

TREATMENT OF HIGH-FLOW, LOW-IRON MINE DRAINAGE WITH A SEMI-PASSIVE SYSTEM¹

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Abstract. Mine drainage flowing at approximately 2600 L/min and containing 5 to 6 mg/L of iron was treated using the influent water to power a dry chemical feed system using lime. After lime addition, the water was directed into four wetland cells with a total area of 0.40 ha. Tracer tests, using a pulse input of potassium bromide, indicated that the four-cell wetland had a detention time of approximately 8 hours. Prior to the addition of lime, the wetland received iron concentrations between 5 and 10 mg/L at a pH of 4.0 to 6.5. As the water flowed through the four wetland cells, pH remained virtually unchanged and iron was not significantly removed with typical iron removal of about 1 mg/L or less. In the summer of 2003, pebble lime (CaO) was added to the influent water using an Aquafix™ system. The system used a split of the influent water to turn a water wheel that is geared to a screw feeder located at the bottom of a hopper containing the lime, which was added at a rate of about 75 kg/day. The pH of the mine water increased from approximately 5 to between 7 and 8. Total iron concentrations were lowered from 6 mg/L at the influent to less than 0.5 mg/L at the effluent. Iron removal rates within the first wetland cell were less than $1 \text{ gd}^{-1}\text{m}^{-2}$ without lime addition and ranged between 6 and $11 \text{ gd}^{-1}\text{m}^{-2}$ with lime addition.

Additional Key Words: pebble lime, water-powered devices, water wheel, wetlands, iron removal.

¹ Paper was presented at the 2004 National Meeting of the American Society of Mining and Reclamation and the 25th West Virginia Surface Mine Drainage Task Force Symposium, April 18-24, 2004. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2004 pp 1962-1973

DOI: 10.21000/JASMR04011962

<https://doi.org/10.21000/JASMR04011962>

Introduction

For many abandoned coal mine sites, conventional treatment of mine drainage is cost prohibitive. Passive treatment using wetlands, anoxic limestone drains and reducing and alkalinity producing systems have been very successful at numerous sites (Watzlaf et al., 2004). Selection of the most effective unit operations is based on water quality. At sites receiving net alkaline or net neutral mine water, aerobic wetlands are typically used for the oxidation, hydrolysis and settling of iron. Large flows of mine water may require very large areas for effective iron removal. Often the required area is not available. In these cases, a system using the flowing water as a source of power to add an alkaline material may be more effective than a strictly passive system. These systems have been termed “semi-passive” treatment systems.

Iron removal from net alkaline mine waters is limited by the oxidation rates of ferrous iron to ferric iron. This oxidation rate is extremely dependent on pH. Typically, net alkaline mine drainage has a pH of about 6.0. As the water flows through ponds and wetlands, carbon dioxide is removed and pH increases, typically to about 7.0. Most active mine drainage treatment plants operate at a pH of 8.0 to 8.5 for rapid oxidation of ferrous iron. Semi-passive systems can use water power to add lime in order to reach the pH values necessary for rapid iron oxidation, thereby reducing the area required for ponds and wetlands.

Site Description

Lorberry Creek receives drainage from an underground anthracite mine in Schuylkill County, PA. A portion of Lorberry Creek (2250 – 2800 L/min) is directed to the treatment area (located approximately 35 miles northeast of Harrisburg, PA). The treatment system was constructed in the summer of 2001 and consists of four wetland cells as shown in Fig. 1. Cell 1 contains both deep (110 cm) and shallow (15 cm) areas. Cells 2, 3, and 4 are shallow wetlands about 15 cm deep. The wetlands were not planted, but by the summer of 2003, all but the deep area in cell 1 contained numerous species of aquatic vegetation. Two baffles, constructed of rigid fiberglass panels, were placed in the deep area of cell 1 to limit short-circuiting. Water is conveyed between cells by a rectangular weir and a riprapped ditch to promote aeration. The elevation difference between each cell is approximately 60 cm.

In the summer of 2003, lime was added to the influent water using the system shown in Fig. 2. The lime treatment system used is a medium-sized Aquafix™ unit consisting of an overshoot water wheel, which is geared to a screw feeder placed at the bottom of a 1-ton hopper (see Skousen and Jenkins, 2001). The system is intended to feed pebble lime (CaO). The lime feed rate is controlled by the flow to the water wheel.

Water is collected from Lorberry Creek about 200 m upstream of the treatment system. The water is piped from this point, which is about 8 m higher in elevation than the berm of cell 1. A small split of the water is taken from the main line for turning the water wheel. An additional split of water is piped to the trough located under the lime hopper to aid in carrying the lime to the pond. The remaining flow (>95%) travels down the main flow pipe and into the beginning of cell 1. At the end of the main flow, a 45 degree elbow is used to direct this flow to the point where the solid lime enters cell 1 to minimize any accumulation of lime solids.

Methods

Pebble lime was added to the mine water beginning on August 19, 2003. Water samples were collected to determine the performance of the system during two separate time periods: August 20 – 22 and October 9 – 10, 2003. Lime feed rates were adjusted by adjusting the flow of water to the water wheel. The speed of the wheel was measured by counting the number of revolutions over a 30 to 60 second period. The amount of lime added was measured by collecting the lime in a plastic bag over a 5 minute period. The lime was weighed on an electronic scale in the field. Flow of water to the wetlands was measured using an in-line flow meter.

Water samples were collected at the influent to cell 1 and at weirs 1 – 4 (see Fig. 1). Each sample consisted of an unfiltered, acidified sample and a filtered, acidified sample. An ampoule containing 2.0 mL of concentrated hydrochloric acid was added to each 125-mL sample bottle. This was sufficient acid to lower the pH to less than 1. Filtered samples were filtered through 0.45 micron syringe filters prior to acidification. Field pH was measured using a calibrated portable pH/ISE meter. Concentrations of Fe, Ca, Mn, Al, and S were determined in both the filtered and unfiltered samples using Inductively-Coupled Argon Plasma – Atomic Emission Spectroscopy.

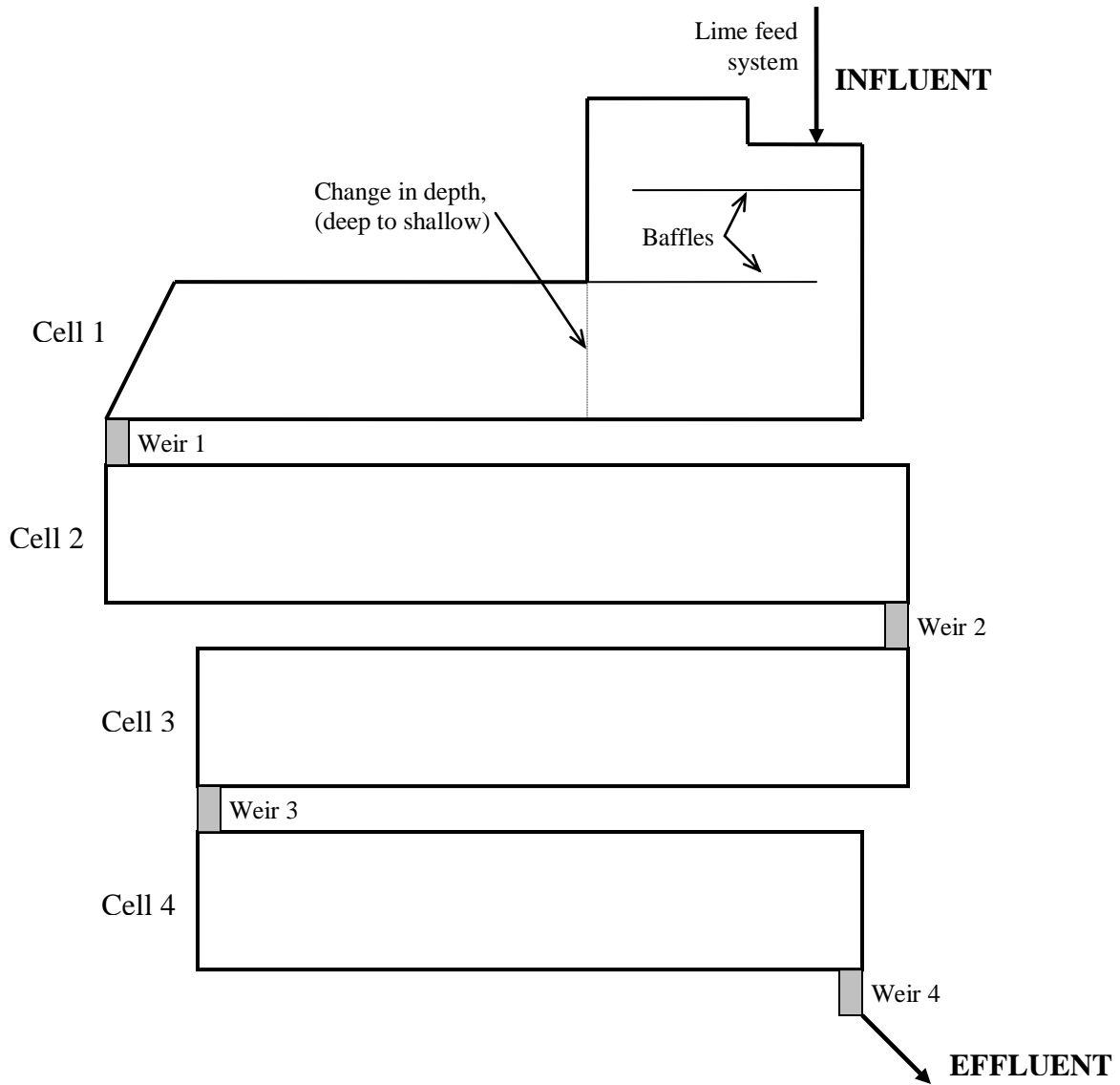


Figure 1. Schematic of four wetland cell treatment system at Lorberry.

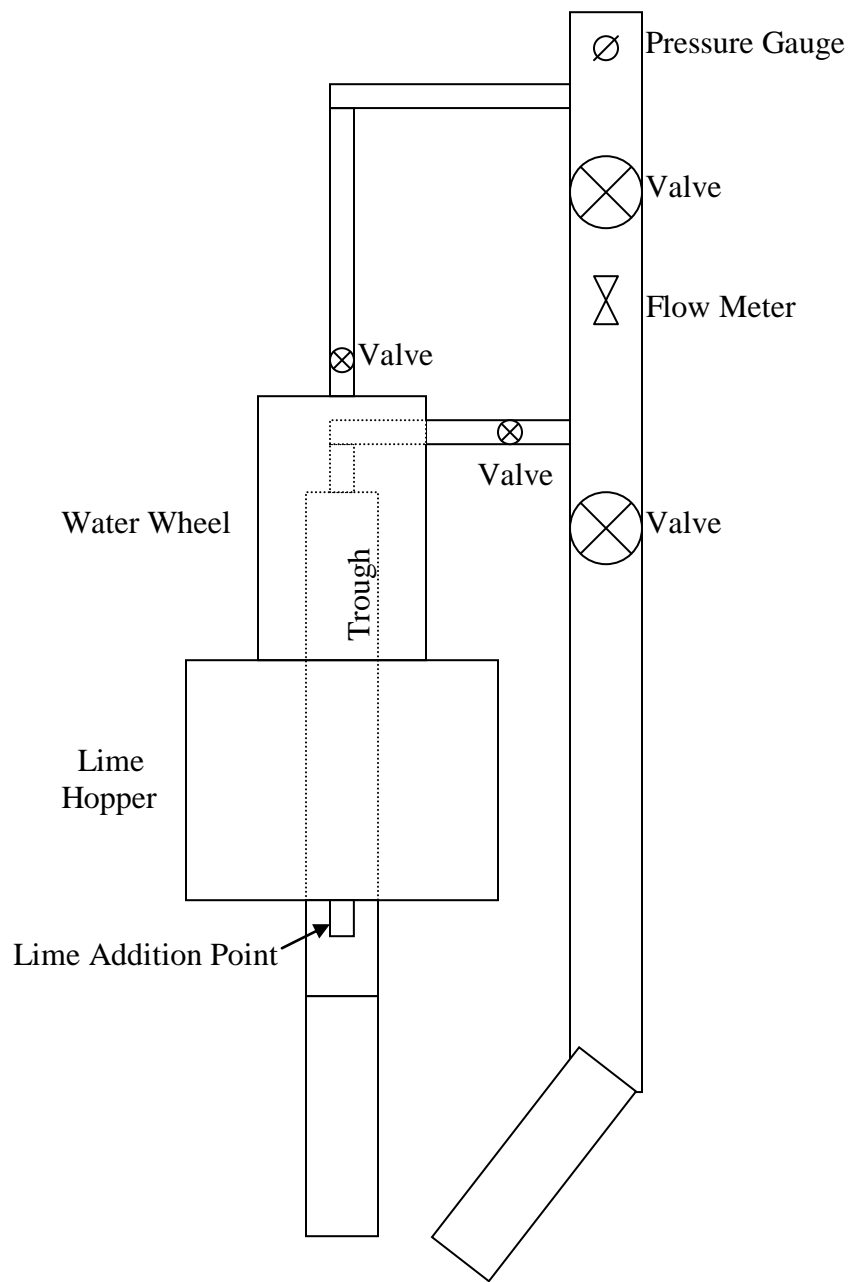


Figure 2. Schematic of the lime feed system.

Prior to the addition of lime, in March 2002, a tracer test was conducted at the site to determine the detention times for each of the four wetland cells. Potassium bromide was used as the tracer. A total of 9.07 kg of KBr was dissolved in 38 L of deionized water and stirred until completely dissolved. The tracer solution was added to the influent over a period of less than 1 minute (i.e., pulse input). Influent mine water flow measurements were taken before and periodically during the tracer test. Samples were collected at all four weirs prior to addition of tracer and at 30 minute intervals after addition. Two 125-ml samples were collected: one for immediate Br analysis in the field, and one to be analyzed in the laboratory. Field Br measurements were made using a selective ion electrode and were used as a guide in the field to determine sampling times. Ten hours (600 min.) after tracer addition, automatic samplers were set up at effluent of cells 1 and 4 to collect samples every 60 minutes during the overnight hours. The next morning, at 1540 minutes after tracer addition, final samples were collected “manually” at all four cells. Selected samples were analyzed in the laboratory for Br by ion chromatography.

Results and Discussion

Results of the tracer test are shown in Fig. 3 and 4. All bromide concentrations used in these graphs were based on laboratory analyses. Background levels of bromide averaged about 0.1 mg/L and this amount was subtracted from all measured concentrations prior to graphing. The time at which the peak of the tracer concentration and time that 50% of the cumulative load of tracer passed weirs 1 through 4 are given in table 1 along with the corresponding theoretical detention times based on flow and pond volume. As expected, the system did not act like an ideal plug-flow reactor. Evidence of some short-circuiting was discovered by the presence of tracer at times shorter than the theoretical detention time. Evidence of some mixing can be inferred from the long tails of Fig. 3. The secondary peaks at weirs 1 and 4 at about 1000 minutes can not be explained. These secondary peaks were not seen at weirs 2 and 3 because they were not sampled during this time. Total recovery of tracer at weirs 1, 2, 3 and 4 totaled 103%, 110%, 104% and 104%, respectively.

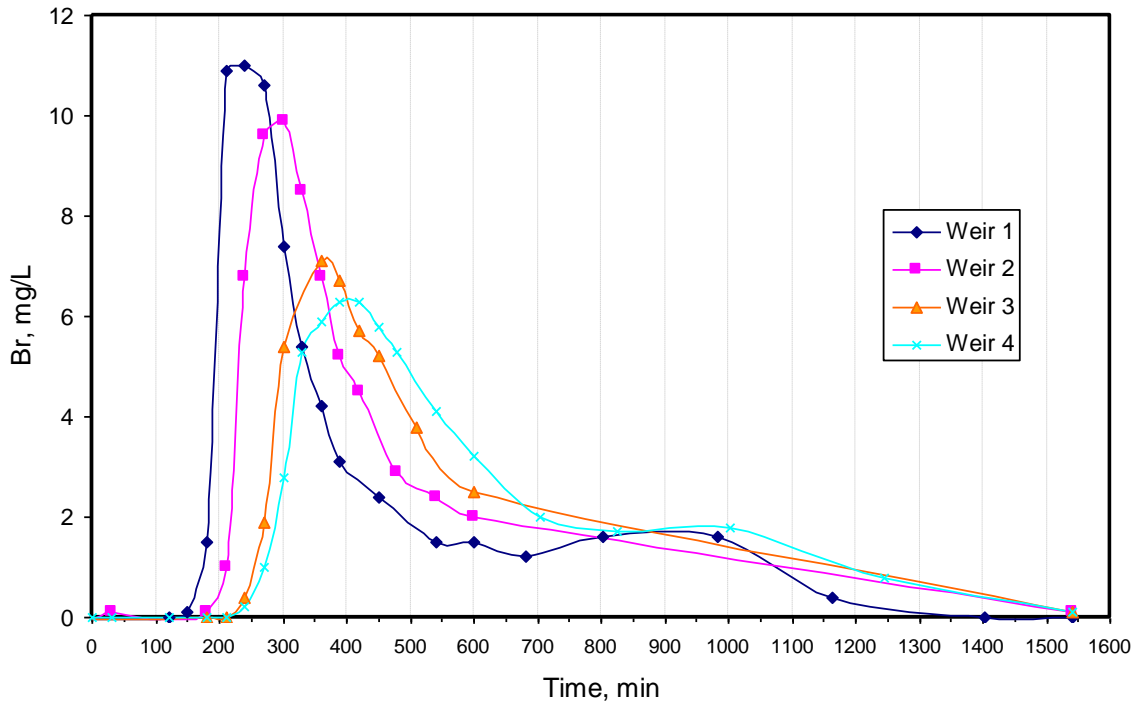


Figure 3. Tracer Concentration at the effluent of the four wetland cells with time.

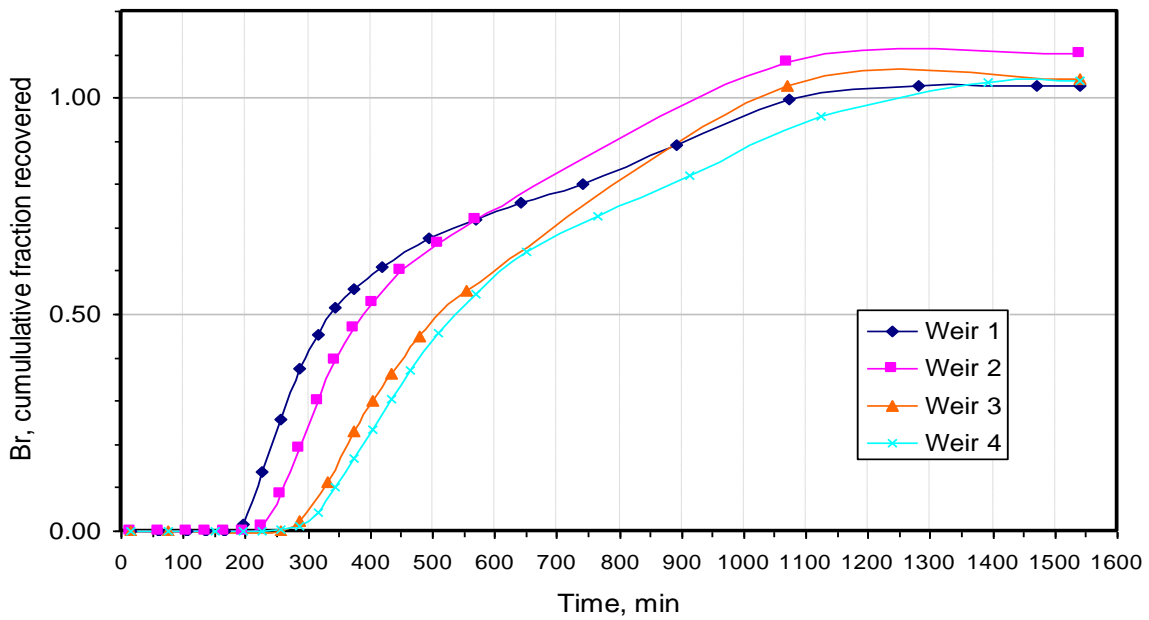


Figure 4. Cumulative Tracer Load – Fraction of Bromide Recovered

Table 1. Estimated detention times at the four weirs.

Basis of Detention Time Estimate	Detention time in minutes at the listed location			
	Weir 1	Weir 2	Weir 3	Weir 4
<i>Peak concentration of tracer</i>	240	300	360	405
<i>50% of tracer load</i>	340	390	514	537
<i>Theoretical</i>	430	492	547	597

Lime feed rates correlated fairly well ($r^2 = 0.91$) with the speed of the wheel as shown in Fig. 5. During the duration of test 1 (Aug 20-22) and test 2 (Oct 9-10), lime was added at an average rate of 3500 g/min and 2800 g/min, respectively.

Iron concentrations versus detention times based on the tracer test results are shown in Fig. 6 and 7. Detention times were based on the time to reach the peak bromide concentration and were adjusted linearly based on the flow during the day that the water was sampled. Data points for the December 2001 and November 2002 tests when no lime was added represent one sampling event each. Data points for the August 2003 test are the average values of five separate sampling events over a three-day period. Data points for the October 2003 test represent the average of two sampling events over a two-day period.

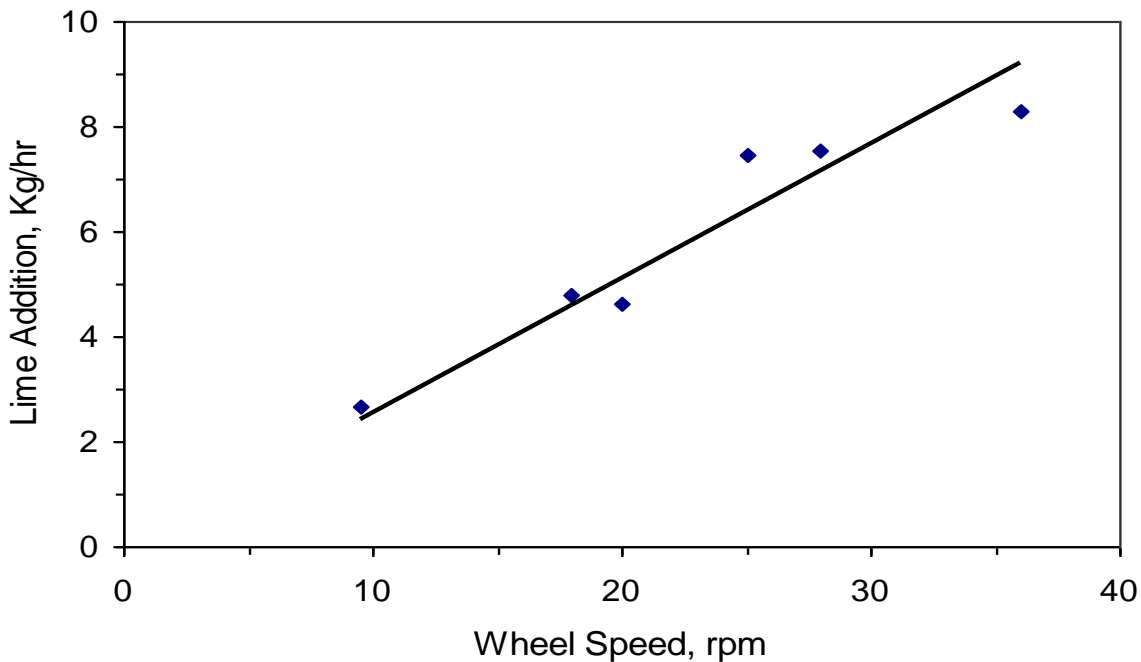


Figure 5. Relationship of wheel speed to lime feed rate.

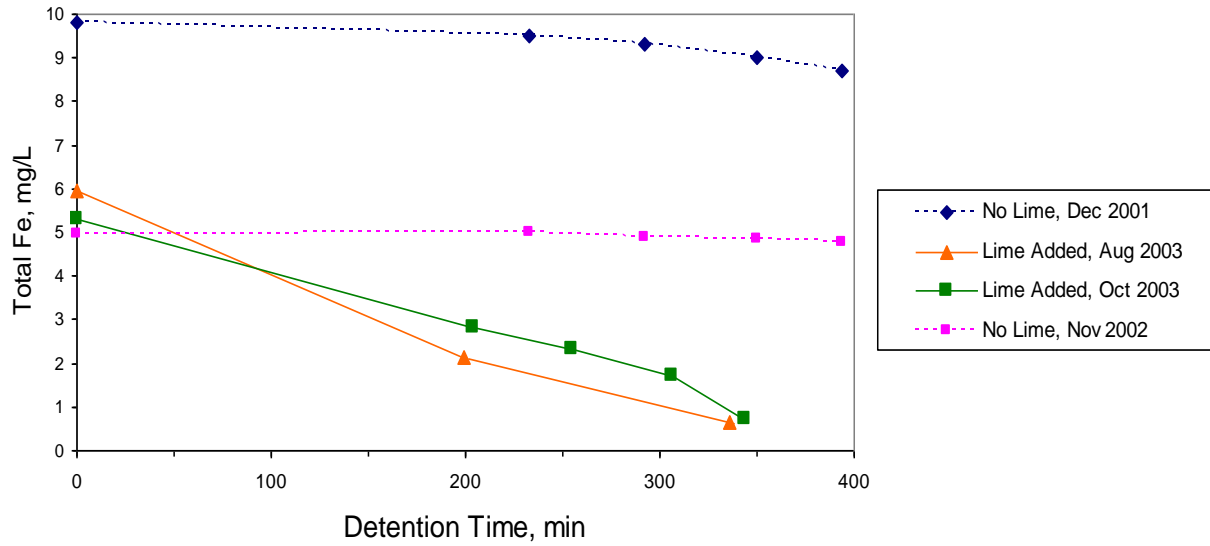


Figure 6. Total iron concentration as a function of detention time with and without lime addition.

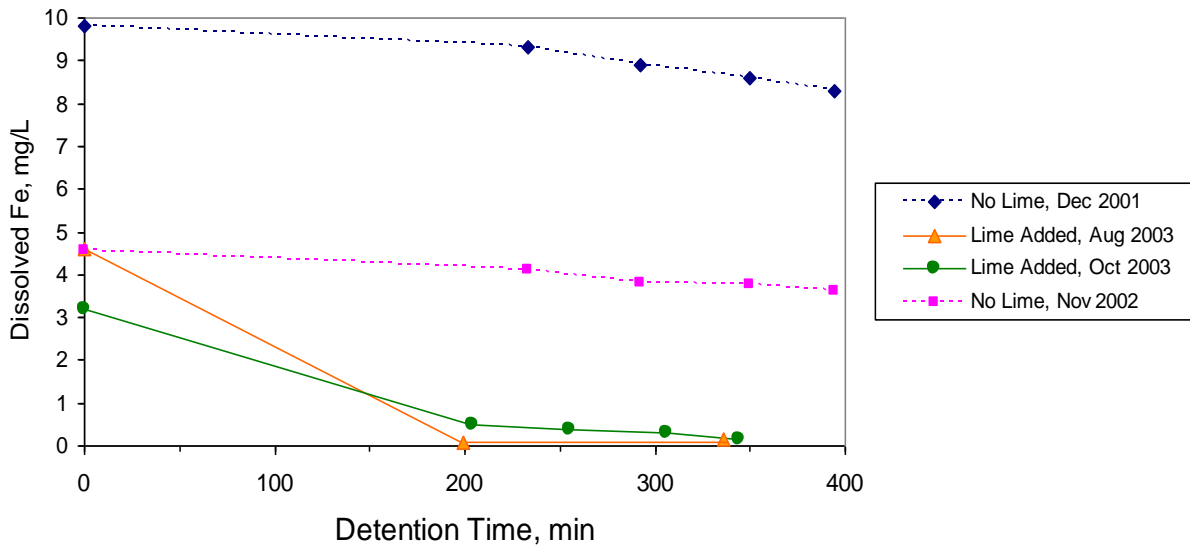


Figure 7. Dissolved iron concentration as a function of detention time with and without lime addition.

During the December 2001 and November 2002 sampling, as the mine water passed through the system (influent to effluent), pH only increased from 6.4 to 6.6 and from 3.9 to 4.0, respectively. For the August and October 2003 test (when lime was added), pH increased from about 5 to between 7 and 8.

As can be seen in Figure 6, total iron concentrations remain virtually unchanged as the water passes through the system when no lime is added to the water (3 – 11% reduction). During the lime addition tests, however, significant reductions in total iron concentrations were achieved (86 – 89%). Similar trends were noted for dissolved iron (Fig. 7) with reductions of only 15 – 21% without lime addition and reductions of 95 – 97% with lime addition. Much of the dissolved iron was removed after ~ 200 minutes which corresponds to the effluent of cell 1. Additional suspended iron was removed in cells 2 through 4 as evidenced by decreases in total iron in Fig. 6. Vegetation in these cells seemed to aid in the settling of the fine particles of suspended iron.

Aerobic wetlands have been shown to remove between 10 and 20 g/day of iron per square meter of wetland (Hedin et al., 1994). It has been observed that these removal rates decrease with decreasing iron concentration. At the low iron concentrations at this site (<10 mg/L), iron removal rates without lime addition were extremely low, about 1 $\text{gd}^{-1}\text{m}^{-2}$ or less (Fig. 8). During the lime addition test, most of the iron was removed by the time the water reached the effluent of cell 1. Iron removal rates for cell 1 during lime addition ranged from 6 to 11 $\text{gd}^{-1}\text{m}^{-2}$.

Costs associated with the semi-passive part of this treatment system are less than conventional treatment. The Aquafix™ system with a 1-tonne hopper cost \$16,000. Additional capital costs would include the pipe and valves and would be somewhat site specific depending on the distance that the water needed to be piped. Operating costs include the cost of the pebble lime. Bagged pebble lime costs about \$160 - \$200 per tonne including delivery. The bags are 23 kg (50 lbs) and can be handled fairly easily (proper personal protective equipment should be worn). The hopper at this site only holds enough lime for about 2 weeks under normal operating conditions. Annual lime cost would total about \$5000. The filling of the hopper is fairly labor intensive taking two people approximately 30 minutes. If a larger hopper was used, it would reduce the required labor and reduce lime costs. Bulk lime to this site would cost about \$100 per tonne, delivered.

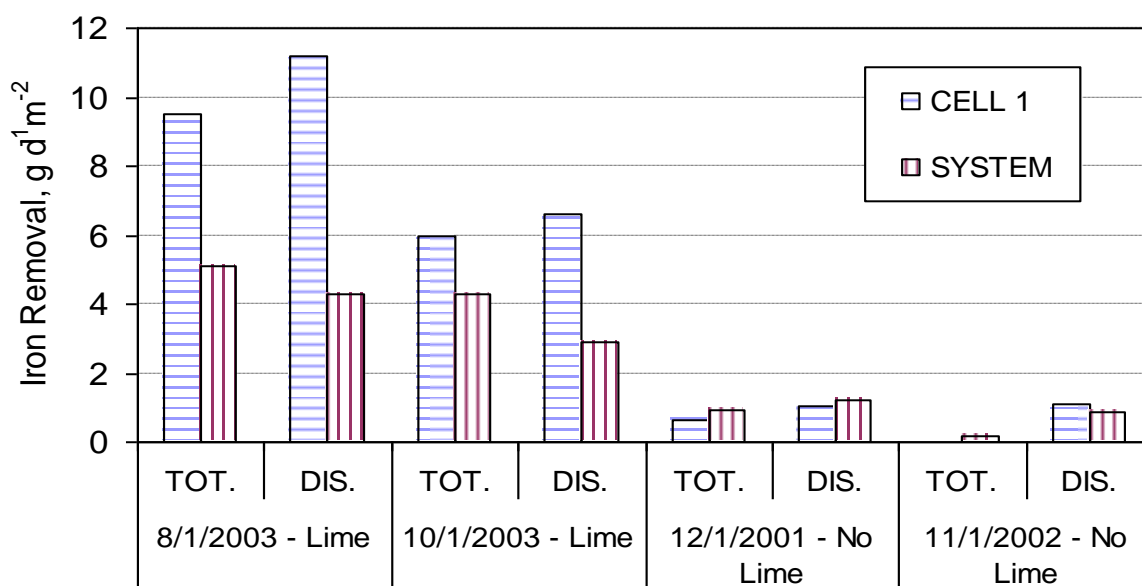


Figure 8. Total and dissolved iron removal rates with and without lime addition.

Conclusions

This study determined that semi-passive treatment using a water-powered lime feed in conjunction with wetlands can be very effective for high-flow, low-iron mine discharges. An Aquafix™ system used in combination with wetlands (0.40 ha) effectively reduced iron concentrations from between 5 – 6 mg/L to less than 1 mg/L. At this particular site, this type of treatment system may be the best option available. Conventional active treatment can be very expensive and labor intensive. Passive treatment alone (without the addition of lime), would require a much larger area (up to ten times) to remove iron to less than 1 mg/L and this area was not available at this site.

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