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USING PASSIVE TREATMENT SYSTEMS FOR MINE CLOSURE - A GOOD APPROACH OR A RISKY ALTERNATIVE

by

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ABSTRACT

In 1991, LTV Steel Mining Company decided to close an open pit taconite mine in northeastern Minnesota, using a passive treatment approach consisting of limiting infiltration into the stockpiles and wetland treatment to remove metals. Over 50 million metric tons of sulfide-containing waste had been stockpiled adjacent to the mine during its 30 years of operation. Drainage from the stockpiles contained elevated levels of copper, nickel, cobalt and zinc. Nickel is the major trace metal in the drainages, and prior to closure annual median concentrations ranged from 1.5-50 mg/L. Copper, cobalt, and zinc are also present but are generally less than 5% of the nickel values. Median pH ranges from 5.0 to 7.5, but most of the stockpile drainages have pH greater than 6.5. Based on the chemical composition of each stockpile, a cover material was selected. The higher the potential a stockpile had to produce acid drainage, the lower the permeability of the capping material required. Covers ranged from overburden soil removed at the mine to a flexible plastic liner. Predictions of the reduction in infiltration ranged from 40% for the native soil to over 90% for the plastic liner. Five constructed wetlands have been installed since 1992, and have removed 60-90% of the nickel in the drainages. Total capital costs for all the infiltration reduction and wetlands exceeded \$6.5 million, but maintenance costs are less than 1% of those for an active treatment plant. Since mine drainage problems can continue for over a hundred years, the lower annual operating costs should pay for the construction of the wetland treatment systems within seven years.

INTRODUCTION

When iron ore was discovered in Minnesota in the 1880's, concern about the impact of mining on water quality was not a major issue. Fortunately, the vast majority of the rock associated with Minnesota's iron ore did not contain acid-generating minerals and, with the exception of erosion and sediment transport, there has been little impact on water resources. As a result, when LTV Steel opened the Dunka Mine in 1962, little thought was given to the handling of waste rock from the operation.

Unfortunately, the iron ore at this site was partially covered by an igneous intrusive rock formation known as the Duluth Complex, a gabbro which contained disseminated copper and nickel sulfides. During thirty years of operation, over 50 million metric tons of sulfide-containing waste were removed and stockpiled on 120 hectares of land adjacent to the mine. As water infiltrated this material, drainage with elevated copper, nickel, cobalt, and zinc was produced. Annual median concentrations in the drainage from the stockpiles of Duluth Complex have ranged from 1.5-50 mg/l for nickel, <0.1-1 mg/l for copper, <0.1-3 mg/l for cobalt and <0.1-4 mg/l for zinc. Most of the drainage had pH's greater than 6.5, but two sites produced acidic drainage.

In 1986, LTV conducted a preliminary feasibility study to determine the best method to mitigate the drainage problem at the Dunka Mine. They examined both active treatment systems (lime treatment, reverse osmosis) and passive alternatives (limiting

infiltration into stockpiles, wetland treatment; Barr Engineering, 1986). An active treatment plant, which would treat all the stockpile drainage, was projected to have a capital cost of \$8.5 million and an annual operating cost of \$1.2 million. The passive alternative was projected to cost \$4 million to construct but only \$40,000 in annual maintenance. Since mine drainage problems can persist for over 100 years, LTV decided to pursue passive alternatives.

However, acidic drainage developed in 1989 at a site (Seep 3) which had previously been neutral (Figure 1). As a result, the company was forced to construct a lined equalization pond and an active treatment plant to treat seeps emanating from some of the stockpiles on the eastern side of the mine. LTV's goal was still to have a completely passive system, and when the decision to close the mine was made in 1991, LTV began to develop and implement a final closure plan. This plan included reducing infiltration into the stockpile and treating all residual drainage with wetland treatment systems.

SITE DESCRIPTION

The Dunka Mine is a large open pit taconite mine that covers approximately 160 hectares and has a depth of around 100 m. It sits along the western edge of a small watershed (920 hectares), which is drained by a small stream (Unnamed Creek, Figure 1). The watershed is typical for this area of Minnesota and is characterized by a series of upland ridges and low areas containing wetlands. Sulfide-containing waste material from the mine was stockpiled along the eastern edge of the mine and adjacent to these wetlands.

Due to shallow water tables, precipitation that infiltrates the stockpiles appears as seepage in many places along the toes of the stockpiles. Although some of this seepage is diffuse, the majority of the flow occurs as discrete flow, which generally flows continuously from spring melt in April till freeze up in late November. Average flows from the various seepages prior to closure have ranged from 3 L/min to 840 L/min, but flows exceeding 6000 L/min had been observed after periods of heavy precipitation.

Approach

The company's preferred approach for long-term mitigation was treatment of drainage with passive wetland treatment systems. Since there was a limited area available for construction, and because wetland systems function best under low flow conditions, it was important that the flow rates be reduced as much as practical. This was accomplished by reducing the upstream watershed which may contribute to the drainages and by capping the stockpiles to limit infiltration of precipitation.

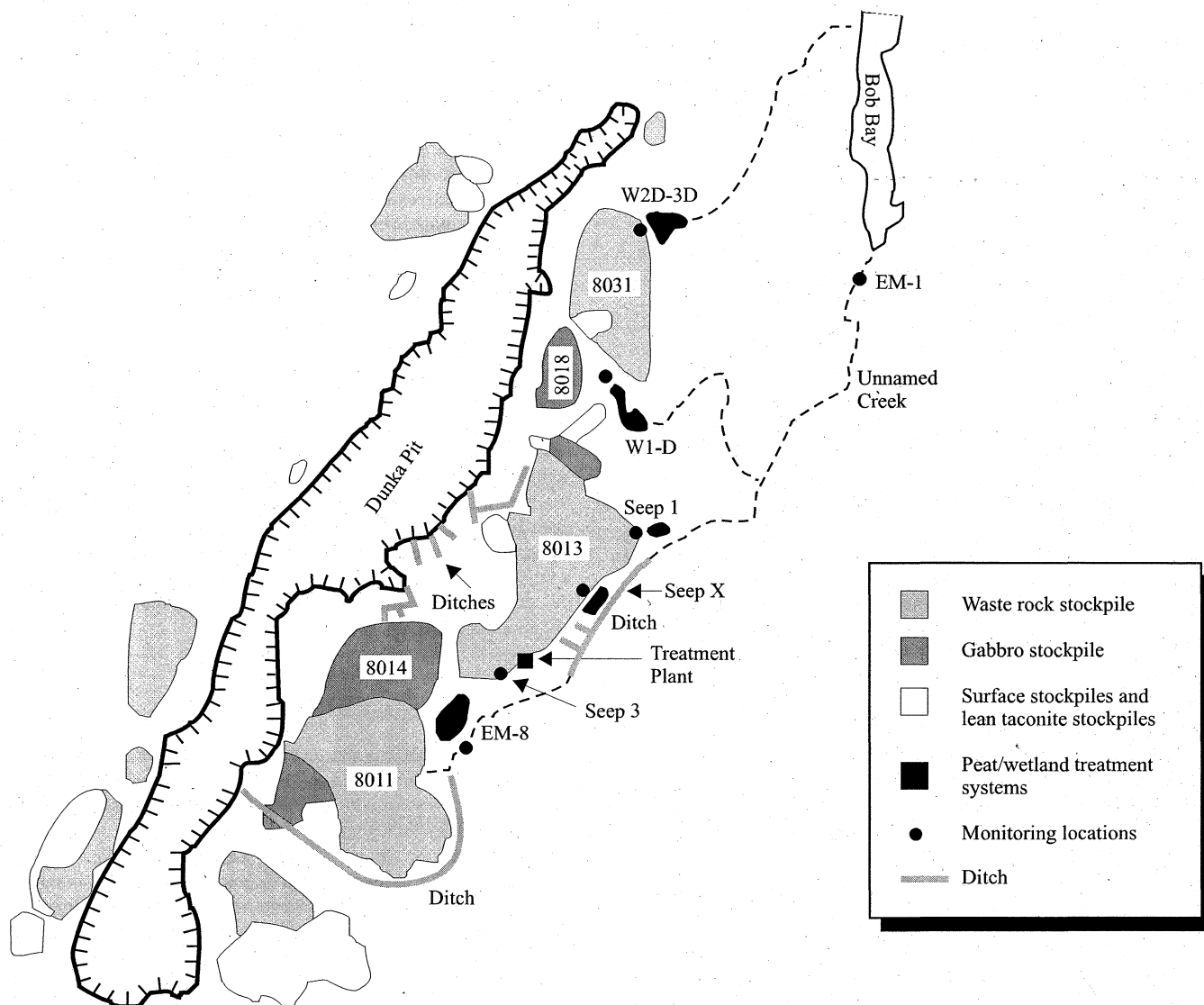


Figure 1. LTV Steel Mining Company's Dunka Mine, located near Babbitt, MN.

Watershed Reduction

LTV conducted an extensive investigation of the surface and groundwater in the area and identified several areas where surface water was believed to flow through Duluth Complex stockpiles. Drainage ditches were constructed to route water away from the piles (Figure 1). Although most of these were relatively shallow ditches (~ 2 meters), the ditch at the southern end of the mine, around the 8011 stockpile, was much larger. In order to isolate a relatively large upstream watershed (83 hectares), a 670 m long ditch, up to 18 m deep, was excavated through bedrock into the mine. The original plan was to drill and blast to fracture the bedrock and create a drain. The drain did not have sufficient permeability to drain the area, and as a result, the bedrock had to be excavated. This ditch cost over \$600,000, and accounted for the majority of the total ditching budget.

Based on the hydrological study, LTV also concluded that by channelizing flow in Unnamed Creek they could lower the water level in the surrounding wetlands and, as a result, reduce the amount of water in contact with the stockpile in these wetlands. The channelization project included straightening and deepening portions of the stream and required cutting through bedrock at several locations (Figure 1).

Limiting Infiltration into Stockpiles

Once the amount of surface and ground water entering the piles had been minimized, the next step was to limit the volume of precipitation entering the stockpiles. Minnesota's mineland reclamation rules require that the tops and benches of rock stockpiles that do not produce water quality problems, be covered with two feet of soil and vegetated. When water quality problems exist, additional steps to limit infiltration must be taken. Traditionally, infiltration is decreased by covering the waste with several feet of clay. For this mine, the nearest clay source is over

40 miles away and the high transportation cost to the site made this approach too expensive. As a result, a pilot test was conducted to investigate the effectiveness of various cover systems (Eger et al., 1990). These results, in addition to computer model runs using the EPA HELP model (Schroeder, 1984), were used to design an approach to selecting covers for each of the stockpiles based on the chemical composition of the pile and the observed water quality in the drainage.

Stockpiles that contained Duluth Complex material with less than 0.2% CuO and less than 0.05% NiO and that produced neutral drainage were covered with two feet of native soil, with at least 10% silt (-200 mesh), screened to minus 15 cm. Stockpiles containing more mineralized material and/or with acid drainage were covered with a barrier layer of compacted soil or a 30 mil low density polyethylene liner (Table 1). Since these stockpile were constructed prior to the realization that a water quality problem would develop, the piles were constructed to place the maximum amount of material in the minimum area.

Stockpiles were generally built in 10-15 meter lifts with 45 degree side slopes. Only the flat top portions of the stockpiles could be economically covered. Reductions in infiltration for the covered portions were predicted to range from 40% for native soil to over 90% for flexible membrane liners. Since the side slopes were not covered, the total reduction in flow would be a function of the ratio of the area of the top to the total area of the stockpile.

Treatment

In 1988, four pilot wetland cells were built to determine the feasibility of using wetland treatment to remove metals from stockpile drainage at the Dunka Mine. Nickel removal was on the order of 90% and the cells were capable of producing water that met water quality standards (Eger et al. 1994, 1993). Based on these results, LTV designed and constructed two wetland systems in 1992 (Eger et al., 1992, Frostman, 1992). These systems were 4200 m² (W2D/3D) and 7000 m² (W1D) and were designed to treat water with 1-5 mg/L nickel and flows on the order of 75 L/min.

These systems were constructed with a series of pools and soil berms to reduce the hydraulic gradient, and contained a substrate which was a mixture of peat and peat screenings (a waste product from the production of horticultural peat) between the berms. In 1995, one of the original wetlands (W1D) was increased by 10,000 m² and two new systems (Seep 1, Seep X) were built (Eger et al., 1996). These new systems also contained a series of soil berms, but every other berm in the cell had a limestone cobble base to permit underflow through the berm.

In 1997, another wetland (EM8) was designed and constructed to maintain water level at a uniform depth of between 10 and 15 cm, better distribute flow and maximize treatment area. Input flow is controlled by three adjustable stainless steel weirs, and adjustable stop log style weirs were built on all of the berms in the system. A summary of the size, water quality, and cost for each of the wetlands is presented in Table 2.

Since reducing the upstream watershed and limiting infiltration into the stockpile will decrease the total flow from the stockpile, the effectiveness of these steps must be considered together.

Diverting upstream flow reduced the watershed contributing to flow at Seep X and EM8 by 13% and 54%, respectively. Most of the other ditching did not affect the watersheds which contributed to the major discrete seepages, but reduced the overall watershed through the stockpiles. The largest watershed affected was upstream of the 8011 stockpile, in which 83 hectares were removed from the watershed.

Stockpile capping began in 1991 when 21 hectares of stockpile 8013 was covered with a cap consisting of 27 cm of compacted soil and 60 cm of soil cover (Gale, 1992). The top of the stockpile was extensively contoured with a complex of ridges and ditches and four 76-cm culverts were installed to carry water off the pile. Observations and periodic measurements indicate that a substantial quantity of water is routed off the piles, particularly during spring melt (Halberg, personal communication). Flow monitoring instrumentation was installed in 1998 so that quantitative data can be collected. Since 1989, LTV has capped about 76 hectares of stockpiles containing Duluth Complex material, with capping material ranging from uncompacted soil to 30 mil polyethylene membranes (Table 1).

Flow measurements for most of the seeps were made from water level measurements. All seeps were instrumented with a Stevens level recorder and a 60° v-notch weir. Continuous flow measurements are generally available from May 1 to October 31. Freezing temperatures before and after these dates often makes collection of continuous data difficult. As a result, flow during spring melt is generally not recorded. Although this flow can be substantial, 74% of the annual precipitation in northeast Minnesota occurs during the months of May through October. In the past, estimates of spring and fall flow have been made (Eger et al., 1981) but for purposes of comparing the effectiveness of the stockpile capping program, only the data representing actual flow measurements has been used.

The sites with the best long-term record and the largest changes to the watershed contributing to the drainage were EM8 and W1D. In the early 1990's the watershed that contributes to EM8 was reduced by 54% by an extensive and expensive ditching program, and in 1996 and 1997 the flat portions of the stockpile were covered with native soil and vegetated. Over the past three years, average volume for May through October was around 100 million liters. Prior to any activity which might have dramatically altered the flow at EM8 (1977-1979) the flow for this same period was 240 million liters, more than twice the post reclamation flow.

At W1D, around 60% of the total area of the stockpile was covered with 30 mil polyethylene. Since the stockpile contributes 40% of the total area to the monitoring weir, an overall flow reduction of around 25% was expected. Data from the first two years after capping indicates that flow from May through October decreased 36%, from an average of 36 million liters to 23 million liters.

RESULTS

Flow Reductions Related to Ditching and Infiltration Control

Table 1. Stockpile Capping Summary, LTV Dunka Mine.

Stockpile	Area Capped (hectares)	Stockpile Classification	Cap	Costs	
				Total	\$/hectare
8011	14	Waste rock	Screened soil, no barrier	445,000	32,000
8031	22	Waste rock	Screened soil, no barrier	835,700	38,000
8013	21	Waste rock	Compacted soil barrier	1,180,000	56,000
8014	18	Gabbro	Screened soil. A flexible membrane liner was placed over a mineralized portion of the pile.	963,000	54,000
8018	3.7	Gabbro	Flexible membrane liner	455,000	123,000

Treatment

All the wetlands at the Dunka Mine have been effective at removing metals, but some are not always effective at achieving compliance with permit limits. Annual average metal removal has ranged from around 60-90% for nickel, 70-90% for copper, 70-90% for cobalt, and 50-75% for zinc (Table 2). The ability to achieve compliance is largely a function of the wetland's size and the hydraulic and metal loading rate. The Dunka wetlands range in size from 2500 to 17,000 m² and the average nickel loading rate ranges from 15-70 mg m²/day. Pilot scale tests indicated that adequate nickel removal could be achieved with a residence time as low as two days, and that nickel removal rates were on the order of 40-80 mg/m²/day (Eger et al., 1994).

With the exception of the system constructed in the fall of 1997 (EM8), the wetland systems were constructed with a series of berms and pools that ranged in depth from 0.3-0.6 m. This design increases the overall residence time in the systems but decreases the area where the drainage is in direct contact with the substrate. Flow channels have developed at the low spots in the berms, further reducing contact with the substrate. The newly constructed system at EM8 was built with a series of adjustable weirs so that flow distribution can be controlled and contact with the substrate can be maximized. This system is expected to have fewer problems with flow channelization and provide more effective treatment than the older wetlands.

Although the wetland systems are generally effective at removing metals, efficiency tends to decrease as temperatures decrease in the fall. In general, stockpile flow ceases during the winter as precipitation accumulates as snow and as seep flow freezes. Most of the stockpile drainage ceases in the winter, but some winter flow has been observed at site Seep X and EM 8. Nickel concentrations in the outflow from Seep X increase in the fall and approach inlet concentrations in December (Figure 2).

Nickel removal in the test cells and the WID system also

decreased in the fall (Eger et al. 1994, 1996). Winter operation data for other wetland systems is limited, but year round copper removal has been reported in British Columbia (Sobolewski et al., 1995) and metal removal was also observed throughout the winter in the Big 5 Tunnel pilot cells in Colorado (Wildeman et al., 1992). Recent work in Montana (Pantano, personal communication) also found that metal removal occurred during winter operation. Additional data is needed on the LTV systems to determine if these systems can be manipulated so that water quality standards can be met throughout the year.

Effect of Mitigation on Unnamed Creek

The cumulative impact of the mitigation efforts at the Dunka Mine are measured at the mouth of the stream that drains the area (Unnamed Creek, site EM-1, Figure 1). Water quality data has been collected from the site since elevated concentrations in the drainage were first noticed over 20 years ago. The best measure of the success of LTV's efforts can be seen in the reduction of nickel concentration and nickel load in the creek.

Nickel concentrations averaged around 0.2 mg/L from 1975 to 1982, then increased to around 0.45 mg/L when the mine dewatering discharge from the southern portion of the mine was switched to another watershed (Figure 3). The pump discharge averaged around 3800 L/min, contained less than 0.01 mg/L nickel, and diluted nickel concentration in the stream. In 1992, the active treatment plant began to treat water from sites EM8, Seep 3, Seep 1, and Seep X, and the first wetland systems were built to treat sites W1D and W2D/3D. Average nickel concentrations in Unnamed Creek dropped by 65% to around 0.16 mg/L.

Since the mine was not initially designed to include a water treatment plant, all water must be currently collected and pumped to the plant. Pipelines are constructed with flexible PVC pipe and

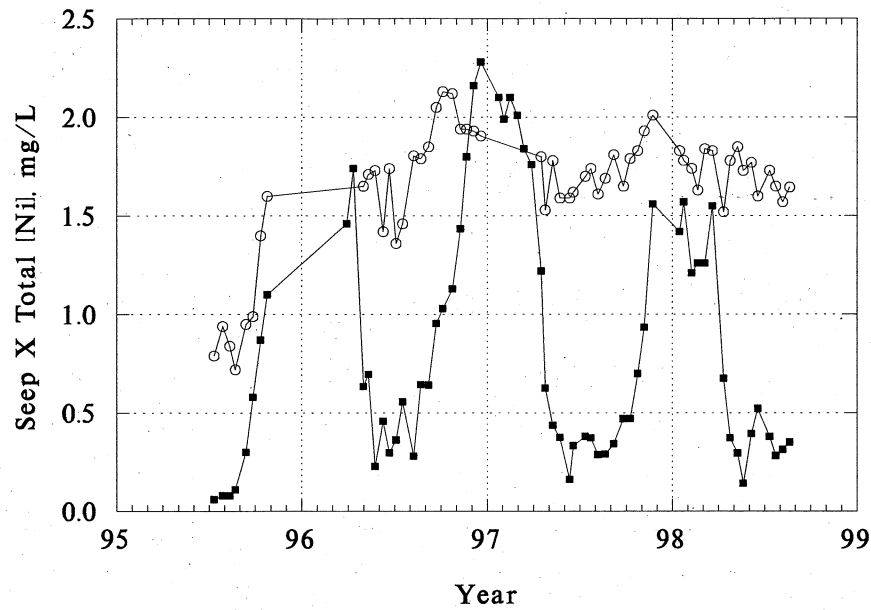


Figure 2. Nickel concentrations in the outflow from Seep X increase in the fall and approach inlet concentrations in December. (Dark squares are output concentrations, and open circles are input concentrations.)

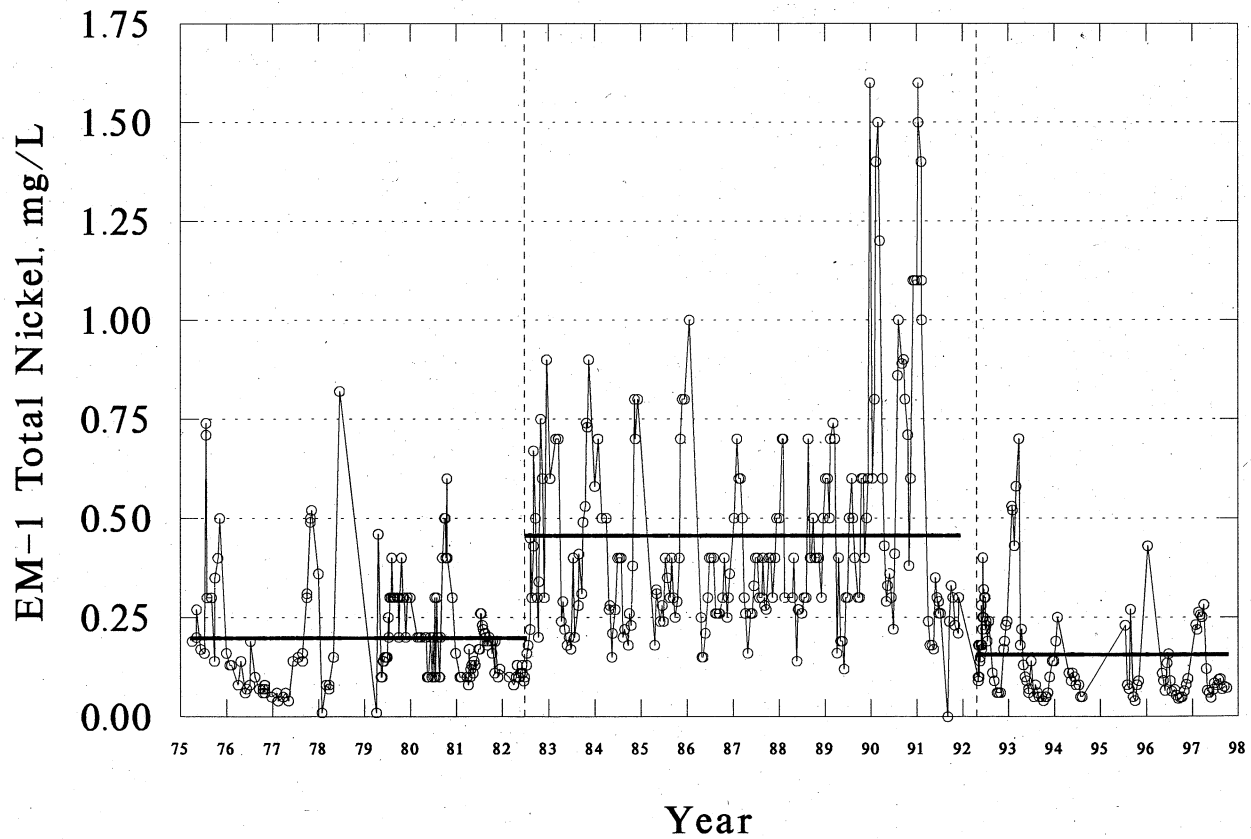


Figure 3. Nickel concentrations (total) vs. time at EM-1. The horizontal lines depict the mean concentrations of the three time periods. (Mine dewatering was routed away from Unnamed Creek on 6/23/82, and the active treatment plant and the first of the wetland treatment systems were put on line in March 1992.)

run from collecting sumps at each seep, across the wetlands, to the plant. Pumps must be removed and the pipes must be drained in the fall to prevent damage from freezing, and the pumping system cannot be used in the spring until danger of freezing is past. As a result, early spring and late fall flow is not collected and nickel concentrations increase in the stream. Although the efficiency of the wetland systems decreases in the winter, these systems should provide some treatment year round.

Biology of Unnamed Creek

Numerous surveys of the biology of the receiving stream, Unnamed Creek, have been conducted (Doran 1990, Rattei and Gebhard 1983, Doran 1982, Johnson and Williams 1978). In general, no significant impacts attributed to trace metals have been observed. The most recent survey (conducted in the summer of 1998) found a minnow population comparable to unimpacted streams of comparable size in this area (Niemala, personal communication). Macro invertebrate samples were also collected, but the samples have not yet been analyzed.

Costs

Mine closure is an expensive undertaking. LTV has spent over \$6.5 million to close the Dunka Mine. Capping the stockpiles containing Duluth Complex material was the most expensive cost at around \$3.9 million. Costs ranged from \$32,000/hectare for a soil cover to \$123,000/hectare for flexible membrane liners. These costs generally included some reshaping of the stockpiles. Covering the stockpiles with two feet of native soil, as required by mineland reclamation laws, generally costs about \$20,000-25,000/hectare.

A total of \$1.2 million was spent to construct the wetland systems. The design of these systems has changed over time; costs have ranged from \$18/m² for the systems built in 1992 and 1997, to \$24-28/m² for the systems with under drains built in 1995.

Active treatment for the southern portion of the mine (which began in 1992), cost around \$1.3 million to construct and has an annual operating cost of \$200,000. Maintenance costs for the passive systems generally decrease as vegetation becomes established on the stockpiles and in the wetlands, and by the fourth season, the only maintenance required is the annual inspections in the spring and fall. LTV has projected an annual maintenance cost of less than \$2,000, or less than 1% of the cost of the actual plant. With an annual savings of \$198,000, LTV will recover the cost of the wetland treatment systems in about six to seven years.

CONCLUSIONS

Despite an expenditure of over 6.5 million dollars for flow reduction and the construction of active and passive treatment systems, water quality standards are not met continuously at the discharge points. Wetland systems were built to use all available area, and further expansion of these systems would be difficult and expensive. Obtaining acceptable treatment in the winter is still an unresolved problem.

The water quality standards in LTV's current permit are based on the toxicity of the trace metals in their discharge and the low flow of the stream (i.e. the 7Q10, which is the average 7-day low flow that is expected to occur once every 10 years). Since both the flow in the stream and the flow from the stockpiles are driven by

precipitation, LTV was able to demonstrate that stockpile flow varied with stream flow, and as a result the 7Q10 approach was too restrictive in this situation. A new permit will be issued and may replace the existing standards with some form of an acute toxicity criteria at the discharge. If this occurs, the allowable metal concentrations at the discharge from the wetland systems will increase.

From an overall perspective, closure at the Dunka Mine has been a success. The passive approach has been successful in reducing flow and removing trace metals. Metal concentrations in the receiving stream have been reduced, and no significant impacts on the aquatic system from trace metals has been documented.

The problem is the inability to meet specific numeric standards. Negotiations underway may lead to a solution that will allow the company to use its passive systems and still provide protection for the environment.

ACKNOWLEDGMENTS

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Dennis Koschak, LTV's manager of environmental services, was the driving force behind the implementation of the Dunka closure, and without his vision and commitment, the passive systems would never have been built.

Geno Halberg, of LTV's environmental control section, supervised the construction of all of the closure activities and has been responsible for the operation of all the treatment systems at Dunka. He designed the wetland system constructed in 1997, and without his willingness to supply data and answer our innumerable questions, this paper could have never been written.

REFERENCES

- Barr Engineering. 1986. Feasibility assessment of mitigation measures for gabbro and waste rock stockpiles - Dunka Pit Area. Prepared for Erie Mining Company, Hoyt Lakes, MN.
- Doran, P. 1982. Benthic ecology of Unnamed Creek. Report prepared for Erie Mining Co. by the Environmental Analysis Program, Vermilion Campus, Arrowhead Community College, Ely, Minnesota.
- Doran, P. 1990. Listing of invertebrate taxa collected from Unnamed Creek. Personal communication, 1990.
- Eger, P., Antonson, D., and Udoh, F. 1990. The use of low permeability covers to reduce infiltration into mining stockpiles. Presented at Western Regional Symposium on Mining and Mineral Processing Wastes, May 30 - June 1, 1990. Berkeley, CA. 9 p.
- Eger, P., Lapakko, K. A., Weir, A. 1981. The environmental leaching of stockpiles containing copper-nickel sulfide minerals: A study of chemical release, chemical transport, and mitigation conducted at Erie Mining Company's Dunka Mine, Babbitt, MN,

1976-1980. MN Dept. Nat. Resour., Div. of Minerals, St. Paul, MN. 62 p. plus appendices.

Annual Meeting Canadian Mineral Processors, Ottawa, Ontario. Paper #32.

Eger, P., G. Melchert, D. Antonson, and J. Wagner. 1993. The use of wetland treatment to remove trace metals from mine drainage. Constructed Wetlands for Water Quality Improvement. G. Moshiri, Ed., Lewis Publishers, Boca Raton, FL.

Eger, P., G. Melchert. 1992. The design of a wetland treatment system to remove trace metals from drainage. Achieving land use potential through reclamation. Proc. 9th National Meeting, Duluth, MN, June 14-18, 1992. p. 98-107.

Eger, P., Wagner, J., Kassa, Z., and Melchert, G. 1994. Metal removal in wetland treatment systems. Proc. International Land Reclamation and Mine Drainage Conference / Third International Conference on the Abatement of Acidic Drainage. Pittsburgh, PA, April 25-29, 1994.

Eger, P., Wagner, J. and Melchert, G. 1996. The use of overland flow wetland treatment systems to remove nickel from neutral mine drainage. Success and Failures: Applying research results to insure reclamation success. Proc. 13th National Meeting ASSMR, Knoxville, TN, May 18-23, 1996. p. 580-589.

Frostman, T. 1992. Constructed peat/wetland treatment system for heavy metal removal. Achieving land use potential through reclamation. Proc. 9th National Meeting, Duluth, MN, June 14-18, 1992. p. 255-259.

Gale, L. 1992. Reclamation of minerock stockpiles. Achieving land use potential through reclamation. Proc. 9th National Meeting, Duluth, MN, June 14-18, 1992. p. 232

Halberg, G. 1997. LTV Steel Mining Company, Hoyt Lakes, MN. Personal communication.

Johnson, M., Williams, S. 1978. Regional Copper-Nickel Study, Erie Mining Project, Biological Sampling. Prepared by the Minnesota Environmental Quality Board in cooperation with Erie Mining Co.

Rattei, M. Gebhard, A. 1983. (Barr Engineering Co.) Comparison of benthic taxa from 1975 to 1982. Personal communication.

Niemala, S. 1998. Minnesota Pollution Control Agency (MPCA), St. Paul, MN. Personal communication.

Pantano, J. 1997. Arco Mining, Anaconda, MT. Personal communication.

Schroeder, P., Morgan, J., Walski, T. and A. Gibson. 1984. The hydrologic evaluation of landfill performance (HELP) Model Volume 1. Users Guide for Version 1. U.S. EPA Technical Resource Document. EPA /530 /2-87 /050.

Soboleski, L. Gormely, and R. Kistritz. 1995. Copper removal from mine drainage by an experimental wetland at Bell Copper Mine, Smithers, B.C. Sudbury '95, Mining and the Environment, Sudbury, Ontario, May 28-June 1, 1995 p. 683-692

Wildeman, T., Dugan, L., Bolis, J., and J. Gusek. 1991. Constructed wetlands that emphasize sulfate reduction: A staged design process and operation in cold climates. Proceedings 24th