PIT LAKE TREATMENT AND MAINTENANCE AT LES MINES SELBAIE[1]

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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 open pit has since been allowed to fill with groundwater, site runoff, and treated slurry issuing from a lime treatment plant. The mixture of these three water sources had formed a pit lake containing approximately 22 Mm^3 of water in the summer of 2005. The open pit had also been a repository for tailings, potentially acid generating waste rock, and metal laden contaminated soils. Water balance modeling had 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 first summarises the successful treatment of dissolved Zn in 22 Mm^3 of water in 52 days. The follow-up monitoring results are then discussed along with the mitigation measures taken to maintain a low Zn concentration in the pit lake.

Introduction

Les Mines Selbaie terminated operations in 2004 and currently have an open pit which contained approximately 22 million cubic meters of water (22 Mm^3) in spring 2005. 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. The site is characterised by waste rock piles, a tailings pond, a plant site, and a treatment plant. The mill and other infrastructure from the plant site were removed in the three years following closure (2004 to 2006). Drainage from the waste rock is collected in raw water ponds 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, metal laden contaminated peat, and soils also contaminated by metals (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. In spring 2005, a relatively uniform concentration of 10 mg/L of Zn was measured at depth in the water column. 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 was to 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

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completed. It was also considered possible to maintain the low Zn concentrations in the pit lake once the initial treatment is completed.

The pit lake treatment was performed in the fall of 2005 and the level of the pit has continued to rise in the meantime. In 2005, it was estimated that the pit lake would be full by 2008 or 2009. In summer 2007, the pit lake volume was approximately 28.5 Mm^3. The most recent estimate for discharge was updated to either 2010 or 2011. Regular monitoring of the water quality has continued since the batch treatment and is presented here.

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 summarily 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

Pails of pit lake water sampled from a depth of 5 m were transported to a laboratory for testing. The tests were carried out using 1-L volumes from these pails. 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 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 24 hours after neutralisation using a syringe with the tip immersed just below the water surface. These samples were used to determine the efficiency of the treatment test by analysis of Zn and Cd in all cases, and often a full ICP-MS scan of metals. Both filtered and unfiltered samples were tested.

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. 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. The contained water volume in each limnocorral was about 31 m^3.

Treatment tests were completed in all but one of the six limnocorrals, the control. Three of the six limnocorrals were treated at surface by lime slurry addition with surface agitation. One of these three had a secondary treatment of Red Mud and another had an algae inoculation and regular nutrient addition. The two other limnocorrals were treated by recirculation. The first recirculation test had water collected at depth, limed and released at surface. The second recirculation test had water collected at surface, limed, and injected at depth. The recirculation tests were operated for 5 to 6 days.

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.

Experimental Results and Discussion

Laboratory Experiments

The treatment goal was to attain a total Zn concentration of less than 0.5 mg/L. Figure 1 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 a 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 at about 0.4 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 2, 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.

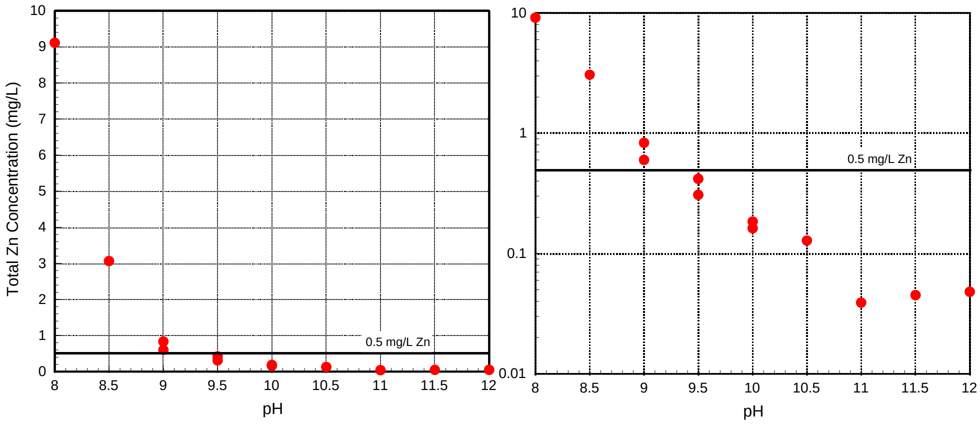

Figure 1: Zn Concentrations with Respect to pH for Lime Addition Tests

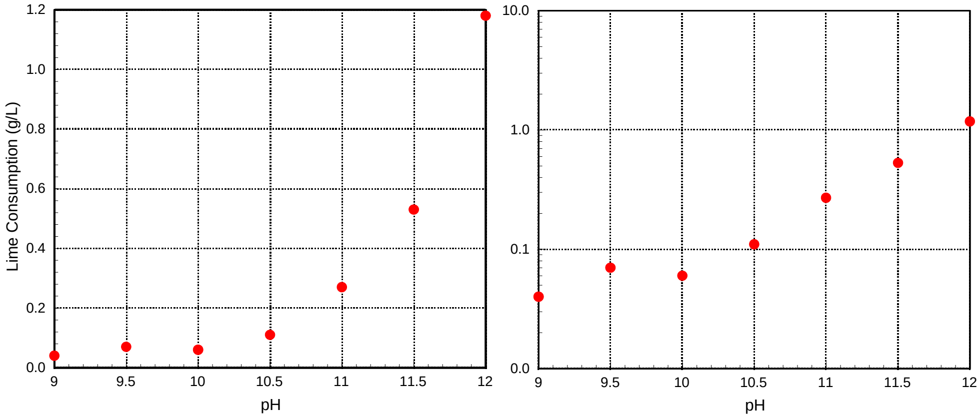

Figure 2: Lime Consumption with Respect to pH

Limnocorral Tests

Surface treatment in the limnocorrals proved that surface lime addition can successfully treat the epilimnion (warm upper layer of the lake). Surface treatment did not effectively penetrate the thermocline as only the top 4 m of water had an increased pH and decreased Zn concentration. This was shown in all three limnocorrals where surface lime addition was applied. In the limnocorral where Red Mud (a waste product from aluminium refineries) was added as a secondary treatment, a Zn concentration decrease of 41% was measured. This shows that the Red Mud could be used as a coagulant to decrease Zn concentrations. The secondary treatment with inoculation of algae and weekly fertilisation for nutrient control 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 partially control Zn concentrations in the long term.

The recirculation test completed by drawing water at depth, liming, and discharging at surface showed that this treatment method penetrates the thermocline. This was shown as the sample at the 5-m depth was well within the treatment target of 0.50 mg/L with 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. This was also the result of drawing water at the surface, liming and injecting at depth: thermocline penetration was evident, but mixing of the lower portion of the limnocorral with the lake water made it so the results could not be interpreted.

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 the recirculation tests showed that drawing water from one layer and injecting it in the other could serve to properly treat the entire water body including the thermocline. Additional details are given on the limnocorral testing in Huls et al., 2006.

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% of the flow 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 3 and Figure 4). 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 3 and 4 for the cross-sectional and plan views respectively. Figure 5 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.

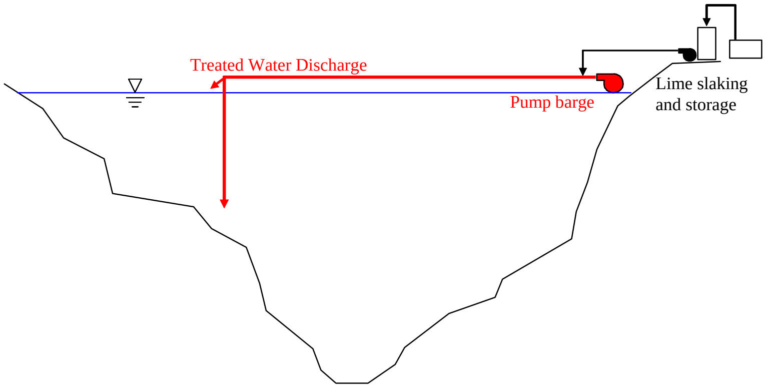

Figure 3: Conceptual Representation of the Treatment System (cross-section)

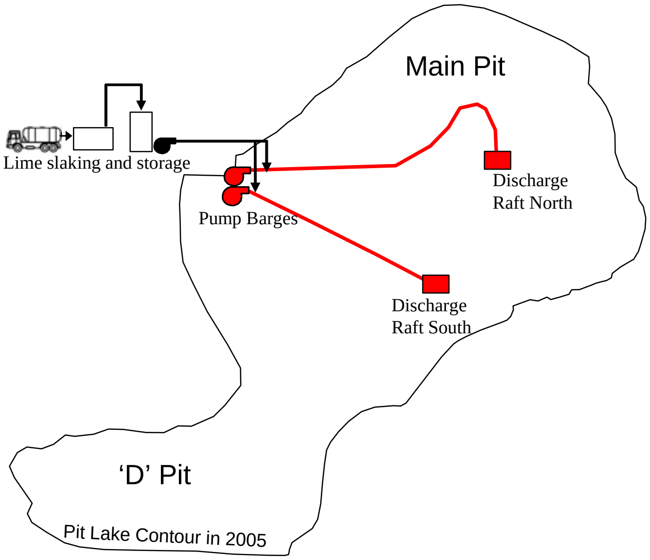

Figure 4: Conceptual Representation of the Treatment System (plan view)

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 distribution of the limed water 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. The lime system (including portable slaker, lime storage tank, and pumps) was installed near the pit ramp on a solid bed of crushed rock.

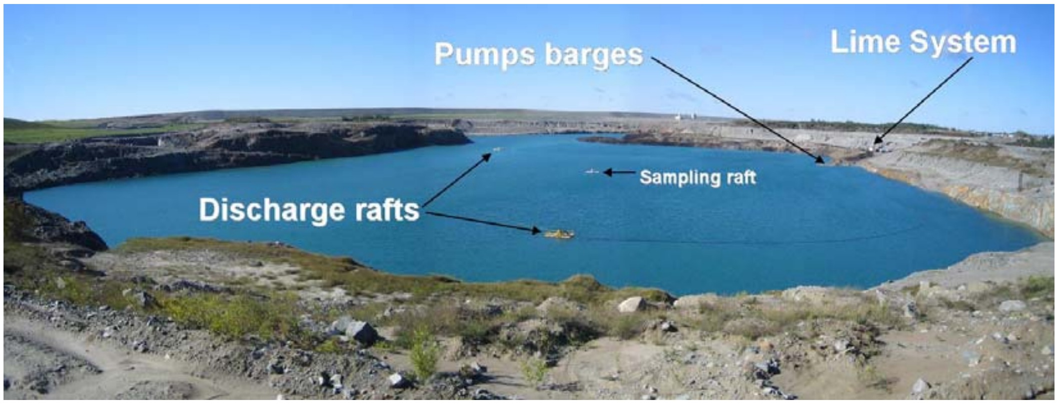

Figure 5: Photo of Treatment System soon after Commissioning

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 2) this pH range represented a hydrated lime injection rate between about 0.5 and 1.2 g/L of water pumped. The lime system was operated 24 hours per day over 52 days (until November 25th). Operations were very efficient with less than 5% downtime. The system consumed essentially one 40-tonne truckload of quicklime per day.

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 4). 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 6 shows some of the pH and Zn profiles measured in the pit lake during treatment. As shown in Table 1, 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 and runoff into the pit 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.

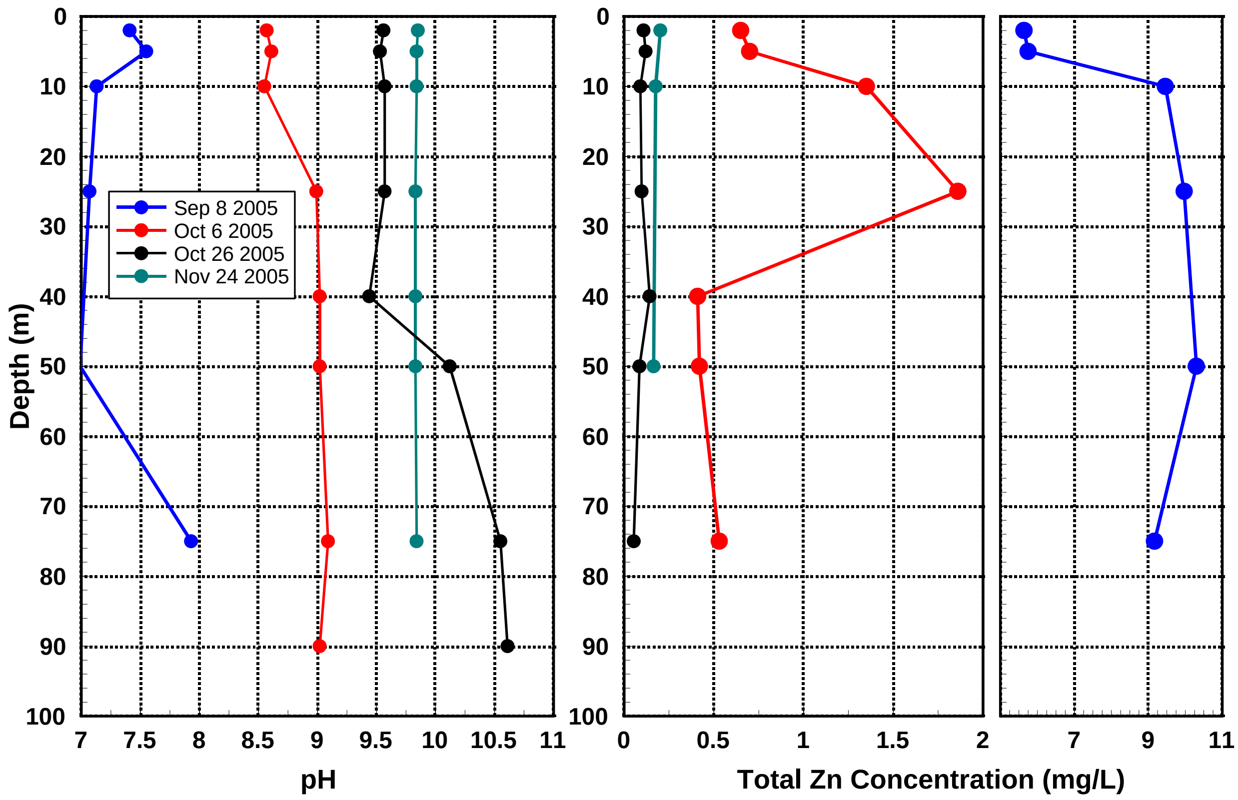

Figure 6: Profiles of pH and Total Zn in Pit Lake during Treatment

The right side of Figure 6 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.

Table 1 shows the average pH and Zn concentrations measured in the pit lake during treatment. 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, +19 days). 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. Overall, the treatment results have exceeded expectations as the final Zn concentrations were below 0.2 mg/L.

Table 1: Average pH and Total Zn Concentrations in the Pit Lake during Treatment

DATE	08/09/05	06/10/05	13/10/05	19/10/05	26/10/05	25/11/05
Treatment Days	0	22	29	35	42	52 +19
Total Zn (mg/L)	9.41	0.93	0.37	0.12	0.09	0.17
pH	7.20	8.90	9.19	9.41	9.69	9.83

Pit Lake Maintenance

As previously mentioned, the main inputs to the pit lake are the treated slurry from the WTP and site runoff which flows by gravity. Two other inputs of lesser magnitude include the groundwater flow and direct precipitation. Since the pit lake batch treatment, the pH setpoint at the WTP has been increased from 9.5 to 10.5 in order to provide additional alkalinity to the water body and maintain an alkaline pH. More importantly, the majority of the site runoff has been captured and combined by ditches and is being limed prior to flowing into the pit lake. This runoff is a relatively clean source of water, with Zn concentrations of less than 5 mg/L and decreasing yearly. Lime is added to this stream to bring the pH up above 11, thereby providing significant alkalinity to the pit lake. The objective is to maintain a Zn concentration of less than 0.3 mg/L and ensure that when the open pit level reaches the overflow, that the surface water will meet all discharge criteria. Note that the WTP is shut down in winter and occasionally in the summer for maintenance.

Regular monitoring of the pit lake chemistry has been continued since treatment in the fall of 2005. Eight complete physico-chemical profiles have been taken in 2006 and 2007. These have also included sampling for analysis of Zn and Cd in all cases and complete metal scans twice. This paper will focus specifically on the pH and Zn concentration results. The following three figures show the most pertinent results: Figure 6 shows some selected pH and Zn concentration profiles, Figure 7 shows the trend of average pH since treatment, and Figure 8 shows the average Zn concentrations trend since treatment.

The profiles in Figure 6 show how the pH and Zn concentrations fluctuate. These show that there is some variability with depth, but that the changes between profiling campaigns are more important than the changes with depth in a single sampling campaign. For example, when the pH is higher at surface, it is also higher at depth. This suggests that the pit lake is reasonably well-mixed. It has been shown, through modelling and sampling, that the pit lake turns over in the fall (Lorax, 2005). The same study has also shown that the addition of treated slurry to the pit lake causes underwater currents that provide mixing of the entire hypolimnion (deep, cold layer of the water body).

Figure 8 shows that the average pH decreased continuously for the first year following treatment. This is due principally to CO_2 dissolution into the water body. There is also a possibility of contaminated groundwater infiltration and some uncaptured runoff that could help decrease the pit lake pH. There is a clear indication that the pH decreased faster when the lime plant was down for maintenance or shut down for the winter. For example, between July 31 and October 2006, the plant was down for four weeks for modifications. There is a significant pH drop during this interval. As it was then operated until winter, we see that the pH was maintained until the December profiling. The 2006-2007 winter shutdown shows a significant pH decrease to below 8.0. Fortunately, the excess lime addition from the spring of 2007 brought this pH up to 8.45.

Figure 9 shows that as long as the pH was maintained near or above 9.0, the Zn concentrations remained low. During the plant shutdown of summer 2006, the Zn concentrations increased. In the fall of 2006, the addition of excess alkalinity helped decrease the Zn concentrations. The March sampling of 2007 showed a total Zn concentration exceeding the target 0.3 mg/L. The excess lime addition during spring runoff was sufficient to reverse this trend and bring the average Zn concentration down to 0.11 mg/L. The dissolved Zn concentrations essentially follow the total Zn trends and represent 50 to 90% of the total loadings.

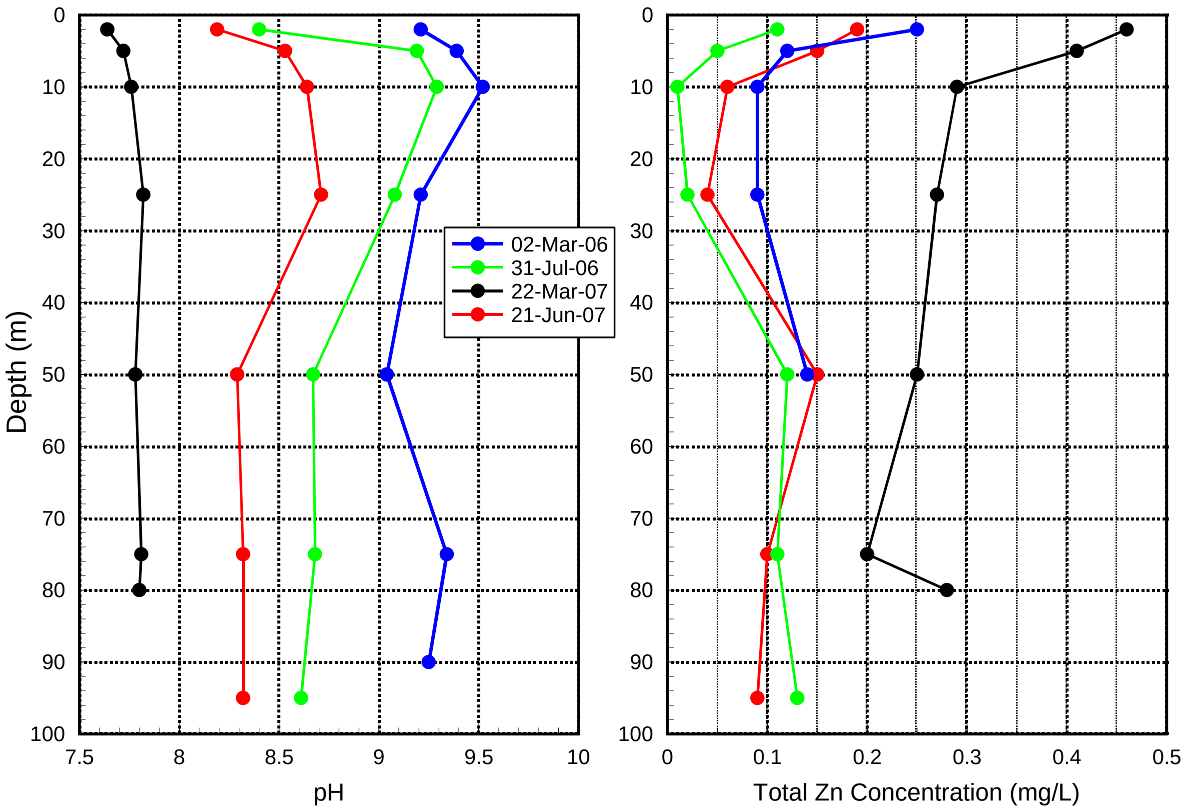

Figure 7: Selected pH and Zn Profiles since Treatment

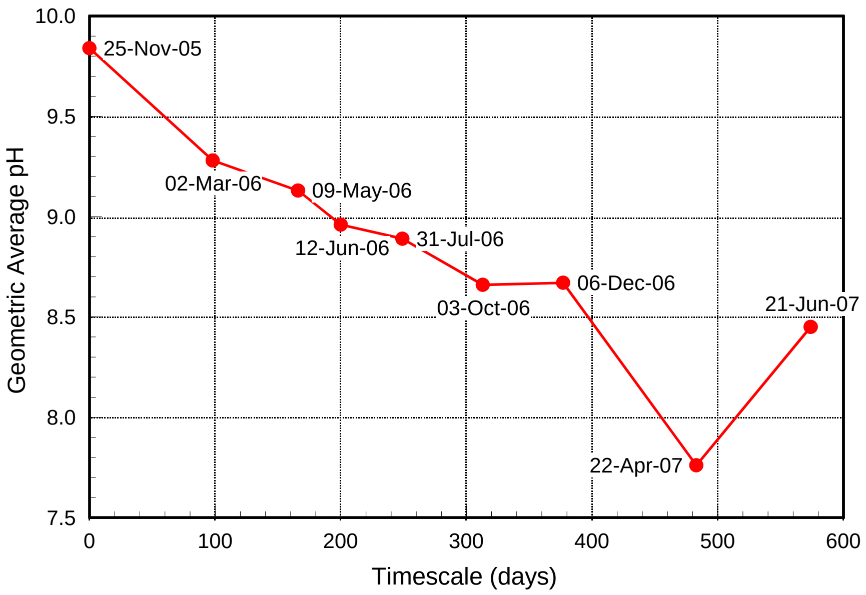

Figure 8: Trend of Average pH in Selbaie Pit Lake since Batch Treatment

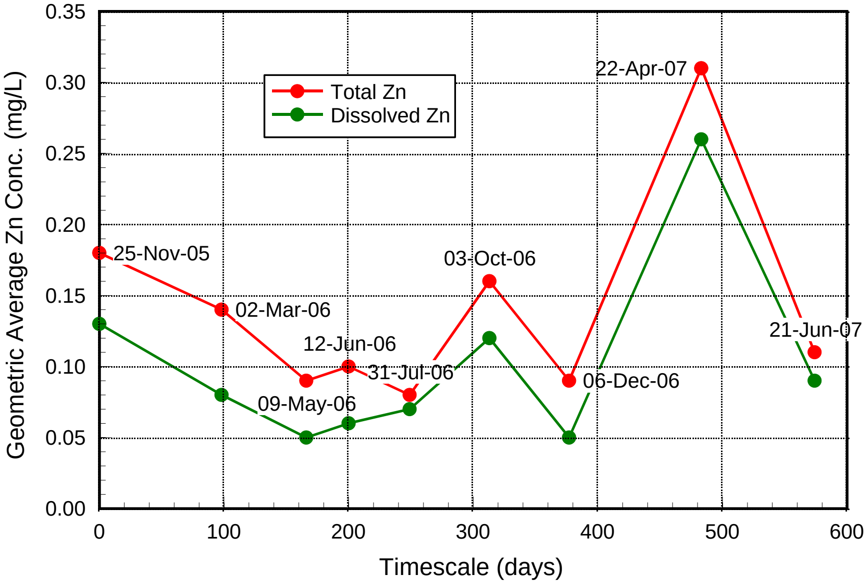

Figure 9: Trend of Average Zn Concentrations in Selbaie Pit Lake since Batch Treatment

Results show that the runoff treatment is of particular importance in the spring as it is a large volume of water being treated during freshet. Liming the runoff provides an opportunity to add significant alkalinity to the pit lake on a yearly basis without the need for pumping water or any other additional infrastructure. The recent results suggest that the current strategy will be sufficient to ensure that the effluent will meet all discharge criteria when the pit lake is full. That being said, there are also contingency plans in place to use the existing lime plant to pump water from the pit lake, add lime, and recirculate if ever the Zn concentrations increase beyond expectations.

It should be noted that the pit lake water meets all other discharge criteria including toxicity, which was measured in summer 2007.

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 efficiently while allowing for rapid treatment of the dissolved Zn. The current strategy for maintaining the zinc concentrations low and the pit lake water compliant with discharge criteria appears to be working very well.

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