01 – 20/01/02 (n = 72)

Assay Point	As Total (ppm)	% Reduction	Cd Total (ppm)	% Reduction	Zn Total (ppm)	% Reduction
Input	99.6		4.97		314.25	
Anaerobic One	28.21	71.4	2.03	59.1	128.97	59.0
Anaerobic Two	5.67	80.0	0.37	81.8	99.62	22.8
1st Plant	1.59	80.4	0.04	89.1	47.01	52.8
2nd Plant	1.11	30.2	0.04	0	39.88	15.2
Typha	1.04	6.8	0.04	0	25.35	36.4
Holding Pond	0.95	8.7	0.04	0	18.67	26.4
% Reduction		99.1		99.2		94.0

Metal Removal by Bacteria

Metal Removal in Anaerobic Bioreactors 14/05/01 – 20/01/02

Cell	As Total (ppm)	% Removed in Cell	Cd Total (ppm)	% Removed in Cell	Zn Total (ppm)	% Removed in Cell
Anaerobic One Input	99.6		4.9		314.3	
Anaerobic One Output	28.2	71.4	2.0	59.2	129	58.6
Anaerobic Two Output	5.7	80.0	0.4	81.8	99.6	22.8
Total % Removed		94.3		92.6		68.3

Microbial Populations

	Microbial Populations, #/g or #/ml* (Average values)		
Location	Fermentative Bacteria	Sulphate Reducing Bacteria	Iron Reducing Bacteria
First cell: surface	1.3×10^4	1.3×10^6	5.1×10^4
First cell: 5-20 cm	2.2×10^6	7.4×10^5	6.3×10^4
Second cell: surface	6.4×10^4	8.2×10^6	2.1×10^6
Second cell: 5-20 cm	1.1×10^6	1.7×10^7	4.1×10^6
Plant cell #1 outlet *	n.d.	3.3×10^5	7.9×10^3
Plant cell #2 outlet *	n.d.	3.1×10^4	7.9×10^4
Typha cell outlet *	n.d.	3.3×10^5	7.9×10^3
Holding pond *	n.d.	2.7×10^5	3.3×10^5

Metal Removal by Plants

Plant Species	N =	Zn (ppm)	As (ppm)	Cd (ppm)	Pb (ppm)	TOTAL
Epilobium grandifolia	63	2249	157	13	74	2493
Rheum rhaponticum	19	2281	130	14	33	2459
Deschampsia	6	1747	61	11	65	1884
Typha latifolia	46	423	29	10	35	1313
Salix (ssp streamco)	24	1021	9	5	19	1054
Salix (spp native)	16	951	18	12	21	1002
Comparison						
Grasses (various)	19	370	6	1	6	385
Salix (Native)	43	361	6	1	6	374
Typha latifolia	86	361	6	1	6	374
Epilobium grandifolia	24	351	5	1	6	363

Conclusions

- A biologically based treatment system to remove heavy metals from landfill leachate has been constructed and operated year-round.
- Anaerobic bioreactors can remove more than 90% of metals.
- A list of plants that are metal tolerant and in some cases capable of accumulation has been developed.
- Some problems occurred with pH adjustment mechanism that resulted in reduced Zn removal efficiency. This has been solved by a design change.

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