Field Scale Prototype Anaerobic/Wetlamds Cells for Removing Heavy Metals from Water Leaching from a Historical Capped Landfill

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ABSTRACT

A passive treatment system utilizing an anaerobic digester followed by three plant based treatment cells has been built in Trail, British Columbia, site of the world's largest non-ferrous smelter. Water becomes contaminated with heavy metals as it passes through discarded materials from the smelter and through a former Arsenic storage area. This water, containing large amounts of dissolved Zn., Cd., and As is collected and pumped to the pilot scale treatment facility.

The facility, capable of treating 12-15,000 L of water daily includes a large anaerobic digester that utilizes waste by-product from the pulp and paper industry as a matrix for Sulphur Reducing Bacteria. The partially treated water then flows through a series of hydroponics cells containing a mixture of metal-resistant fast growing plants. The system uses gravity based hydroponics flow-through and solar powered aeration cells between garden cells.

During the summer months transpiration will yield expected (or greater) results. All plants are perennials and after two months of operation there were no signs of impaired plant functioning.

SITE PROBLEM

A historical vegetation-capped landfill, near the Cominco smelter in Trail BC, produces a leachate that contains toxic metals. Prior to 1997, rainwater percolating through the landfill dissolved metals and traveled downwards through an extensive layer of sand until bedrock was reached. At this point it moved laterally, eventually making its way to Stoney Creek and into the Columbia River. In 1996, Cominco Ltd. hired Klohn-Crippen, an engineering consulting firm to characterize the seepage flows and geohydrology of the Stoney Creek basin. They used the characterization study to design and build a seepage collection system in 1997. This collection system funneled the seepage water into a system of collection sumps. From the final sump it is pumped to a lime-based Effluent Treatment Plant.

Table 1: Approximate total volume of water and metal contaminants entering Stoney Creek daily from seeps originating from capped landfill and an Arsenic storage area.

Total Volume/Day	**Containing Following Heavy Metals (ppm)**			
	Arsenic	**Cadmium**	**Zinc**	**Lead**
77,000 liters	45	3.64	205	0.056

Table 1 shows the average amount of water that enters Stoney Creek daily after flowing downwards through the now-capped landfill site. While passing through discarded material from the landfill it dissolves metals including Zn and Cd and trace amounts of other metals. Arsenic entered the creek from a storage area on the other side of the valley. To arrive at the figures in the table, volumes from separate seeps have been combined. The metal presence is based on highest readings as taken from the initial input into the treatment system.

To evaluate an alternative treatment technology that could be built near the seeps, Northern Water, Environment & Training Services was contracted by Cominco Ltd. to design and build a prototype phytoremediation treatment system.

SYSTEM DESIGN AND CONSTRUCTION

During the summer of 1997 a series of self-contained sub-surface flow wetland cells were constructed on a Cominco property. The property was ideal topographically and, in addition, had a stream of clean water that ran year round. Jim Hall, a local contractor was hired to build three treatment cells, two aeration cells and a final holding pond. The: cells were designed and built using typical constructed wetland techniques (Kadlec, and Knight, 1996).

Cells were planted with fast growing plants chosen for their reported abilities to sequester heavy metals and for their potential as root filtration systems. The first cell was planted with *Brassica juncea* and *Helianthus annuus* following reports in the literature discussing their abilities to function as phytoremediators, (Salt et al, 1995, Dushenkov et al, 1995). A local grass *(Agrostis stolonifera)* growing proliilcally in the area was planted in the front half of the second cell. This was augmented by an extensive planting of *Calamagrostis canadensis* utilized because of its extensive root structure, invasive habit and ability to survive and thrive in difficult habitat. A final cell was planted with *Typha latifolia* used for its high biomass production and excellent rhizosphere potential.

The first two cells are $50m^2$ and the final cell is $300\ m^2$. A final large lined holding pond was built as the final stage in the system. Water is held there for final testing before being delivered back to the environment.

Oxygen depletion during treatment in each cell was an important system design consideration. Accordingly, a $6m^2$ aeration cell was built between cells one and two and two and three. These cells serve as the location for a control system to set water level in the preceding cell and they are convenient sample points for testing purposes.

BENCH-SCALE TESTING

With the co-operation of Dr. W. Rauser and Dr. B Husband at the University of Guelph, space was secured in the greenhouse for bench scale testing. Models of the system as built in Trail were constructed and planted with the species being investigated. Large 77 L containers, each containing one or more of the metals found as contaminants in the leachate were used to provide water at a rate that corresponded to that planned for the field-scale system. Three systems were exposed to solutions containing 5, 10 and 40% of the metals present in the leachate as well as a control system using deionized water.

This greenhouse research showed that the metal levels in full-strength leachate were too high for the chosen plants. Metal levels would need to be reduced by 50 - 90% if complete treatment of the leachate by wetlands were to be successful. During the same period Cominco Research personnel examined the efficacy of various biomass materials to remove metals in an anaerobic environment. This work showed that as much as 90% of the metals present in the leachate could be removed using a locally available residual biomass product from a nearby pulp mill.

For purposes of the prototype both dilution and pre-treatment using an anaerobic digester were considered. The second option was chosen as it would provide complete treatment and allow the pilot plant to be scaled up to treat the seepages in situ. Therefore, during the early summer of 1998 a large, 50Om^3 anaerobic digester was built to provide a complete treatment system.

DESIGN AND CONSTRUCTION OF ANAEROBIC CELL

Three main factors are crucial to the design and sizing of an anaerobic cell. These include the volume of water to be treated, the concentration of metals present and the treatment area required to do so, and the composition of the organic biomass

The potential to treat 20,00 liters per day (13.9 L/min) was used to estimate cell area. The volume sized 'rule of thumb' used in calculation based on metal concentrations is the removal of 0.3 mol/(m^{3}d) of metal where the volume component is the total volume neglecting the pore space and moisture content (Dvorak et al, 1991; Hedin et al, 1989; Gusek and Wildeman, 1997). Zn content can range up to 500 mg/L and Cd. up to 10 mg/L and As up to 45 mg/L. Therefore:

$$\text{Cell Volume} = (155\ \text{mol/d})/(0.3\ \text{mol/(m}^3\text{d)}$$
$$= 517\ \text{m}^3 \qquad (1)$$

While the area based 'rule of thumb is estimated to be between 10 m^{2}min/L and 20 m^{2}min/L (Gusek and Wildeman, 1997). this factor is pH dependent upon pH in the range of 5-7 with higher pH values requiring lower loading factors. Therefore,:

$$\text{Cell Area} = (20\text{m}^2\text{min/L})\ \text{X}\ (13.9\ \text{L/min})$$
$$= 278\ \text{m}^2 \qquad (2)$$

The composition of biomass used was 60% pulp mill residuals, 35% sand and 5% cow manure.

Based on these parameters and allowing for adjustments due to site characteristics a cell was constructed that was 24 m X 18 m at the top with sides that sloped to a bottom area that was 18 m X 10 m. The total depth was 3.5 meters. The retention time was increased by the addition of two 400m^2 baffles that divided the biological treatment medium into three equal layers with a flow through gap at opposite ends of each layer. Water to be treated enters at bottom of cell and is discharged at the top.

RE-PLANTING

Experience with the previous summer's growth habits and continuing research in plant's phytoremediation potential as reported in the literature lead to changes in plantings in the second year. The *Brassica juncea* had responded very well to the growing situation at the research site with long hot days and ample water. However, it had been bred as a cultivar and the seedpods did not shatter. This meant that for a re-seeding to take place that either new seed had to be procured or that the pods would have to be hand broken once or twice a year. Furthermore, the particular cultivar that we used was not a strong performer in the greenhouse trials at the University of Guelph. Although it survived it did not thrive, as did other plants. The *Helianthus* would also require transplanting each year. As a result of continued research (E. Gatleif, personal communication) it was decided to replace the *Brassica* with a grass species, *Tripsicum dactyloides* and to replace the *Helianthus* with hybrid poplar and willow.

The original vegetation cap on the landfill was planted during the summer of 1997. A mixture of grasses was used. The landfill has two levels although the site is continuous. Seeding on the lower level was successful and the site was fully grassed but on the upper level only patchy areas of grass became established. Given the success of hybrid poplars to grow exceedingly fast with a subsequent ability to transpire large volumes of water (M. Carlson, personal communication) it was decided to add this species to the area planted. In the spring (1999) 7,500 hybrid poplar and willow cuttings were planted. The area where; grass had become successfully established was marked out in a 2m x 2m grid and a circle '/2 m^2 was sprayed with glyphosphate. Two weeks later, professional tree planters planted 20 cm. cuttings. In the larger upper area where grass had not been as successful, the same sized grid was used but initial vegetation reduction spraying was not required. Cuttings were also planted along the visible markings where the seeps traced downwards to the creek.

Lysimeters were constructed and installed in three locations. These were set so that the bottom was level with the depth of the cap layer. They were backfilled with the material from the hole and typical vegetation re-planted, including a cutting from a poplar tree. Rain gauges were installed at the lysimeter sites so that water percolation could be monitored. A paddle wheel flowmeter was also installed in the collection system to provide more accurate monitoring of flow rates. These installations will allow us to monitor flow rates during the: course of at least one full growing season and thereby be able to present a detailed picture of the vegetation caps efficiency at reducing seepage rates.

RESULTS

Late in the 1998 growing season the construction work had been completed and all necessary pipelines laid. Metal contaminated water was then pumped into the anaerobic and following cells and allowed to remain for several days to allow for a period of stabilization and a first flush of the dissolved organic material.. After a few days grab samples were then taken from (Figure 1):

- A valve stem installed at the top of the vertical header that delivers water to the bottom of the anaerobic cell. This provided the raw sample of contaminated water.
- From the outflow of this cell as it enters a specially constructed small aeration cell,
- At the outlet of each of the three subsequent plant based treatment cells.

An initial set of samples was taken August 9th, followed by further samples in late August, late September and early October. In total in 1998, four sets of samples (09/08/98, 24/08/98, 22/09/98, 02/10/98) each including five points were sampled and assayed using ICP/AES for the three metals of interest, Zn, Cd, and As.

Figures 2, 3 & 4 graphically illustrate the size of the reduction in metal presence that takes place. For each metal of concern it shows that the largest proportion of the removal process is completed in the first cell but that removal does continue as water passes through each of the following cells. The initial value is the concentration of a metal in untreated water as it flows into the anaerobic cell. The 2nd value is the output of the anaerobic cell/input to the first plant cell; 3rd values is the output of first cell/input into second plant cell; 4th value is output of the second cell/input into third plant cell. The final value is the output of this final plant cell into the holding pond.

Table 2: Zinc, Cadmium & Arsenic (mg/l) in each stage of a four-stage biologically based treatment system. Percent removed represents the percentage of dissolved metal entering the cell that was removed during passage through that cell.

Date	Stage	Zinc	% removed	Cadmium	% removed	Arsenic	% removed
09/08/98	*1st input*	*130*		*3.6*		*45*	
	output to trees	78	40.00	0.43	88.00	8.1	82.00
	output to grass	7.9	89.90	0.3	30.23	1.5	81.48
	output to *Typha*	4.3	45.57	0.18	40.00	0.62	58.66
	output to pond	0.12	97.21	0.01	94.40	0.05	91.90
% removed from all stages		*99.90*		*99.70*		*99.89*	
24/08/98	*1st input*	*205*		*3.4*		*42.0*	
	output to trees	78	61.95	0.45	86.76	9.5	77.38
	output to grass	31	60.26	0.36	20.00	5.0	47.37
	output to *Typha*	24	22.58	0.29	19.44	3.4	32.00
	output to pond	3.9	59.11	0.1	65.52	0.79	76.76
% removed from all stages		*98.09*		*97.06*		*98.12*	
22/09/98	*1st input*	*140*		*2.3*		*23*	
	output to trees	88	37.14	0.16	93.04	8.2	64.35
	output to grass	74	15.90	0.14	12.5	8.4	(+2.3)
	output to *Typha*	1.9	97.43	0.04	71.42	1.5	82.14
	output to pond	0.38	80.00	0.02	50.00	0.48	68.00
% removed from all stages		*99.72*		*99.1*		*97.91*	
02/10/98	*1st input*	*75*		*1.0*		*17*	
	output to trees	72	4.00	0.21	79.00	8.0	52.94
	output to grass	50	30.55	0.11	47.62	5.8	27.50
	output to *Typha*	0.56	98.88	0.02	81.82	0.82	85.86
	output to pond	0.54	3.57	0.01	50.00	0.56	31.70
% removed from all stages		*99.28*		*99.00*		*96.71*	

The system was designed to treat 10-15,000 liters a day during the summer months when plants are growing most rapidly and using water and nutrients. Unfortunately contaminated water was not introduced until relatively late in the growing season giving less that a full season's results. In 1999, a full growing season trial is planned.

Metal Speciation

The system design included a layer of non-woven geotextile laid down over the biosolids mixture and a layer of sand on top of that, however, a certain amount of metal sulphides were expected to move through this filtering mechanism into the plant containing cells. A filtering mechanism had been included at the outlet *of* each of the cells before water exited to the aeration units. The system had been designed with an understanding that anaerobic activity would take place in all of the cells. As a result of this activity we anticipated that additional metal sulphides would be formed. This did, indeed occur and the results are evident when examining the continuous reduction of metals in the water as it flows through each stage of the system. However, since samples were taken from aeration cells and from the exit of the anaerobic cell some metal sulphides were included in each sample. Therefore;, some of the dissolved metals measured present in the cells could be metal sulphides as assays did not differentiate between dissolved and insoluble colloidal metals.

Volume Treated

Setting flow rates was a trial and error procedure. Since the metal-containing water was being introduced for the first time the system was initially kept at less than 50% potential treatment volume. This ensured that a steady state anaerobic condition was attained in all cells and that plants would not be flooded with concentrations of metals that were not sustainable to life.

Table 3: Volume treated (L/d) measured as output of the anaerobic cell

Date	Volume leaving anaerobic cell
12/09/98	10,944
13/09/98	12,470
14/09/98	13,252
15/09/98	17,855
16/09/98	13,828
17/09/98	13,603
18/09/98	13,358
19/09/98	14,842
20/09/98	13,714
21/09/98	6,768
22/09/98 *	13,896
23/09/98	14,592
24/09/98	14,784
25/09/98	8,304
26/09/98	8,640
27/09/98	8,640
28/09/98	12,144
29/09/98	12,638
30/09/98	13,171
Average (19 days)	**12,497**

*Note that there were samples taken for assay during the time frame described in this chart as well as one immediately following this time period on October 2nd.

The average flow through during this period is what is expected during operations throughout the summer months. Flow through was markedly lower on four days when levels in the anaerobic cell had dropped below the threshold required to maintain adequate flow. The anaerobic cell is charged over a 1-2 day period that supplies about 1 week for the other downstream cells.

Following this period the system was once again slowed down as plants were well advanced into senescence and transpiration had stopped or severely slowed down.

FUTURE CONSIDERATIONS

We are encouraged by the results obtained to date and are looking forward to a full growing season of operations. We expect to begin operations this spring as soon as snow cover has gone, plants have begun to emerge and leaf buds have broken. Additional tree material will be planted and the system checked against over-wintering damage. Solar powered aeration units will be re-installed in the aeration cells and augmented as required.

A complete season's operations will provide greater understanding of the systems potential and, at the same time, ensure a detailed record of operation values throughout spring, summer and fall.

Now that the system is fully planted and plants have reached a mature level of root growth, additional procedures will be implemented that will ensure a more detailed testing of many facets of the system's operating parameters.

This season we will:

- Plant a tree cover on landfill and install measuring equipment to monitor changes in water flow through
- Investigate metal speciation in the anaerobic cell with particular reference to arsenic;
- Research passive filters to remove metal sulphides from suspension;
- Assess each plant species ability to sequester metals;
- Install flow meters at inlets and outlets of the three tiered wetlands system to monitor treatment rates more thoroughly;
- Determine the most efficient residence time in the anaerobic digester while still ensuring adequate flow rates.

An important aspect of the work this summer will be to begin to understand the life expectancy of the system. Core samples of the biological residue in the anaerobic cell will be taken and analyzed to determine levels of metal sulphide build-up and amounts of carbon and sulphur remaining.

Future work to determine winter treatment rates is required to develop a year-round treatment system. This is desirable as the seeps flow year-round. However, this winter work is dependent on the success of the summer trials and will require additional capital expenditure.

REFERENCES

Dushenkov, V., Nanda Kumar, H. Motto and I. Raskin, 1995, Rhizofiltration: The Use of Plants to Remove Heavy Metals from Aqueous Streams, Environmental Science and Technology, 29, pp. 1239-1245.

Dvorak, D.H., Hedin, R.S., Edenborn, H.M., and Mclntire, P.E., 1991, *Treatment of Metal Contaminated Water Using Bacterial Sulfate Reduction: Results from Pilot Scale Reactors.* In: Proceedings of the 1991 National Meeting of the American Society of Surface Mining and Reclamation, American Surface Mining and Reclamation, Princeton, WV, pp. 109-122.

Gusek, J. and Wildeman, T., Short Course # 6: Treatment of Acid Mine Drainage, Presented at the 4th International Conference on Acid Rock Drainage, Vancouver, B.C., May 31 - June 6, 1997.

Hedin, R.S., Hammack, R.W., and Hyman, D.M., 1989, *Potential Importance of Sulfate Reduction Processes in Wetlands Constructed to Treat Mine Drainage.* In: Hammer, D.A. éd., Constructed Wetlands for Wastewater Treatment, Lewis Publishers, Chelsea, MI, pp. 508-514.

Kadlec R.H., and Knight R.L. *Treatment Wetlands* Lewis Publishers, Boca Raton, 1996, Chapter 19

Salt D.E., M. Blaycock, N.P.B.A. Kumar, V. Dushenkov, B.D. Ensley, I.Chet, and I. Raskin, 1995, Phytoremecliation: A Novel Strategy for the Removal of Toxic Metals for the Environment Using Plants, Biotechnology 13, pp. 468^475.

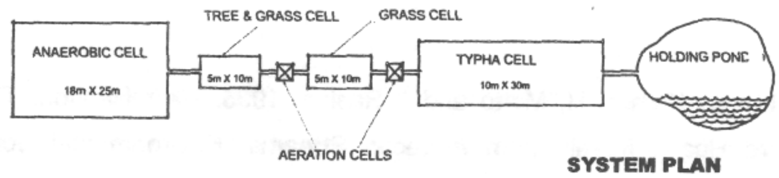

Figure 1 Plan of Prototype System as Installed in Trail British Columbia for Removal of Heavy Metals from Landfill Leachate. Water Enters System at Left of Anaerobic Cell and Flows Downhill through each Cell to Holding Pond. Collection Points are at the Exit from each Cell.

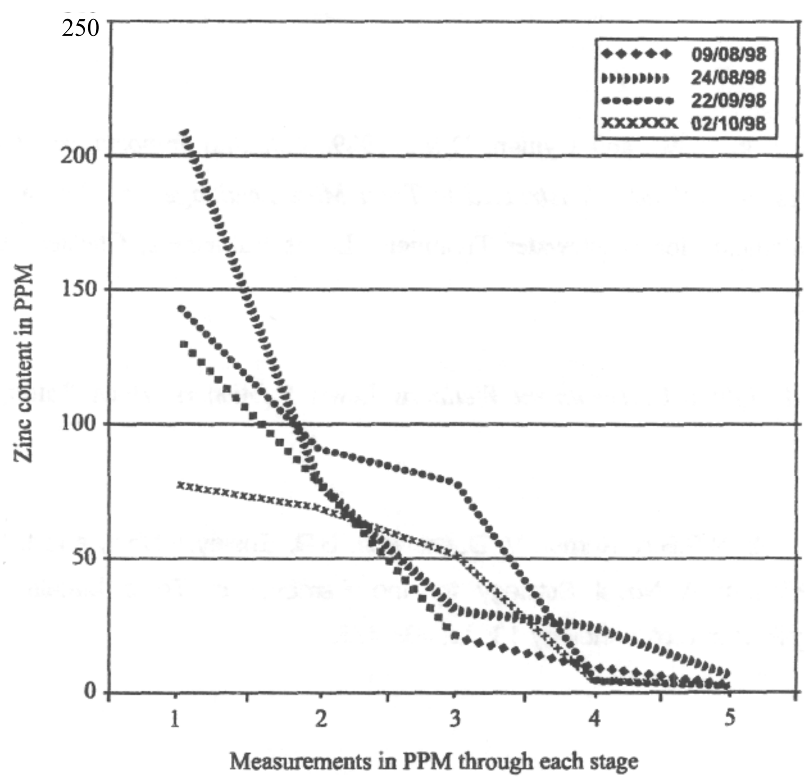

Figure 2 Zinc Reduction in Four-Stage Biological Remediation System

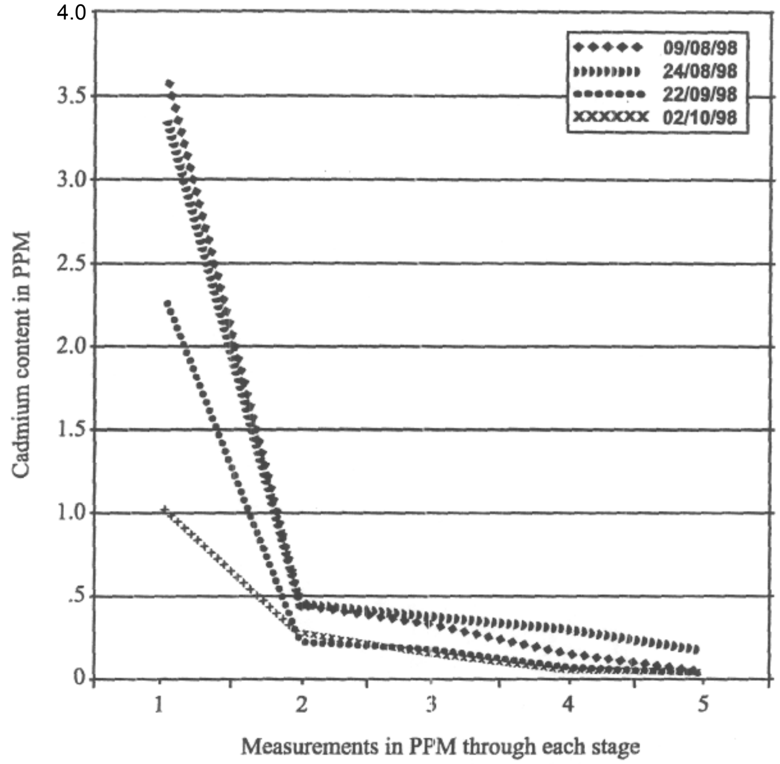

Figure 3 Cadmium Reduction in Four-Stage Biological Remediation System

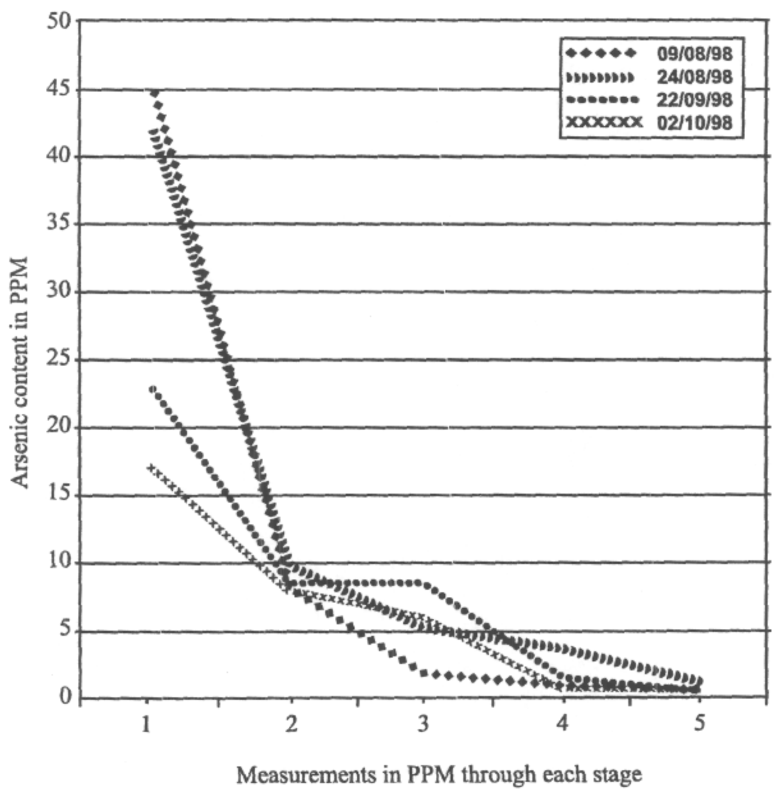

Figure 4 Arsenic Reduction in Four-Stage Biological Remediation System