THE USE OF OVERLAND FLOW WETLAND TREATMENT SYSTEMS[1] TO REMOVE NICKEL FROM NEUTRAL MINE DRAINAGE

by

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Abstract. In 1992, two overland flow wetland treatment systems were built in existing natural wetlands in northeastern Minnesota to remove copper, nickel, cobalt and zinc from neutral mine drainage. Typical input metal concentrations ranged from 2 - 5 mg/L for nickel, to less than 0.1 mg/L for copper, cobalt and zinc. Flow rates were on the order of 75 L/min for both systems. The treatment systems covered 4200 m^2 and 7000 m^2 and contained a series of soil berms installed across the wetland, and about a 30 cm layer of a mixture of peat and peat screenings (a waste material generated during the processing of horticultural peat). Although these systems have been successful in removing about 70 - 90% of the input metals, output nickel concentrations in one of the wetlands exceeded the discharge standard by as much as a factor of four. Average flow rates were greater than the design value by a factor of two, and the wetland was unable to adequately treat this flow volume. In 1993 and 1994, changes made to reduce the hydraulic gradient and minimize channeling improved performance, but nickel concentrations still exceeded permit requirements during periods of high flow and during the fall as temperature decreased. In 1995, the mining company constructed an additional 10,000 m^2 of wetland to provide additional treatment. After the expansion, the discharge was in compliance with permit requirements, until high flows and decreasing temperatures in the fall caused nickel concentrations to exceed standards.

Additional keywords: copper, cobalt, zinc, passive treatment, stockpile runoff

Introduction

Wetlands have been used to address a variety of water quality problems, including those arising from agricultural, municipal and industrial sources (Hammer 1989, Moshiri 1993). Wetlands have also been successful in treating coal mine drainage, and are being examined for their ability to treat metal mine drainage (Hedin and Nairn 1993, Eger et al. 1993, Wildeman et al. 1993). The use of wetlands to treat mine drainage is an attractive alternative to more conventional treatment methods. Wetlands are less costly to build than the conventional treatment systems, use processes which naturally occur in wetlands to remove metals from the water (e.g. adsorption, filtration), and offer a system that ideally should operate with little to no maintenance for extended periods of time.

LTV Steel Mining Company operates several taconite mines in northeastern Minnesota. At their Dunka Mine, located

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near Babbitt, surface drainage with elevated copper, nickel, cobalt, and zinc is generated as water infiltrates stockpiles of mineralized Duluth Complex (an igneous intrusive rock formation which contains disseminated copper and nickel sulfides). In the mid-1980's, LTV began an extensive program to evaluate various options for mitigating the problems at this mine. The company's preferred option was a combination of passive alternatives which would reduce flow emanating from their stockpiles, and which would use wetland treatment to remove metals from the resulting drainage. In 1988, four overland flow test cells were built to investigate methods to optimize metal removal and to provide design data for the ultimate implementation of wetland treatment at this facility. Based on the results of this study, two full-scale wetland treatment systems were built in the winter of 1992. This paper discusses the performance of those two systems.

Methods

General Construction

Each of the two treatment systems was built in existing wetlands. Construction began in the winter of 1992. The wetland systems were designed by STS Consultants, Ltd., and built by LTV Steel Mining Company (Frostman 1992).

Both areas were originally a combination of emergent (wet meadow) and scrub-shrub type wetlands, and the majority of the woody vegetation, which consisted primarily of alder, was removed from the site. The basic design for each system included the construction of a series of soil berms, which were built to control water levels and to maximize contact between the drainage and the substrate (Figure 1). Soil berms were built with glacial till (sandy silt) available from a surface overburden stockpile on the property. After the berms were constructed, a one-foot layer of a mixture of local peat and peat screenings was applied. The screenings are a waste material generated during the processing of horticultural peat and consist mostly of wood fragments and long peat fibers. This material was selected to increase the permeability of the peat to at least 10^{-3} cm/sec and to provide available organic carbon. In the spring of 1992, the berms were hand-seeded with Japanese Millet, while the open water areas were seeded with cattails. To obtain the cattail seeds, cattail heads were placed in a container of water with a small amount of liquid soap and several large bolts, and then the mixture was agitated until the heads broke and the seeds were dispersed. The slurry was then broadcast over the wetland.

W2D/3D system

This system covers 4200 m^2, contains 6 berms, and treats the drainage from two seepages which are associated with waste rock stockpile 8031 (Figure 2). One of the seeps is diffuse with an undefined channel (Site W2D), while only limited flow data exists for the other seep (Site W3D). The average flow from the stockpile has been estimated to be on the order of 75 L/min. From 1992-94, the input to the wetland was estimated to have an average pH of 7, with mean metal concentrations of 1.92 mg/L nickel, 0.05 mg/L copper, 0.05 mg/L zinc and 0.02 mg/L cobalt (Table 1).

W1D system

The majority of the flow to this system originates from the base of the 8018 stockpile, although additional seepage from the 8031 stockpile also drains to this area (Figure 2). V-notch weirs were installed to provide continuous measurement of the input and output flows. Annual average flows, from 1986-94, ranged from 75 - 150 L/min, with peak flows exceeding 750 L/min. Water quality samples of the inflow and outflow were colleted twice per month during the period of flow (generally March - December). Samples were collected within the system about once per month (Figure 2). From 1992-94, the input to the

Table 1. 1992-94 water quality data for the W1D and W2D/3D wetland treatment systems.

	W2D/3D input	W2D/3D output	W2D/3D standards	W1D input	W1D output	W1D standards
pH	7.0	7.0	6.5-8.5	7.1	7.1	6.5-8.5
Copper	0.050	0.006	0.023	0.068	0.010	0.023
Nickel	1.92	0.124	0.213	3.94	0.38	0.484*
Cobalt	0.017	<0.001	0.050	0.032	0.010	0.050
Zinc	0.054	<0.01	0.343	0.051	0.012	0.343

All Concentrations are in mg/L except pH, which is in standard units.
* Nickel standard increased from 0.213 in 1995.

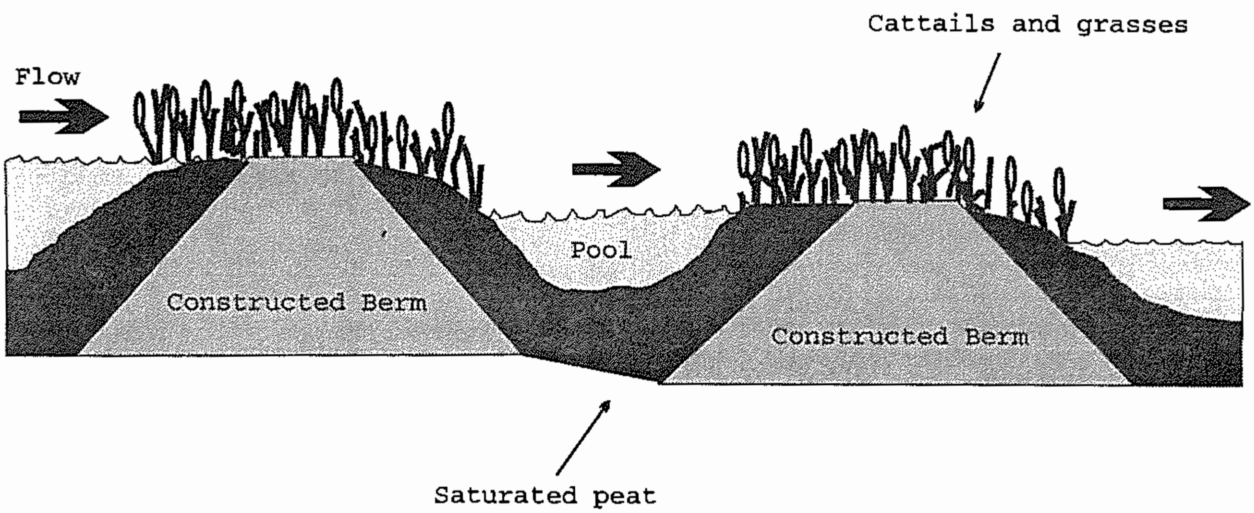

Figure 1. Cross section of typical berms (schematic).

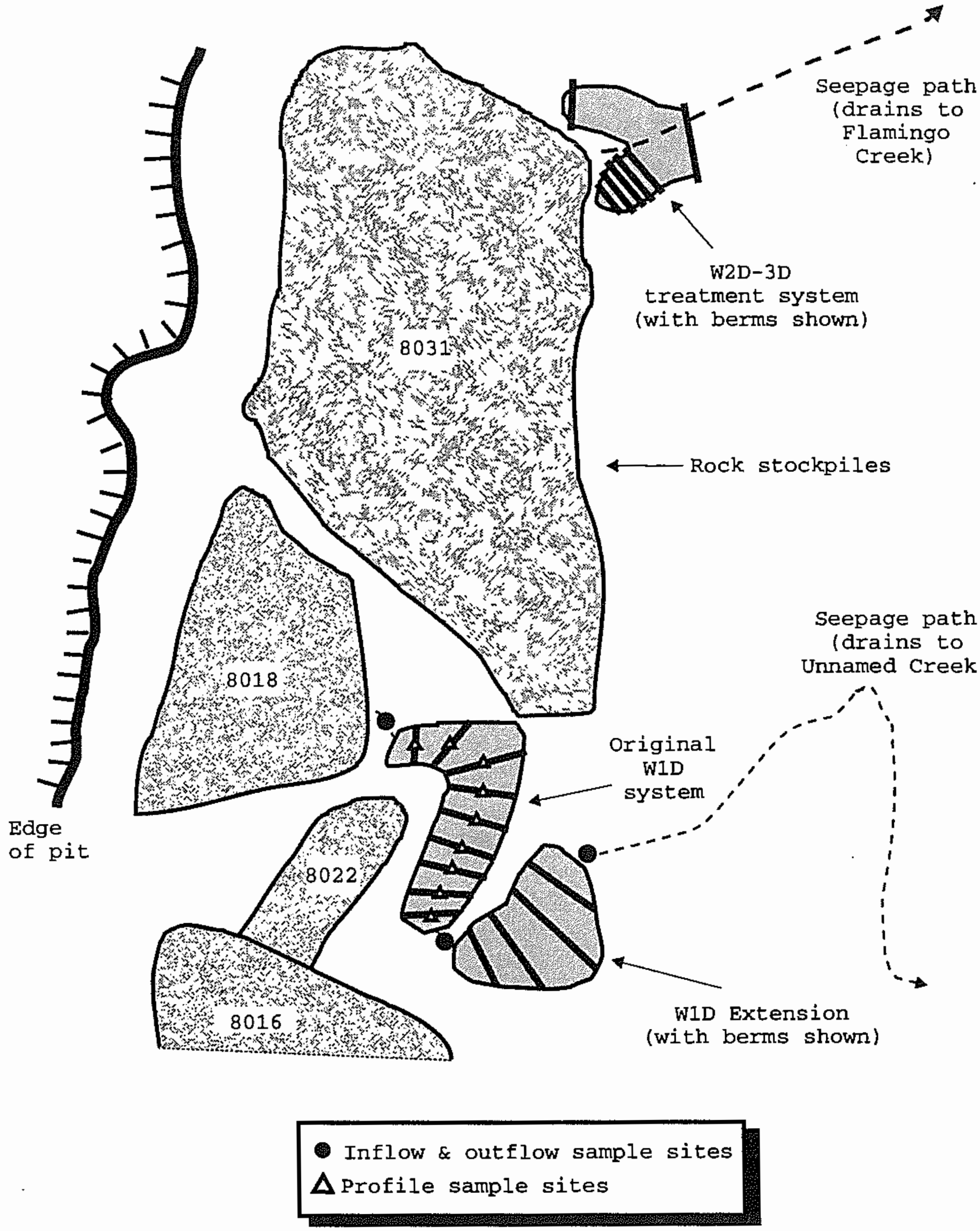

Figure 2. Dunka Pit site map showing locations of the W1D and W2D/3D wetland treatment systems and surrounding waste rock stockpiles.

wetland had an average pH of 7.1, and contained 3.94 mg/L nickel, 0.07 mg/L copper, 0.05 mg/L zinc and 0.03 mg/L cobalt (Table 1).

The original W1D treatment system, constructed in the spring of 1992, covered 7000 m^2 and contained a series of 9 berms. In 1993 and 1994, changes were made to the system to disperse flow, minimize channeling and improve contact between the drainage and the substrate. In 1995, the system was expanded by 10,000 m^2, and included an alternating series of overflow and underflow berms (Figure 3). Prior to construction of these berms, the original organic soils were removed; the berms were then built on the mineral soil base and compacted to minimize any future settling.

Results

This paper will focus on the results from the W1D system. This site has higher flows, higher concentrations of trace metals, and a steeper slope than the W2D/3D system. The W2D/3D system has been in compliance with permit requirements since it was constructed in 1992 (Table 1).

Limited data collected prior to construction indicated that the metal concentrations were reduced to acceptable levels in the natural wetland even before the system was constructed (Lapakko and Eger 1987). The construction of the system and the addition of new substrate has made the system more efficient and increased the length of time the system should be capable of providing treatment.

W1D Flow

For the period 1992-94, the input flow rates were similar to the long term average for the site, with average annual flows of 110 - 150 L/min. Daily input flows ranged from 0 in the winter to around 750 L/min during periods of heavy precipitation. In general, outflow was greater than or equal to inflow, except during those periods of the summer when precipitation was low.

Water quality

Overall, the wetland was effective in reducing metal concentrations. All metal concentrations decreased, ranging from 70% for cobalt to 90% for nickel. Outflow levels of copper, cobalt, and zinc consistently met water quality standards (Table 1). Despite an overall 90% decrease in concentration, nickel exceeded the water quality standard, particularly during high flow periods in the summer and when temperatures decreased in the fall (Figure 4). Nickel concentrations to less than 0.2 mg/L after the size of the system was increased in the spring of 1995. Outflow concentrations were in compliance until October, when concentrations exceeded the effluent limit of 0.484 mg/L (Figure 4).

Mass Removal

Overall metal mass removal in the wetland, from 1992-94, has ranged from 4.5 kg for zinc to 453 kg for nickel. These correspond to areal rates of removal ranging from 1 to 96 $mg/m^2/day$ (Table 2).

Discussion

Trace metal removal in a wetland is influenced by a large variety of physical, chemical and biological processes (Hammer 1989). Physical processes, such as filtration and sedimentation, are important in removing particulate metals, while it is the chemical and biological processes that provide for the removal of dissolved metals. The majority of trace metal removal in wetland treatment systems is associated with the substrate (Wildeman 1993, Gersberg 1984). Data from the test cells constructed at the Dunka mine, indicated that over 99% of the metal removal was associated with the peat, with only about 1% being removed by the vegetation (Eger et al. 1994).

Table 2. Mass removal and areal removal rates, W1D wetland treatment system 1992-94.

	Mass Removed (kg)	Areal Removal Rate * ($mg/m^2/day$)
Copper	6.1	1.3
Nickel	453	96
Cobalt	6.7	1.4
Zinc	4.5	1.0

* Calculated by dividing the total mass removed by the area of the wetland and the number of days of flow

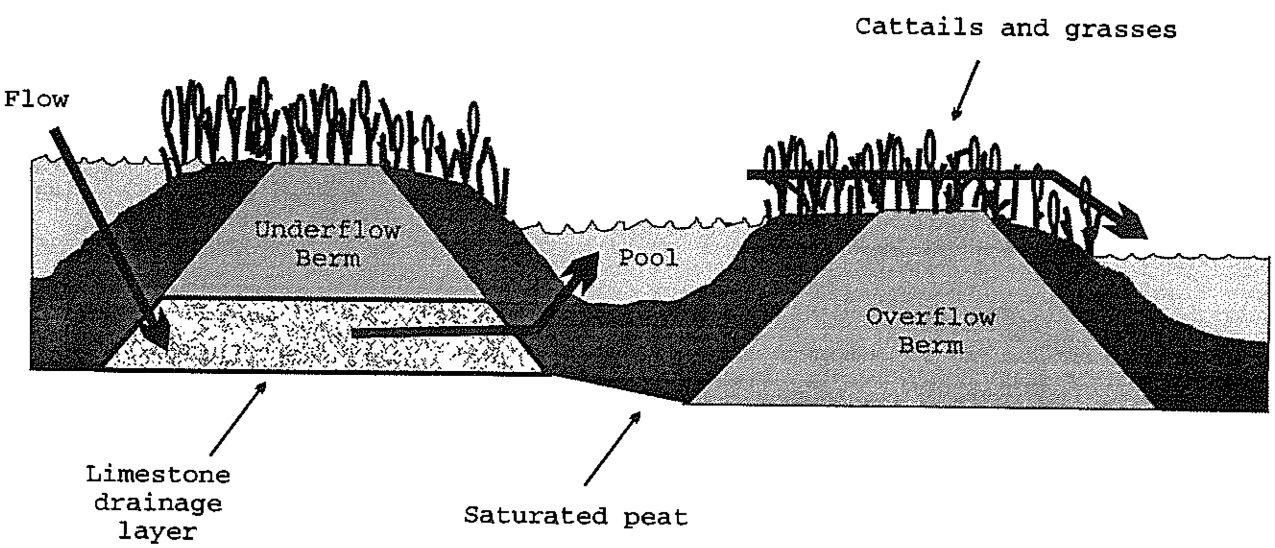

Figure 3. Cross section of an underflow/overflow berm system (schematic).

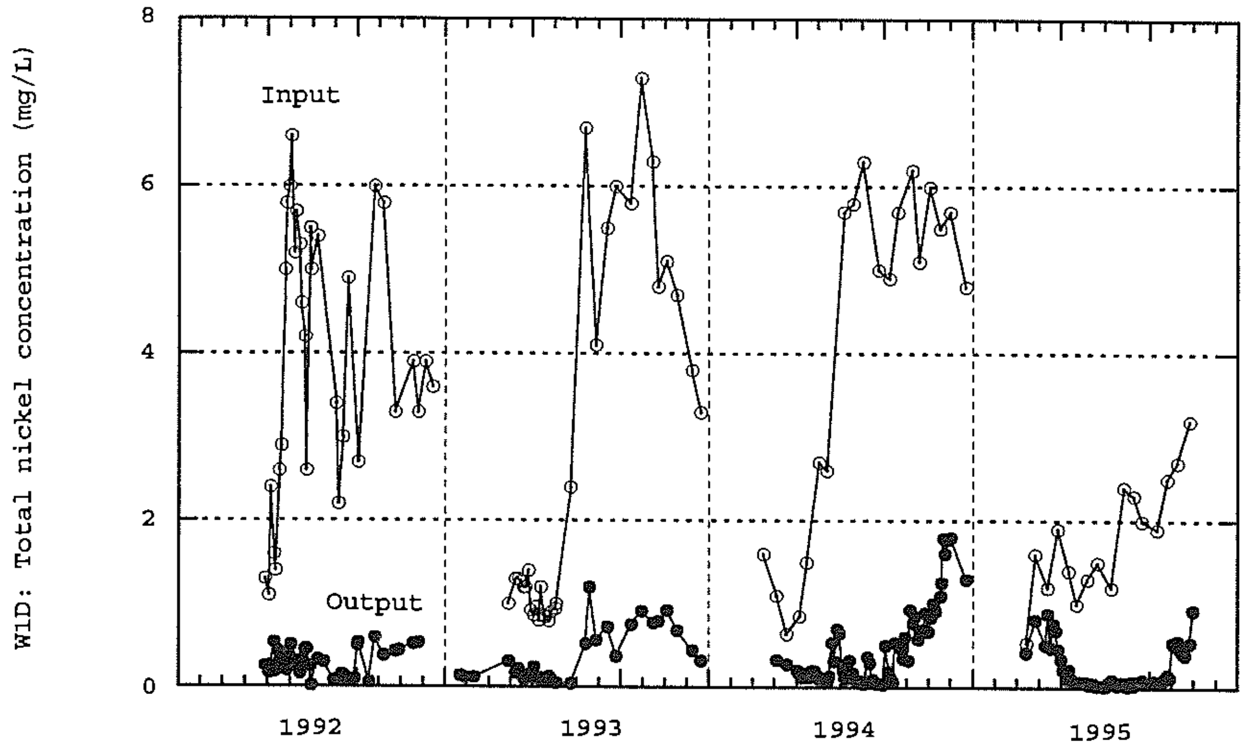

Figure 4. W1D input and output nickel concentrations, 1992-1995.

(Vegetation can enhance overall removal by dispersing flow, increasing the hydraulic conductivity of the organic substrate, and providing a source of new organic material.) Therefore, any full-scale system should be designed to maximize the contact of the drainage with the substrate. Metal removal in the test cells with a water depth of 5 cm was significantly greater than in those where the water depth was 15 cm (Eger et al. 1993). Removal in the test cells also increased as residence time increased, with a minimum of two days needed to achieve optimum removal.

Important factors in the design of a wetland treatment system to remove metals include detailed characterization of the drainage, the effluent standards that must be met, and performance data for the type of wetland to be constructed (Eger and Melchert 1992). Two of the most important design parameters are the residence time and the rate of metal removal in the wetland. Both of these factors are needed to determine the appropriate size of the wetland system.

Using the results from the test cells, an initial size for the W1D system was determined (Eger and Melchert 1992). The required treatment area was calculated based on: 1) the minimum required residence time needed to achieve compliance with permit standards and 2) the measured rate of metal removal expressed per unit area (Table 3). Since the area of the wetland must be of sufficient size compliance with permit standards to satisfy both the residence time and metal removal criteria, the

Table 3. Comparison of the actual constructed wetland size to the site required based on initial design calculations, for the W1D and W2D/3D systems.

	W2D/3D Design Values	W2D/3D[a] Actual Values 1992-94	W1D Design Values[b]	W1D Actual Values 1992-94
pH	7.0	7.0	7.1	7.1
Nickel (mg/L)	2	1.92	5.4	3.9
Flow (L/min)	75[c]	75[c]	75[d]	150
Required Size (m^2)	3700	4200	6300 (12,600)[e]	7000 (17,000)[f]
• Based on Flow	3700	NAp	3700 (7400)[e]	NAp
• Based on Metal loading	2500	NAp	6300 (12,600)	NAp

a: Concentration values are based on samples from site W3D
b: Average Values, 1980-91.
c: Estimated.
d: Average, 1990-91.
e: Value in parentheses based on long term flow value, 1986-1991
f: Wetland site was expanded to 17,000 m^2 in the spring of 1995
NAp: Not applicable

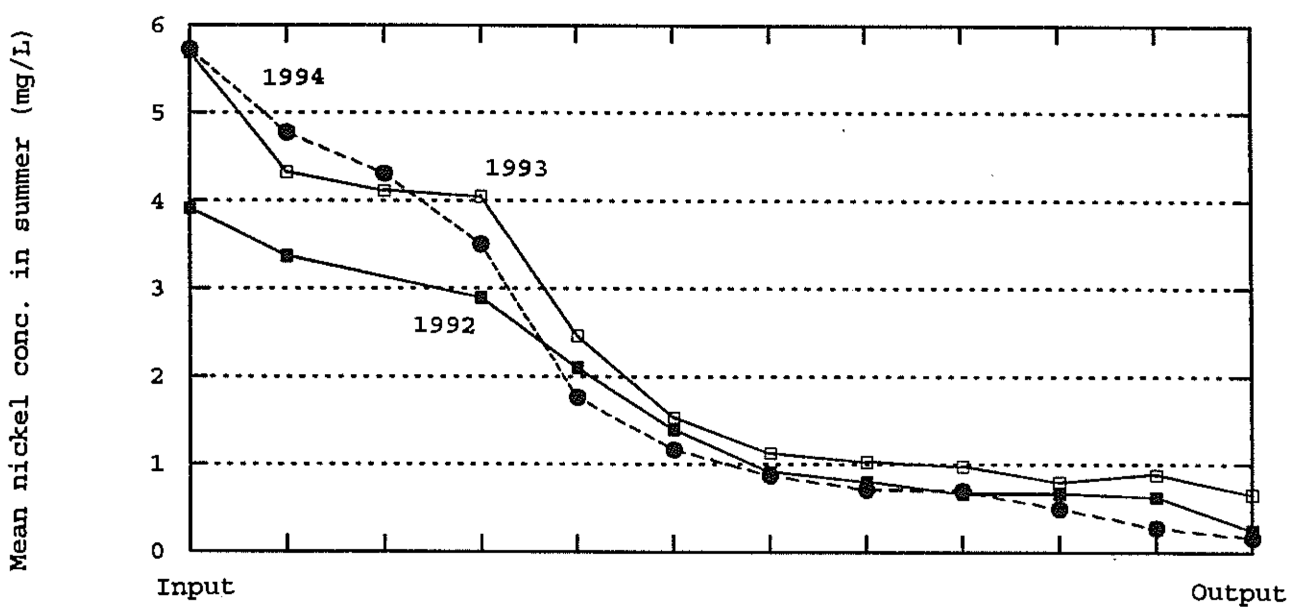

Figure 5. Nickel concentrations within the W1D wetland treatment system during the summer periods of 1992-1994. The values shown for each site are the means of the available summer data.

larger of the two calculated areas should be used as the basis for the design. Assuming an average input flow of 150 L/min (long term average), a residence time of two days, water depth of 5 cm, and good flow dispersion, the wetland size based on residence time was 7400 m^2, and 12,600 m^2 based on the rate of metal removal. Since these calculations use only the average flow, additional area or storage should be included if higher flows are to be treated adequately. Table 3 compares the size of the original W1D system and the W2D/3D system with the initial estimates made from the test cell data.

The initial size of the W1D system was substantially smaller than the area calculated from the test cell data, while the size of the W2D/3D system exceeded the calculated area. There were two reasons for the reduced size of the original W1D system. Since the company was modifying a natural wetland to provide treatment, the Minnesota Pollution Control Agency wanted to minimize the extent of wetland disturbance. The company had also made some changes to the watershed around the stockpiles. They believed that the average flow for the two years immediately preceding construction, although lower than the long term average, was representative of future flow and they based their design on this assumption. If the average input flow had been 75 L/min, the area would have satisfied the criteria developed from the test cells.

The inability of the W1D wetland to produce water which consistently satisfies the effluent requirements is primarily due to its small size and inadequate flow dispersion. Performance is particularly poor during periods of high flow. Flow channels have developed in the wetland, particularly in the lower half of the system, decreasing the contact between the drainage and the substrate. The average measured flow during 1992 to 1994 was essentially the same as the long-term average, and as a result the wetland was undersized by about a factor of two. Water samples collected from within the wetland indicated that metal removal was particularly low in those areas with significant channelization (Figure 5). Dye studies confirmed the lower contact and shorter residence time in this section (McCarthy et al. 1994).

Once the system was enlarged, concentrations decreased to levels below standards until October 1995, when concentrations increased dramatically and exceeded discharge limits (Figure 4). Unusually large rains (13 cm) at the end of September dramatically increased inflow at a time when wetland performance typically decreases due to decreasing temperatures. Additional data will be collected and analyzed to better determine the cause of the lack of treatment efficiency during this time.

Conclusions

Wetland treatment has been successful in reducing trace metal concentrations in stockpile drainage by over 90%. Design criteria derived from test cells provided a reasonable estimate of required wetland size. Measured rates of metal removed expressed per unit area of wetland ranged from 1 $mg/m^2/day$ for zinc to 96 $mg/m^2/day$ for nickel. Enlarging the W1D system improved metal removal and generally produced effluent which met water quality standards. Additional work is planned to investigate the poor performance of the system in the fall of 1995, metal removal within the wetland, and the total metal removal capacity of the wetland.

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