MINE CLOSURE - CAN PASSIVE TREATMENT BE SUCCESSFUL?[1]

by

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Abstract. LTV Steel Mining Company decided in 1991 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 50-90% 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. LTV plans to have a fully passive treatment system for its entire mine by the year 1998.

Keywords: mine closure, passive treatment, wetlands, stockpile capping, copper, nickel, cobalt, zinc

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 the Dunka Mine was opened 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 the 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, reserve 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.

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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 stockpiles and wetland treatment of all residual drainage.

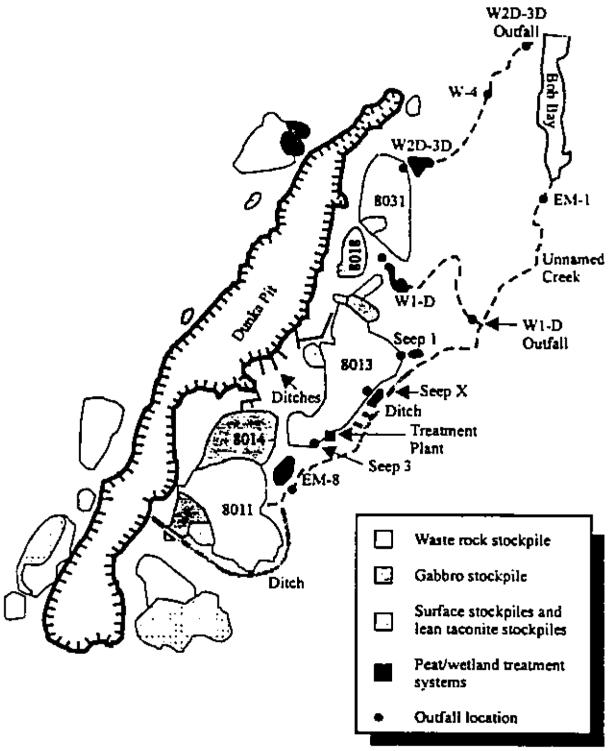

Figure 1. LTV Steel Mining Co.'s Dunka Mine, located near Babbitt, MN.

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 in 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 until 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.

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 containing Duluth Complex material with less than 0.2% CuO, less than 0.05% NiO, and producing neutral drainage were covered with two feet of native soil. This soil was screened to minus 15 cm and contained at least 10% silt (-200 mesh). 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., 1993, 1994). Based on these results, LTV designed and constructed two wetland systems in 1992 (Eger et al., 1992, Frostman, 1992). These systems were 4200 m^2 (W2D/3D) and 7000 m^2 (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 m^2 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 accurately maintain water level at a uniform depth of between 10 and 15 cm, to distribute flow better, and to 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.

Results

Flow Reductions Related to Ditching and Infiltration Control

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 did reduce the overall flow 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 were 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

Table 1. Stockpile capping summary, LTV's Dunka Mine.

Stockpile	Area Capped (hectares)	Stockpile Classification	Cap	Costs	
				Total	$/hectare
8013	21	Waste rock[1]	Compacted soil barrier	1,180,000	56,000
8011	14	Waste rock[1]	Screened soil, no barrier	445,000	32,000
8031	22	Waste rock[1]	Screened soil, no barrier	835,700	38,000
8014	18	Gabbro[2]	Screened soil, flexible membrane liner	963,000	54,000
8018	3.7	Gabbro[2]	Flexible membrane liner	455,000	123,000

[1] Waste rock stockpiles contain <0.2% CuO and <0.05% NiO
[2] Gabbro stockpiles contain >0.2% CuO and/or >0.05% NiO

melt (Halberg, personal communication). Flow monitoring instrumentation will be installed in the spring of 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 make the collection of continuous data difficult. As a result, flow during spring melt is not recorded. Although this flow can be substantial, 74% of the annual precipitation in northeast Minnesota occurs during the months of May though 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.

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

Table 2. Wetland treatment summary, LTV's Dunka Mine.

Site	Time	Size m^2	Ave. Flow	Design Factors - Input					Performance - Output					Cost To Construct
				Average Concentrations (mg/L)					Average Concentrations (mg/L)					
			L/min	pH	Ni	Cu	Co	Zn	pH	Ni	Cu	Co	Zn	
W2D/3D	1992 to 1997	4200	75	7.0	1.9	0.05	0.02	0.05	7.0	.08	.004	.002	.008	$ 75,000
W1D	1992 to 1997	7000	150	7.07	3.98	.068	.036	.052	7.18	.70	.010	.008	.013	125,000
Expanded	1995 to 1997	17,000	150	7.14	1.20	.059	.023	.017	7.38	.18	.005	.001	.011	244,000
Seep 1	1995 to 1997	2500	20	6.94	5.39	.15	.13	.65	7.23	1.85	.05	.04	.29	192,000
Seep X	1995 to 1997	10,000	100	7.03	1.50	.33	.08	.48	7.13	.61	.08	.02	.21	282,000
EM8	1997	16,000	400	7.2	1.9	.043	.015	.059	No data - system just completed					290,000
Water Quality Std									6.5-8.5	.213	.023	.05	.343	$1,200,000

Dunka wetlands range in size from 2500 to 17,000 m^2 and the average nickel loading rate ranges from 15-70 mg m^2/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/m^2/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 to control the distribution of flow and to maximize contact with the substrate. This system is expected to have much less flow channelization and to provide better metal removal 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 sites Seep X and EM8. Limited data from the outflow of the Seep X system suggest that treatment decreases substantially during winter, with outflow concentrations approaching 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 are needed on the LTV systems to determine if these systems can meet water quality standards throughout the year.

In the current draft of LTV's new NPDES permit, the nickel standard has been increased to 1 mg/L. If the limit is increased, all the systems, with the exception of the Seep 1 system and possible winter flows at Seep X, will be in compliance. LTV is investigating the possibility of expanding the Seep 1 system, and additional study of winter removal is planned.

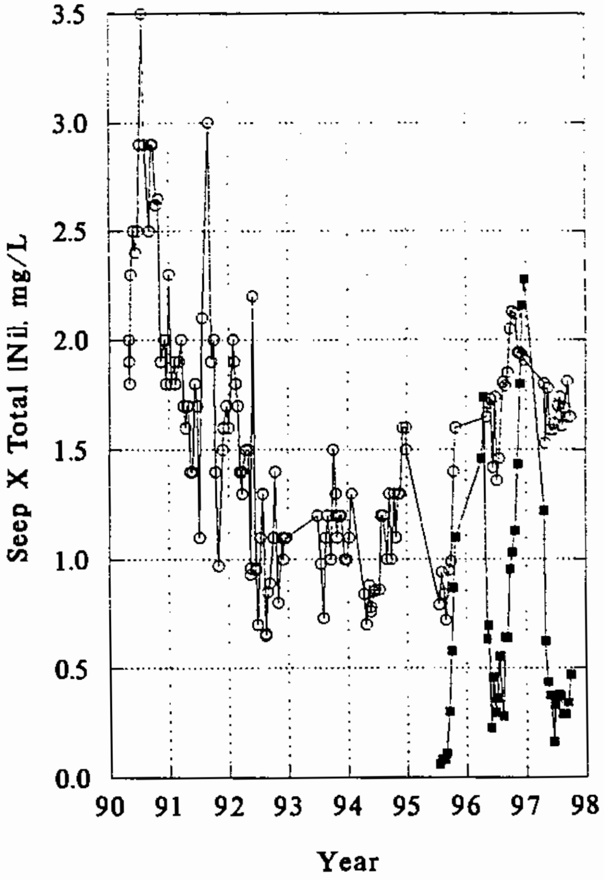

Figure 2. Seep X nickel concentrations vs. time. Dark squares are output concentrations and open circles are input concentrations.

Effect of Mitigation on Unnamed Creek

Although NPDES permit requirements focus on the discrete point flows from the stockpiles, it is the receiving water where the environmental impacts of the discharges occur. Water quality data have been collected from the mouth of Unnamed Creek (EM1) 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 concentrations 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 currently be collected and pumped to the plant. Pipelines are constructed with flexible PVC pipe and run from collecting sumps at each seep, then across the wetlands and 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. LTV also conducts quarterly bioassay tests on the samples collected from the mouth of Unnamed Creek (EM1). Since 1992 there has been no acute or chronic toxicity observed at this site.

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.

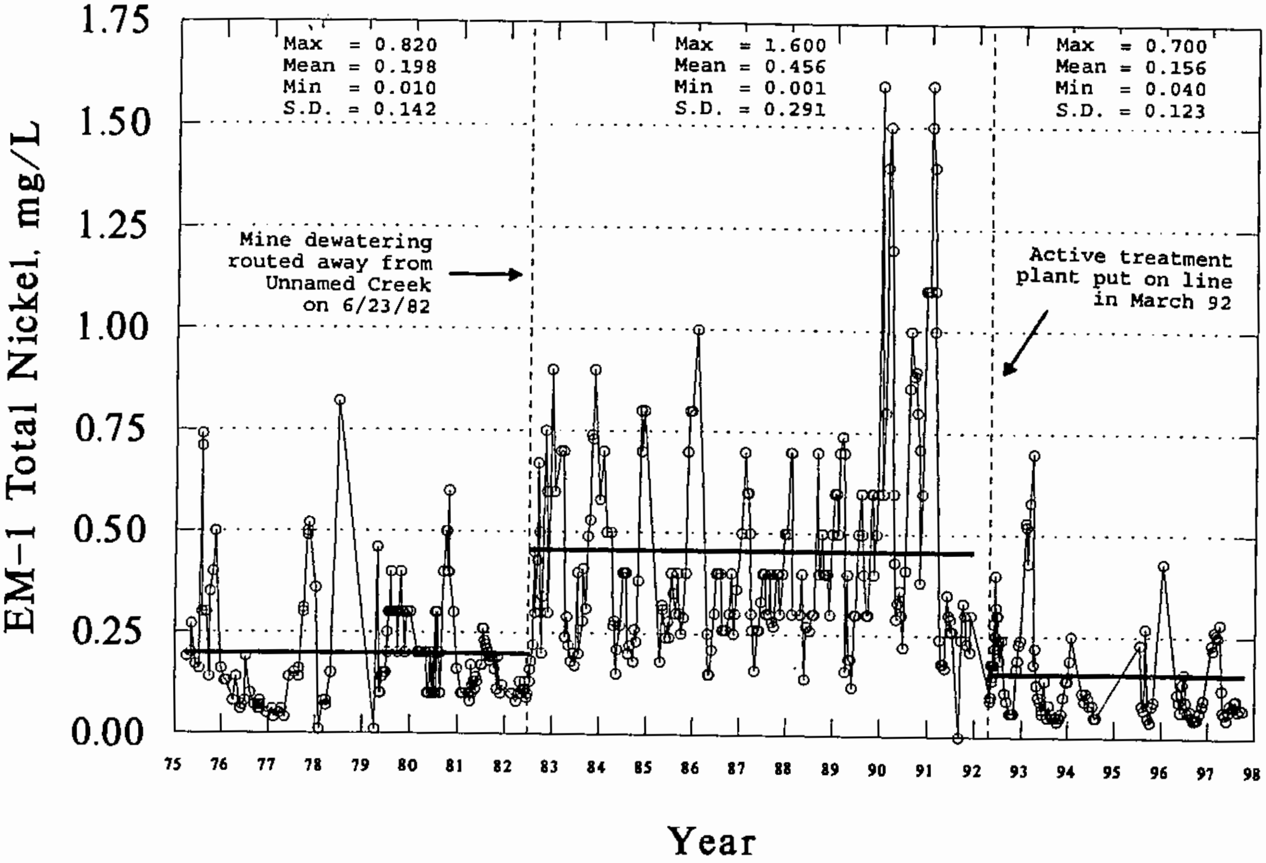

Figure 3. Nickel concentrations (total) vs. time at EM-1 The horizontal lines depict the mean concentrations of the three time periods. (Mine dewatering was routed away from Unnamed Creek on 6/23/82, and the active treatment plant and the first of the wetland treatment systems were put on line March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

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/m^2, for the systems built in 1992 and 1997, to \$24-28/m^2 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 active plant. With an annual savings of \$198,000, LTV will recover the cost of the wetland treatment systems in about six to seven years.

Conclusion

The Dunka Mine has been closed and reclaimed, and by 1998 LTV plans to completely treat all the drainage with passive systems. Stockpile flows have been reduced by a combination of watershed and infiltration reduction. Wetland treatment systems are generally effective at removing nickel, copper, cobalt, and zinc from the drainage, but treatment efficiency decreases in the fall and winter. Savings in operation and maintenance will recover the cost to construct the wetlands in six to seven years.

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 never have been written.

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