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PIT LAKE TREATMENT AT LES MINES SELBAIE

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Abstract

Les Mines Selbaie, located approximately 130 km North of La Sarre, Quebec, is a copper-zinc mine that operated from 1981 to 2004. The pit void has since been allowed to fill with groundwater, site runoff, and treated slurry which is discharged here from a lime treatment plant. The mixture of these three water sources has formed a pit lake containing approximately 22 Mm^3 of water in the summer of 2005. Since 2001, the pit void has also been a repository for low-grade ore, tailings, potentially acid generating waste rock, and metal laden contaminated soils. Water balance modeling has suggested that overflow of the pit lake will most likely occur in 2008 or 2009, when the total lake volume attains approximately 38 Mm^3. The final pit lake overflow water quality will need to meet specific discharge criteria prior to entering the receiving environment. In summer of 2005, the pit lake Zn concentrations averaged approximately 10 mg/L, which is considerably higher than the discharge limit of 0.5 mg/L. All other discharge criteria were met, including pH as it was 7.2. This paper summarises the work completed in the laboratory scale, pilot scale, and full scale for the successful treatment of dissolved Zn in 22 Mm^3 of water in 52 days.

INTRODUCTION

Les Mines Selbaie terminated operations in 2004 and currently have an open pit containing approximately 22 million cubic meters of water (22 Mm3). The closure plan is to maintain good quality pit lake surface water and allow it to overflow to the environment once it fills to the discharge elevation. Contaminated water collected from the mine waste rock pile is treated at a lime plant prior to being fed to the open pit. At the same time, since the introduction of contaminated wastes into the pit from the cleanup of the site, the dissolved zinc concentrations have increased above acceptable discharge concentrations. In spring 2005, a relatively uniform concentration of 10 mg/L of Zn was measured at depth in the water column.

The site is characterised by waste rock piles, a tailings pond, a plant site, and a treatment plant. The mill and most other infrastructure from the plant site were removed in 2004 and 2005. Some of the drainage from the waste rock is collected in a sub-surface drain and flows to a raw water pond to be treated by the water treatment plant (WTP). This source of water is a highly acidic acid mine drainage (AMD), containing more than 3,000 mg/L of Zn and 1,000 mg/L of Fe. Tailings and site run-off are typically lightly contaminated with Zn concentrations of less than 5 mg/L.

Waste materials from around the site were deposited in the pit. These wastes included fresh (unoxidized) tailings, fresh and oxidized waste rock, contaminated peat, and contaminated soils (McKee et al. 2005). Approximately 11.5 million cubic metres of waste materials were deposited in the pit over the period of 2001 to 2005. Measurements and modelling have indicated that the bulk of the dissolved Zn loadings in the pit lake provide from these wastes (Lorax, 2005).

In order to meet the objective of eventually overflowing from the pit lake directly to the environment, it was necessary to remove the dissolved Zn loadings from the pit lake. Though at least three years remained before the pit lake will reach the overflow volume (38 Mm^3), it was decided that the dissolved Zn should be treated immediately to prove that batch treatment of a large pit lake can be efficiently completed. It was also considered possible to maintain the low Zn concentrations in the pit lake once the initial treatment is completed.

EXPERIMENTAL METHODOLOGY

The work described here was completed in three phases: 1) Laboratory, 2) Limnocorral (pilot scale), and 3) Full Scale. The methodologies applied in the first two phases are described here, while the full scale phase is in the body of the report. A large number of tests were completed in the laboratory, including the use of ferric sulphate, aluminium coagulants, and Red Mud to help settle the Zn hydroxide particles. The results shown here will focus primarily on the use of lime addition without coagulants as this was the chosen treatment method.

Laboratory Experiments

Seven 20-L pails were filled with pit lake water sampled from a depth of 5 m using a diaphragm pump. The pails were kept sealed until sampling 1-L volumes for tests. Laboratory-grade hydrated lime was used to control pH and determine the consumption rate of each test. Sufficient lime to reach the pH setpoint was added to the test. The pH was measured and noted at the beginning and end of each test. The slurry was mixed for 5 minutes following attainment of the setpoint pH for all tests and the lime consumption rate determined.

After neutralisation, the precipitates were allowed to settle in the beaker. Samples from the supernatant were taken at 1 and at 24 hours into the test using a syringe with the tip immersed just below the water surface, to minimise the risk of collecting floating particles.

Limnocorral Tests

The laboratory tests were followed by limnocorral experiments in the field. Limnocorrals are experimental enclosures, which are open at the top and bottom and isolate a portion of the water column from lateral mixing within the lake. The limnocorrals used in this project were 2 m in diameter and 10 m in depth (see Figure 1). Limnocorrals were designed to isolate the mixed surface layer (epilimnion), which according to previously collected data was in the 4 to 6 m depth range.

A 16’ x 16’ raft with six bays for attaching the limnocorrals was constructed and deployed at the site. Limnocorrals were fabricated from polyethylene tarp material with support rings (1/2” diameter plastic pipe) inserted into sleeves every two metres along the tube to ensure the tube maintained a cylindrical shape (Figure 1). Floatation was provided by foam cylinders inserted into a sleeve at the top of the tubes. A collar extended approximately 30 cm above the lake surface to reduce waves and spray from outside the limnocorrals entering the isolated water column. The bottom of the tube was weighted with sand-filled plastic pipe. The contained water volume was about 31 m^3.

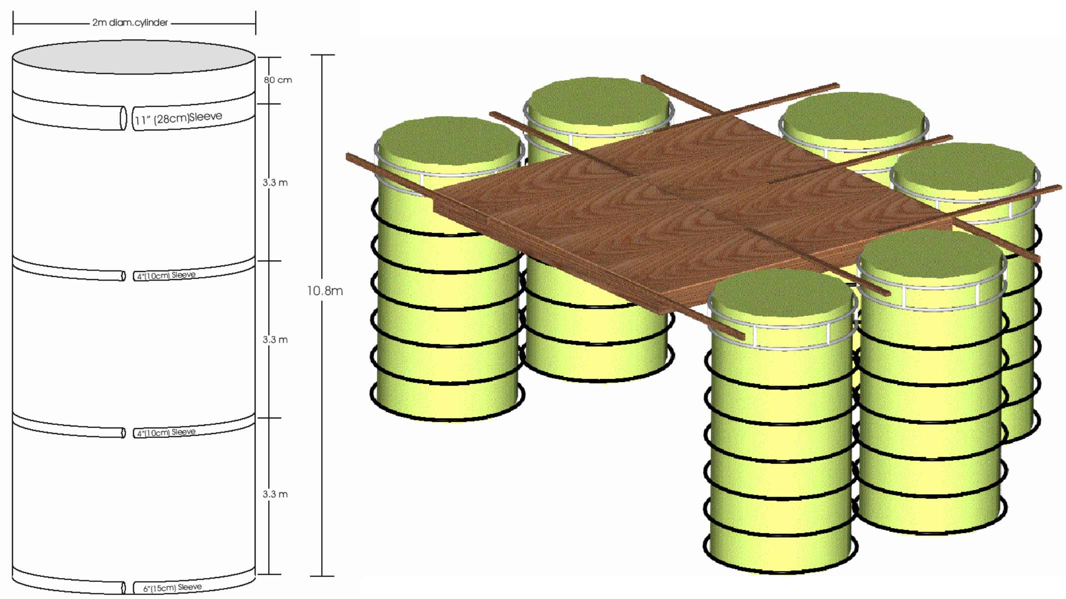

Figure 1: Limnocorral Dimensions and Design of Raft

Treatment tests were completed in all but one of the six limnocorrals, the control (Limnocorral #4). The treatment summary is given in Table 1. The objectives of these tests were to confirm the lime consumption established in the laboratory setting and to establish the most efficient treatment methodology, given the presence of the thermocline.

The first tests to be completed were liming the surface of Limnocorrals #1, 5 and 6, which took less than 30 minutes for each test carried out this way. A well-mixed lime slurry was slowly poured from a bucket into the point of greatest agitation from the impeller, while mechanically stirring the water in the limnocorral. Mixing continued for a few minutes after lime was either fully consumed (Limnocorral #1), or until the desired pH was attained (Limnocorrals #5 and #6).

Table 1: Summary of Limnocorral Experiments

Limnocorral	Initial Treatment	Treated pH	Treated Depth (interval in m)	Secondary Treatment
Limno#1	Surface liming	10.7	0 - 4	-
Limno#2	Recirculation - suction at depth	9.5	0 - 5	-
Limno#3	Recirculation - discharge at depth	11.0	6 - 9	-
Limno#4	Control (no treatment)	-	-	-
Limno#5	Surface liming	9.5	0 - 4	Red mud addition
Limno#6	Surface liming	9.5	0 - 4	Fertilisation and algae seeding

The two recirculation tests to treat Limnocorrals #2 and #3 took 5 to 6 days respectively. Recirculation treatment was effected with a 10 L/min diaphragm pump, conveying untreated water to a 20-L pail where pH was controlled by lime slurry addition (see Figure 2). A pH probe was inserted near the overflow of the treatment bucket and monitored regularly to ensure continuous treatment to the setpoint pH. Lime addition was controlled using a variable-speed peristaltic pump transferring lime slurry obtained from the Selbaie Lime Plant. Both the lime slurry and the treatment buckets were continuously stirred using agitators. Treatment was conducted for 6 to 8 hours per day because operators could not monitor the treatment system at night and during meal times.

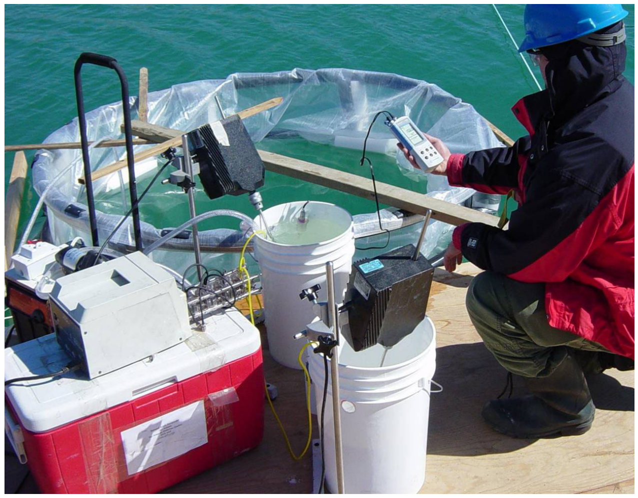

Figure 2: Recirculation Treatment of Limnocorral #2

EXPERIMENTAL RESULTS AND DISCUSSION

Laboratory Experiments

The treatment goal was to attain a total Zn concentration of less than 0.5 mg/L. Figure 3 shows the lime treatment results on both a linear and log scale for better resolution at low concentrations. Duplicated tests show excellent repeatability as illustrated by the points at pH values of 9, 9.5, and 10. Overall, these results indicate that the target concentration of 0.5 mg/L of total Zn is attained at a pH of 9.5. Also evident is a significant improvement when increasing the pH to 10.0, with further minor improvement when raising the pH to 11 or higher.

Given these results, a pH of 10 was selected as setpoint for further test work. Reason is that the Zn concentration when treating at pH 9.5 was only marginally below the target of 0.5 mg/L by 0.1 mg/L. By adding a little more lime and treating to a pH of 10, the final Zn concentrations were below 0.2 mg/L. According to Figure 4, the lime consumption was actually lower for the pH 10 setpoint but this is attributed to experimental error. The difference between the two lime consumption measurements was 0.03 g/L and the balance used to measure the lime consumption had a precision of 0.01 g/L. The logarithmic graph clearly shows a linear relationship between lime consumption and pH, except that the pH 9.5 value is an outlier.

Limnocorral Tests

Figure 5 shows the initial profiles taken after the primary treatment in each of the 5 limnocorrals that were treated (limnocorral #4 was kept as a control). Surface treatment in limnocorral #1 proved that surface lime addition can successfully treat the epilimnion (warm upper layer of the lake). The treatment in this limnocorral did not successfully penetrate the thermocline as the sample taken from a 5-m depth did not meet the 0.5 mg/L target. These results agreed with surface treatment to a pH of 9.5 in limnocorrals 5 and 6, which resulted in Zn concentrations near but not below the target of 0.5 mg/L at 1 and 2-m depths. The 5-m depth was above 2 mg/L for both limnocorrals, thus showing that surface treatment does not penetrate the thermocline.

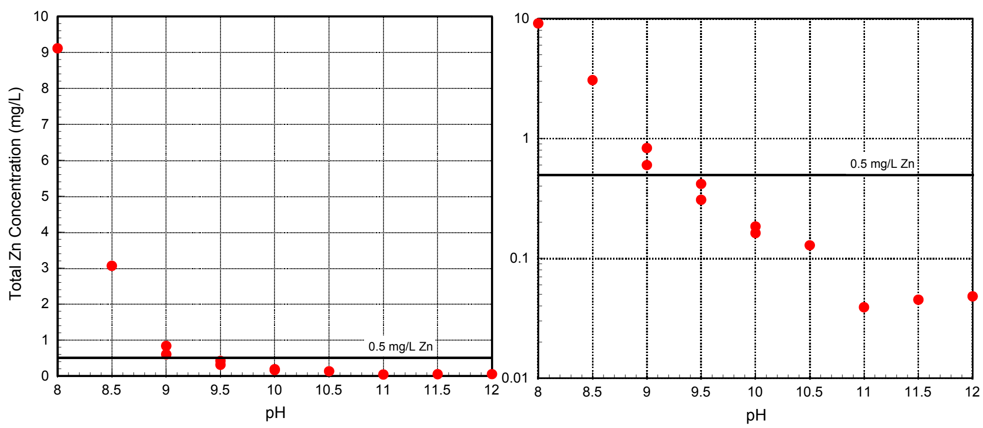

Figure 3: Zn Concentrations with Respect to pH for Lime Addition Tests

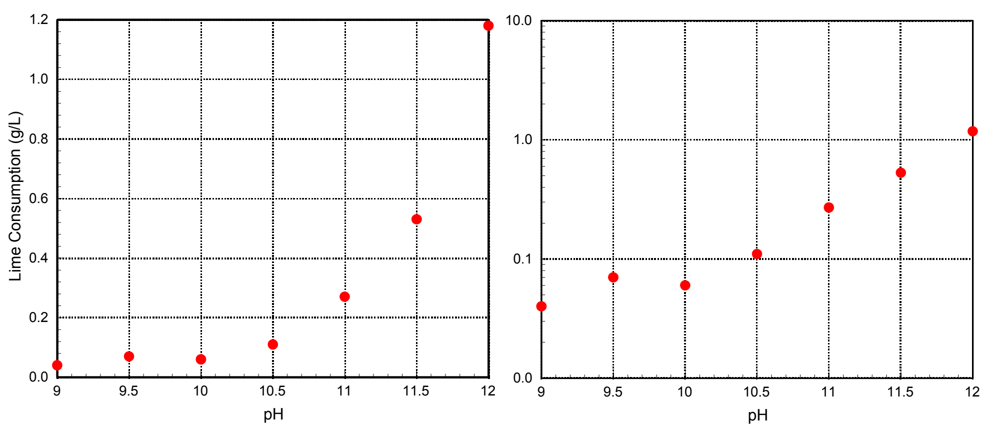

Figure 4: Lime Consumption with Respect to pH

The results from Limnocorral #2 showed that recirculation and discharge at surface can not only treat the epilimnion but also penetrate the thermocline as the Zn concentration at the 5-m depth was 0.12 mg/L. Unfortunately, it was not possible to properly ascertain the treatment efficiency at depth because the lake hypolimnion (deep cool layer of water) mixed with the lower portion of the bottomless limnocorrals. Limnocorrals were originally designed for biological tests where the activity is primarily in the epilimnion. For chemical testing, it would have been preferable to design these with bottoms.

In Limnocorral #3, treatment was accomplished by drawing water at the surface, liming it, and injecting it at depth. Due to the mixing at the bottom, this treatment method was unsuccessful in the limnocorral. Measurements taken during treatment nevertheless indicated that injecting treated water at depth can quickly increase the pH up to the bottom of the thermocline.

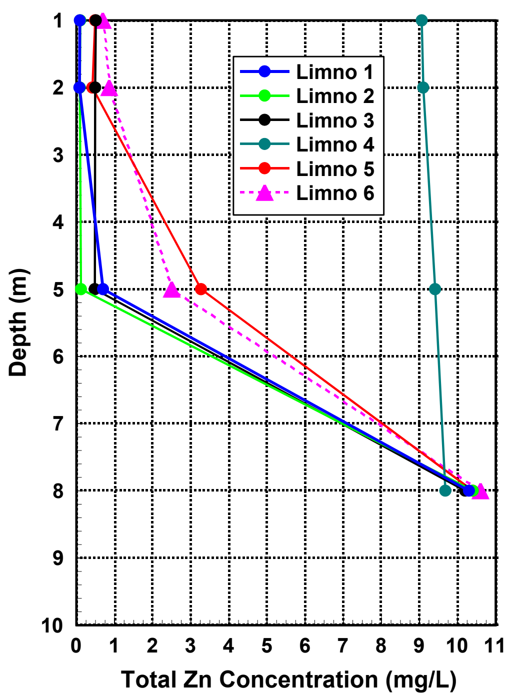

Figure 5: Zn Profiles in Limnocorrals Following Treatment

Secondary treatment in Limnocorral #5 with Red Mud, a waste product from aluminium refineries, decreased the Zn concentrations by 41%. This indicates that Red Mud could potentially be used as a coagulant to reduce Zn concentrations if lime treatment alone was not successful. The secondary treatment in Limnocorral #6 was the inoculation of algae and the weekly fertilisation for nutrient control. This biological treatment was not successfully implemented as no algal growth was measured until late in the summer. Although the algae test was slow to start, this option does show some potential to control Zn concentrations in the long term.

Limnocorral testing proved that lime addition could efficiently control Zn concentrations in the field. The relationship between Zn concentrations and pH setpoints were very much in line with the results obtained in the laboratory. The lime consumption rates in the limnocorrals also corresponded with those measured in the laboratory. This suggested that a pH setpoint of 10 would require approximately 0.1 g/L of hydrated lime and would effectively bring the Zn concentrations in the pit lake well below the target concentration of 0.5 mg/L. The results from Limnocorral #2 showed that recirculation and discharge at surface can not only treat the epilimnion but also penetrate the thermocline. Limnocorral #3 showed that recirculation treatment by treating warm surface water and injecting at depth can quickly increase the pH up to the bottom of the thermocline. It was therefore recommended that a recirculating treatment be used to treat the entire pit lake. To treat all layers of lake, the treatment system was to take the warm surface water, add lime, and inject 90% at depth, and 10% at surface. This ratio was chosen as the top 5 m of the lake (epilimnion) represented approximately 10% of the total lake volume.

PIT LAKE BATCH TREATMENT

Based on these findings, EnvirAubé proposed the conceptual design of a recirculating treatment system to batch treat the entire 22+ Mm^3 of water (see Figure 6). The conservative lime consumption estimate used an expected lime efficiency in the order of 75%.

Lime Treatment System Description

SNC-Lavalin Inc. completed the detailed design, commissioning, and operation of the pit lake treatment system. It consisted of a portable batch slaking system, agitators, and two slurry pumps (all rented) plus a lime slurry storage tank, and two water recirculating systems. Conceptual drawings are shown in figures 6 and 7 for the cross-sectional and plan views respectively. Figure 8 shows a photo of the treatment system with identification of the key elements.

The water pumping system consisted of two submersible pumps of 1,300 and 1,400 m^3/h capacity for water recirculation from the surface (2 m depth) to depth (40 m depth). These pumps were supported by a barge near the existing access ramp. Lime slurry was injected at the pump discharge into the 18” HDPE pipes that conveyed the treated water to the South and North discharge rafts, positioned respectively 330 m and 480 m away. The pipes themselves floated either just below the water surface or up to 2” above during operation.

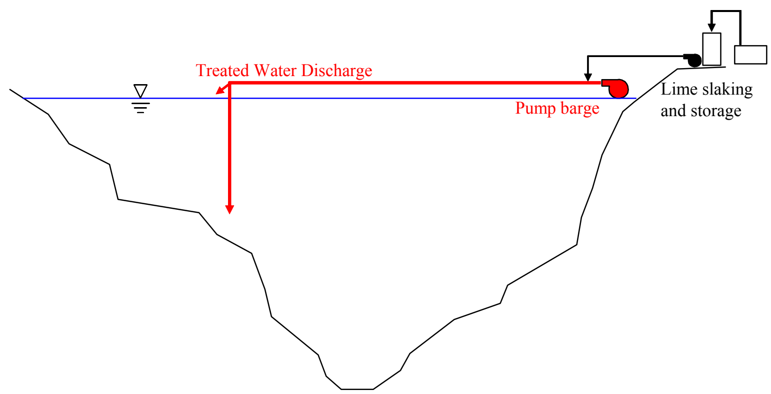

Figure 6: Conceptual Representation of the Treatment System (cross-section)

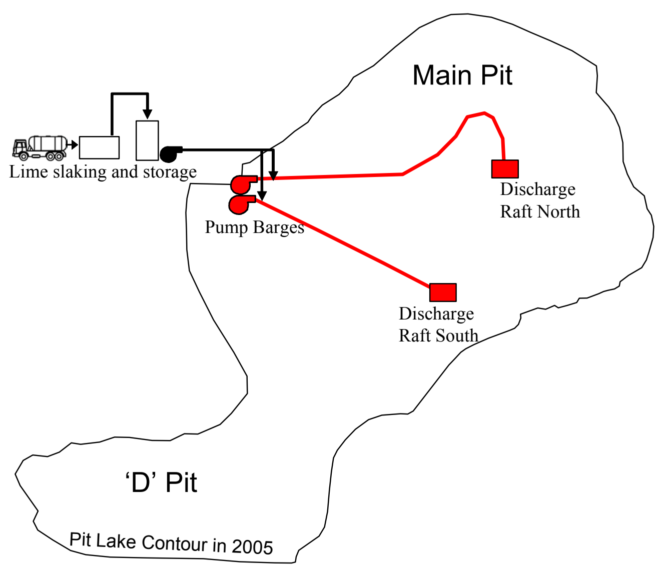

Figure 7: Conceptual Representation of the Treatment System (plan view)

The discharge rafts were fitted with elbows to convey the treated slurry into 40-m downpipes. These steel downpipes were equipped with diffusers in the final 2 m for a better repartition of the lime and to minimize mechanical stress. Above the surface on the discharge rafts, a smaller pipe was fitted into the 18” line to release approximately 10% of the flow on surface and treat the epilimnion.

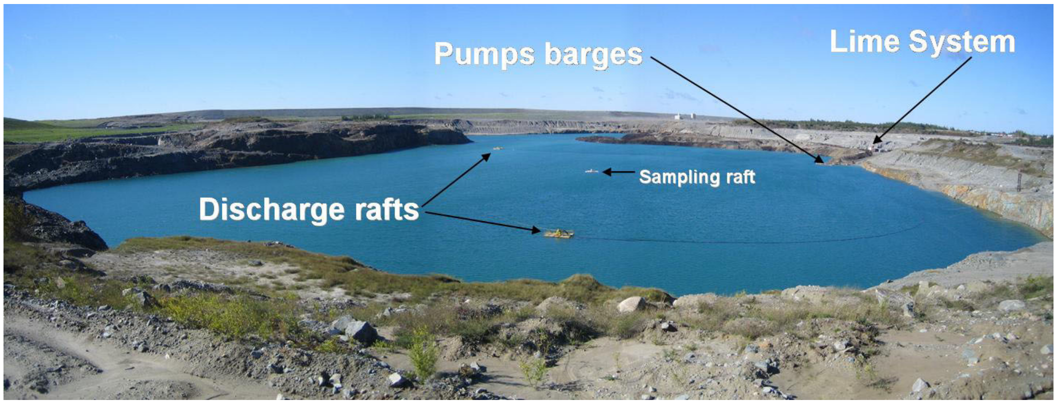

Figure 8: Photo of Treatment System soon after Commissioning

Installation of the Treatment System

The lime system (including portable slaker, lime storage tank, and pumps) was installed near the pit ramp on a solid bed of crushed rock, as shown in Figure 9. The two submersible pumps were installed on a floating barge, accessed by a ramp from the shore. The most challenging phase was the installation of the 40-m steel downpipes. As the mining benches below water were 10 m by 10 m, it was necessary to float the steel downpipes out before bringing them vertical. The pipes were capped at one end to enable them to float. An excavator was used to guide the pipe out before attaching it to the discharge raft and getting it vertical. Figure 10 shows the excavator gently pushing the out the downpipe with the sealed end toward the viewer and the diffuser end submerged. Next to the downpipe is half the pump barge with the pump piping already attached. The two halves of the pump barge were attached following deployment.

Figure 9: Lime Slaker and Slurry Storage Tank

Following the use of the excavator, the downpipe was moved out into the pit lake by attaching it to the discharge raft and pulling it out with a boat. To bring it vertical, a valve installed at the sealed end was opened to allow air out and water to enter from below. Once it was vertical, the downpipe was attached to the raft and fully deployed.

Treatment Operation

The treatment system was installed in late summer of 2005 and commissioned on September 15th. The treatment objective was to gradually inject 2,000 tonnes of quicklime while ensuring proper dissolution efficiency. To promote dissolution while treating quickly, the lime injection rate was to maintain a pH between 11.5 and 12 at the discharge of the piping. A higher pH would decrease the lime dissolution efficiency and result in significant settling of unreacted lime particles. A pH of less than 11.5 would reduce the feed rate of lime and prolong the required time for complete treatment. According to the laboratory tests (Figure 4) this pH range represented a hydrated lime injection rate between about 0.5 and 1.2 g/L.

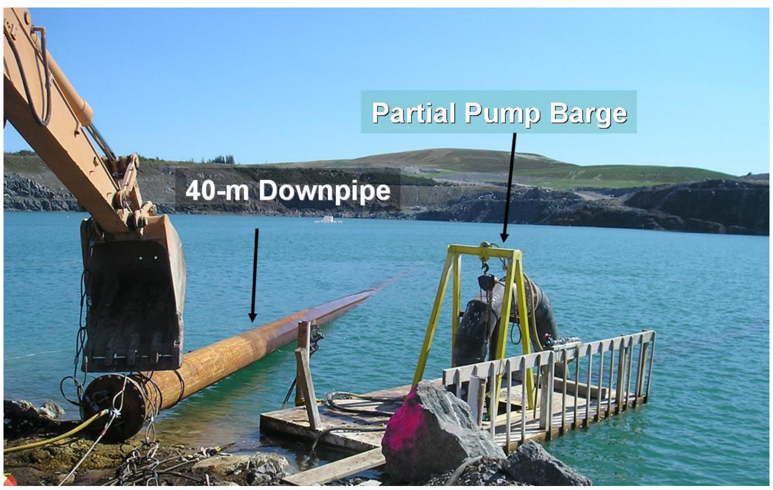

Figure 10: Deployment of Downpipe

The lime system was operated 24 hours per day over 52 days. Operations were very efficient with less than 5% downtime. The system consumed essentially one 40-tonne truckload of quicklime per day. One operating incident occurred when the North recirculating pump shut down and it was not realised by the operator. Being a temporary installation, it did not have flowmeters or an alarm system on power draw. The 18” pipe eventually filled with 20% lime slurry, which significantly increased the weight of the piping. This caused the elbow to weaken at the discharge raft. A few days before meeting the target 2000 tonnes of lime, this pipe broke and continued to discharge at surface. The pipe was allowed to float as no security or operating concerns resulted from the breakage.

Treatment Results

To ensure that treatment progressed as planned, physico-chemical profiles were completed on a regular basis at different locations in the pit lake. The parameters of most interest were the pH and the total Zn concentrations. Also measured were temperature, redox, conductivity, dissolved oxygen, and cadmium concentrations. Samples were collected by pumping from depths of 2, 5, 10, 25, 50, and 75 m. These were analysed for both total and dissolved concentrations of Zn and Cd. The physico-chemical profiling was completed at the same depths plus 90 m using a Hach Hydrolab.

All sampling campaigns were done at multiple locations in the pit. This was important to ensure homogeneous treatment, particularly because the “D” Pit is partially separated from the Main Pit where treatment was accomplished (see Figure 7). Profiles taken at different locations were always reasonably similar during treatment and essentially the same before and after treatment. For this reason, only the results from the central location of the Main Pit are described here.

Figure 11 shows some of the pH and Zn profiles measured in the pit lake during and following treatment. As shown in Table 2, the initial average pH was 7.2. The pH values quickly increased during operation. Due to weather conditions, it was not possible to complete the profiling immediately following treatment, which is why the final pH measurement was taken 19 days after treatment was discontinued. It is likely that the pH had reached the target of 10.0 as in that 19-day interval there had been significant precipitation which may have decreased pH. On October 26, 10 days before the end of treatment, there is a clear increase in pH below the 40-m injection depth. This is caused by the partial settling of limed water due to its’ higher density. At this time the water column was of a relatively uniform temperature of 7ºC. Earlier in the treatment campaign, the water being injected had a temperature above 10ºC while the water at depth was at 6ºC. With initial temperatures, the treated water did not noticeably settle. The surface temperatures decreased naturally due to the decreased air temperatures, but the treatment system itself equalised the temperatures quickly due to the high rate of surface water injection at depth.

The right side of Figure 11 shows the Zn concentration profiles measured at different times in the pit lake. The graph is divided to better show the initial total Zn concentrations (scale of 5 to 11 mg/L) as well as the eventual decrease in concentrations (scale of 0 to 2 mg/L). The initial Zn concentrations were near 10 mg/L at depth and 6 mg/L at surface. The Zn concentrations decreased rapidly and the expected target of 0.2

mg/L was met after only 35 days of treatment. All of the profiles from October 26 onward are not discernable as they are all below 0.25 mg/L.

Table 2 shows the average pH and Zn concentrations measured in the pit lake at various times. The last two samples have sample days identified as the number of days following the end of treatment. The total Zn concentration increased to reach 0.17 mg/L between the end of treatment and the final sampling (November 25th, day +19). In that interval, there was snow accumulation followed by a thaw and this may have caused some uncontrolled Zn concentrations to enter the pit from the immediate catch basin. Another pit sampling campaign completed under the ice on March 2nd 2006 showed that the total Zn concentrations had decreased to 0.13 mg/L, even though the pH had decreased to 9.20. The quiescent conditions offered by an ice cover may have allowed some small particles to settle to the bottom of the pit. Overall, the treatment results have exceeded expectations as the final Zn concentrations were below 0.2 mg/L.

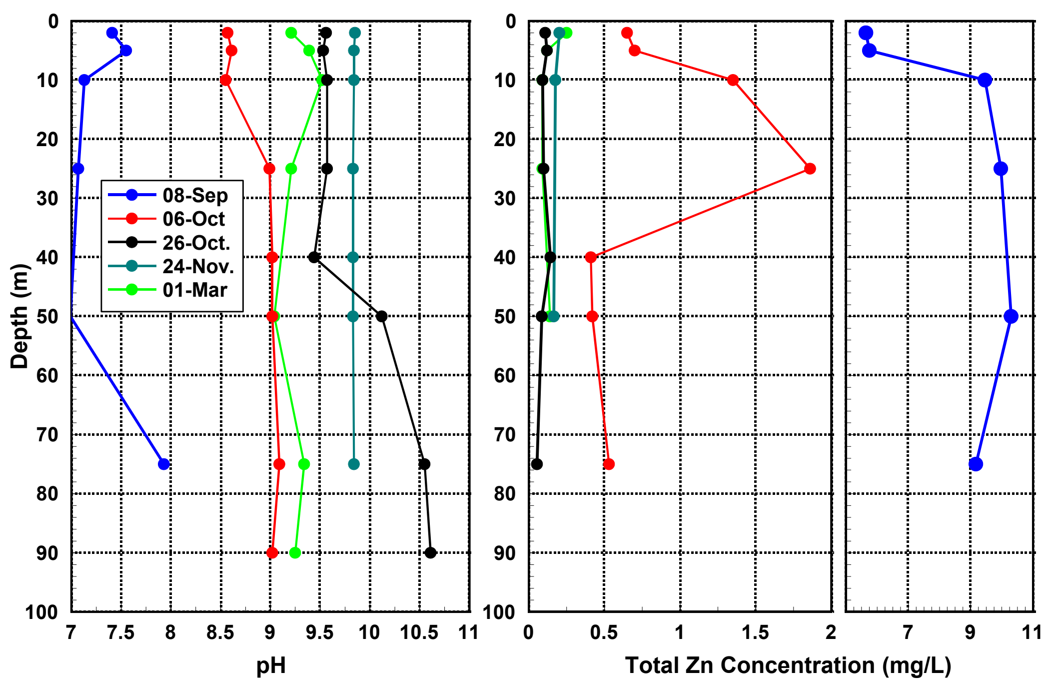

Figure 11: Profiles of pH and Total Zn in Pit Lake

Table 2: Average pH and Total Zn Concentrations in the Pit Lake

DATE	08/09/05	06/10/05	13/10/05	19/10/05	26/10/05	25/11/05	02/03/06
Treatment Days	0	22	29	35	42	+19	+ 4 months
Total Zn (mg/L)	9.41	0.93	0.37	0.12	0.09	0.17	0.13
pH	7.20	8.90	9.19	9.41	9.69	9.83	9.20

Pit Lake Maintenance

The current plan is to maintain a pH of 9.5 to 10 and a Zn concentration of less than 0.3 mg/L in the pit lake until it is filled and overflows by gravity. This will be attained by adding excess lime at the water treatment plant that discharges into the pit. A large ditch also directs contaminated site runoff into the pit. A lime addition system was designed and installed in spring of 2006 to increase the pH of this runoff as needed to ensure that dissolved zinc entering the pit lake will be minimized. At least until the pit is full, this system of treating the runoff with lime will remain in effect as needed to maintain discharge quality water in the surface layer of the pit lake.

CONCLUSION

The laboratory and limnocorral testing were very useful in designing an effective means of treating this large pit lake. The recirculating treatment system used lime very efficiently while allowing for rapid treatment of the dissolved Zn. Maintaining the low Zn concentrations is now a priority at the site to ensure that a clean effluent will be produced when the pit lake overflow discharges directly to the environment.

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