

DESIGN OF *IN-SITU* WATER TREATMENT OF ACID CONTAMINATED LAKE

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ABSTRACT

An in-situ treatment system was designed for Nero Lake, an acid contaminated lake in northern Saskatchewan. The purpose of the treatment system was to neutralize the lake water, which would be accomplished by adding lime to the entire lake. The process design was based on a pilot trial and a water and load balance model study. The pilot trial showed that lime could be delivered to the lake as a dilute lime solution to 10% to 20% of the lake water without significant loss of lime utilization and allowing the natural seasonal turnover of the lake to mix the lime throughout the lake. In-line injection of lime resulted in similar performance as mixing lime slurry and lake water in a mix tank.

A water and load balance model was developed to determine whether addition of excess alkalinity (lime) was warranted as a way of mitigating acidity that may report to the lake in the future. The model was developed as a simple spreadsheet based model. The modelling results showed that since 1978, the annual load of alkalinity to Nero Lake has been greater than the annual load of acidity. This means that the lake will not become acidic following neutralization. The model also showed that any reduction in the current acidity loadings reporting to the lake is unlikely to significantly affect the long-term water quality of Nero Lake.

KEY WORDS

In-situ treatment, lime treatment, lake mixing, load balance, water balance

INTRODUCTION

The Lorado site is an abandoned uranium milling operation located on the western shore of Nero Lake south of Uranium City in northern Saskatchewan. The mill was constructed in 1957 and operated until 1960. Tailings and acidic waste produced by the milling operation were deposited near the western shore of Nero Lake and some tailings were submerged in the Lake (Figure 1). Deposition of milling waste into the lake acidified the water and elevated concentrations of dissolved metals. The mine and mill sites were vacated in 1960 with little or no decommissioning. It wasn't until the 2000s that the provincial and federal governments took stock of the safety and environmental liabilities at the site and made a commitment to deal with the potential human health and environmental risks (Golder 2013).

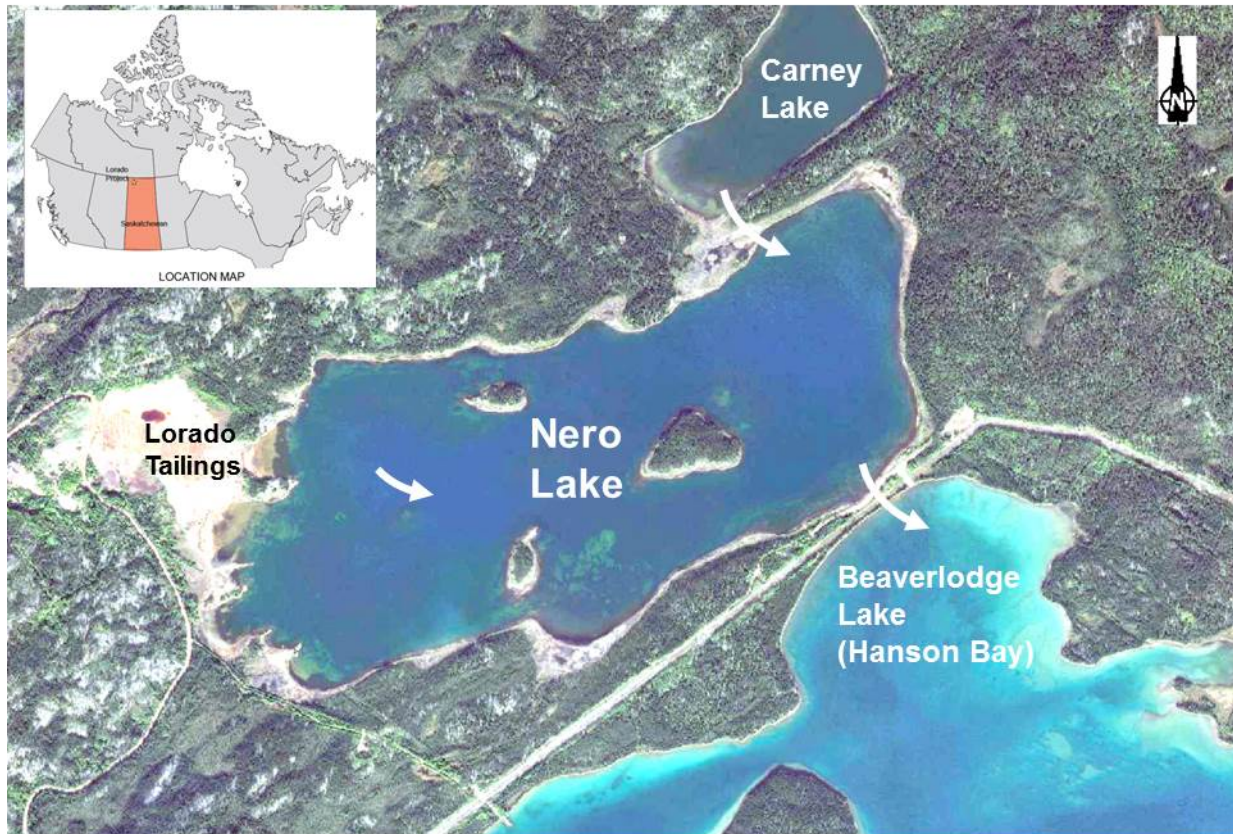


Figure 1 Nero Lake flows to Beaverlodge Lake (Hanson Bay). Carney Lake is located upstream of Nero Lake.

Although not abandoned, the Lorado site was neglected as ownership changed hands, ending up as property of Conwest Exploration Company Ltd. This company oversaw the demolition of the mill buildings in 1990. When the parent company of Encana Corporation bought Conwest, the Lorado site was transferred as well. In 2007, the responsibility for the Lorado site was transferred to the Saskatchewan Ministry of Economy along with funds for site remediation.

The ministry retained the Saskatchewan Research Council (SRC) to manage the development of a Risk Reduction Plan and an Environmental Impact Statement (EIS) for the Lorado Site. The EIS for the Lorado Site were completed in 2013 (Golder 2013). The overall risk management goal identified for the Lorado site was that “risk reduction at the site has achieved an acceptable level of residual risk to human health, and to terrestrial ecological populations, and to the aquatic population of Hanson Bay and Beaverlodge Lake”. The main reclamation activities proposed under the risk reduction plan included:

- Covering of surface tailings in-place, and
- In-situ batch treatment (lime neutralization) of Nero Lake (Golder 2011a).

In 2013, SRC retained SRK Consulting to complete the detailed design of a capillary break cover for the surface tailings and process design for an in-situ batch treatment system for Nero Lake. This paper describes how the results of the batch treatment pilot trial were used along with a water and load balance to develop a design basis and ultimately the process design for water treatment of Nero Lake.

TREATMENT OBJECTIVE AND DESIGN BASIS

Nero Lake has a volume of approximately 11 million m³. The lake is relatively shallow with an average depth of 6.4 m. The total catchment area, including the Carney Lake sub-catchment located north-east of Nero Lake, is approximately 5 km². The deposition of tailings and acidic waste to Nero Lake during the operation of the Lorado milling operation left the lake with acidic water with relatively high concentrations of dissolved metals and sulfate. In 2013, the pH of the lake water was approximately 4.2 and the average acidity concentration was 18 mg/L as CaCO₃. Dissolved metals of concern included aluminum and uranium.

The risk reduction measure identified in the EIS was to neutralize the water in Nero Lake using lime (calcium oxide). Accordingly, the treatment objectives for Nero Lake were to neutralize the lake water and minimize or eliminate requirements for long-term water treatment. Long-term treatment would be required if future acidity loadings from the tailings area were sufficiently greater than alkalinity loads to lake from runoff.

The design basis for the in-situ treatment process was based on a water treatment pilot trial completed in July of 2013 and the results of a water and load balance model. The purpose of the pilot trial was to determine the lime dose required to neutralize the lake and to provide a basis for sizing equipment and defining other process parameters. The purpose of the modelling study was to determine if (and if so, when) future acidity loadings from the tailings area would once again acidify the lake and therefore necessitate another treatment campaign and to determine the natural state of the Nero Lake and downstream environment.

PILOT TRIAL METHODOLOGY

A schematic of the initial treatment concept for Nero Lake is shown in Figure . Quick lime is fed to a lime slaker that hydrates the lime and produces lime slurry. The lime slurry is transferred to a storage tank. Untreated lake water is pumped to the shore where it is mixed with lime slurry in a mix tank. Neutralized water is then returned to the lake.

The purpose of the pilot trial was to inform the full scale design by:

- Determining the lime dose required to neutralize the lake water;
- Assessing the effect of neutralization of Nero Lake water quality;
- Evaluating the long-term stability of the precipitated solids, and
- Evaluating the effect of mixing on lime utilization.

The pilot trial used limnocorrals submerged alongside a temporary dock as a pilot-scale analog for Nero Lake (Figure 2). Limnocorrals are large cylindrical plastic bags made of impermeable high density polyethylene (HDPE) liner (Figure 3). Floats are attached to the top of the liner to provide buoyancy and structural support and chains are attached along the bottom to anchor the corral. The limnocorrals used for the Nero Lake pilot trial had closed bottoms to permit the collection of precipitates formed in the

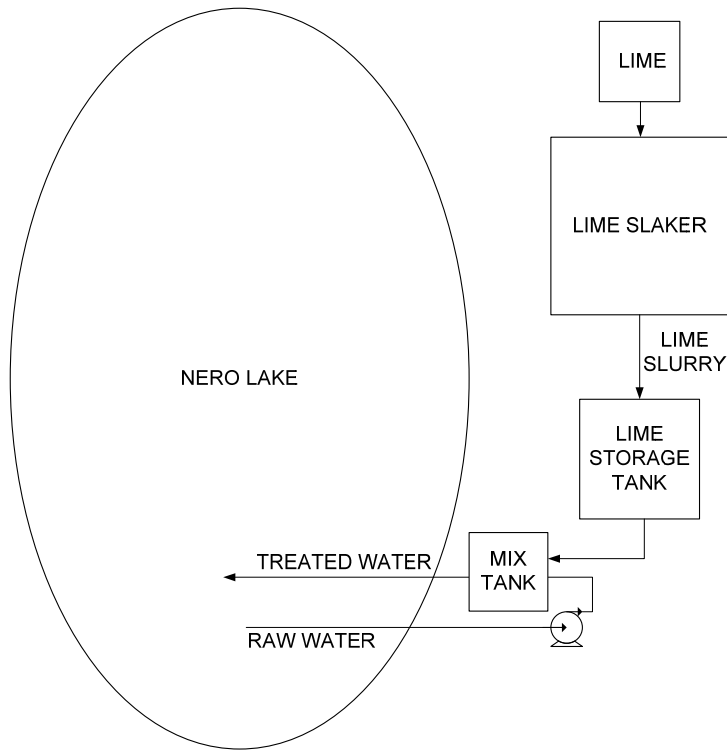


Figure 2 Schematic of Nero Lake Treatment Concept



Figure 3 Limnocorrals Used for the Nero Lake Water Treatment Pilot Trial

treatment process. The use of limnocorrals for piloting in-situ water treatment ensured that temperature, depth and operating conditions are reasonably representative of full-scale conditions. Figure 4 shows a schematic of the pilot trial configuration. For each of the trial runs conducted, the limnocorrals were initially filled with untreated lake water. The untreated water was then pumped to a mix tank on shore

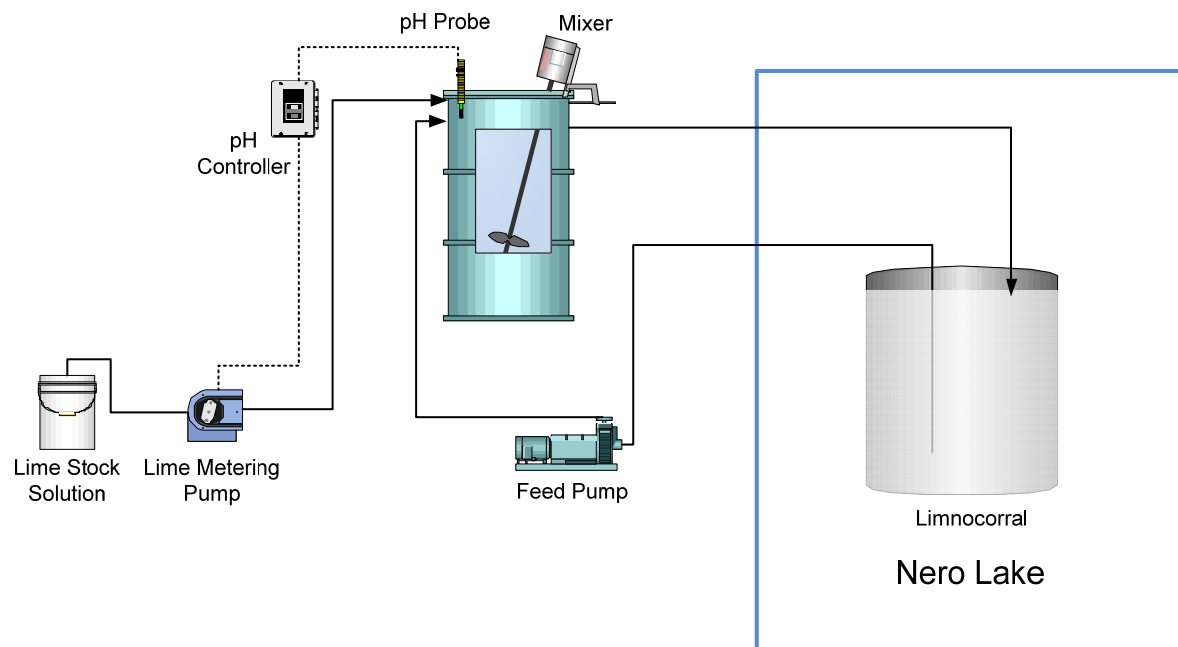


Figure 4 Pilot Trial Schematic

where lime was added to neutralize the water. The neutralized water then flowed back to the limnocorrals where it would mix with untreated water. The nominal capacity of the pilot plant was 60 L/min (16 gpm), which corresponded to a hydraulic retention time of 8 hours for one limnocorral.

WATER AND LOAD BALANCE MODELLING APPROACH

The purpose of the water and load balance model was to determine if acidity loadings from the tailings area were likely to acidify the lake after the treatment campaign. The model relied on information from past studies (Golder 2011b). Inputs included historical water quality data, catchment delineations and hydrology and meteorology baseline data. The modelling approach focused on quantifying annual acidity and alkalinity loadings flowing to Nero Lake. If loadings of acidity consistently are greater than loading of alkalinity, the lake will become acidic over time even if the water is treated/neutralized. Conversely, if the annual alkalinity load to the lake exceeds the annual acidity load the lake will not become acidic after neutralization.

A mass loading model was developed to assess alkalinity and acidity loads to the lake. Figure 5 shows a schematic of the conceptual load balance model. Inflows of alkalinity to the lake include local surface runoff, runoff from Carney Lake and groundwater reporting to the lake.

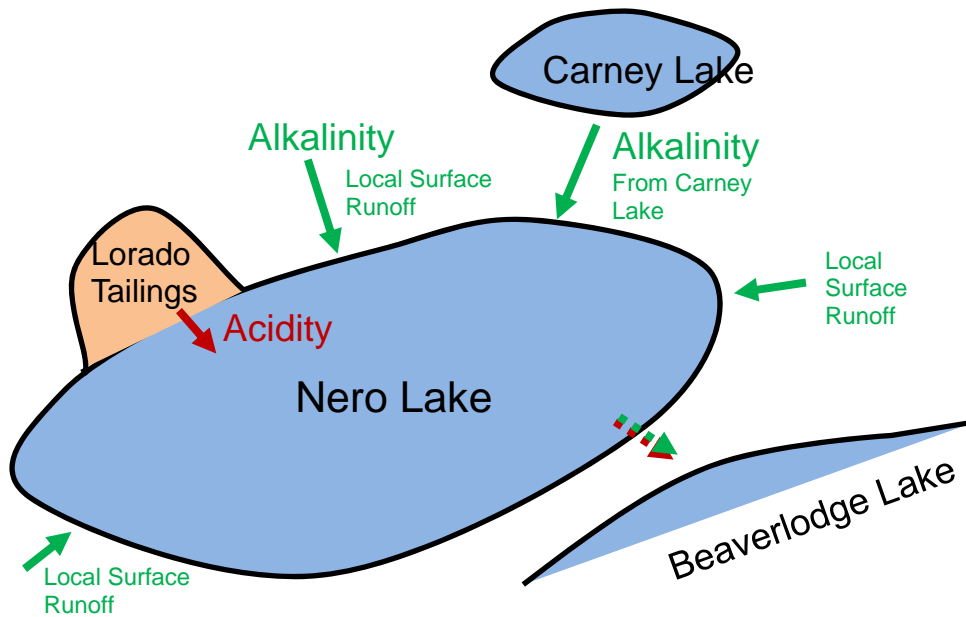


Figure 5 Schematic of the Conceptual Acidity and Alkalinity Load Model for Nero Lake

For simplicity, the surface runoff and groundwater inflow was combined into a single inflow term. Acidity loadings were attributed to flow from the Lorado tailings. Acidity loadings were treated as a single bulk term. No attempt was made to partition loadings into surface loadings from efflorescent salts on the tailings surface and acidity transported with groundwater moving through the tailings beach. Although this distinction is important when planning and designing a cover, it is not important for evaluating the effects of the total loadings on the quality of water in Nero Lake.

Water in Nero Lake flows south through a shallow land bridge to Hanson Bay in Beaverlodge Lake. Historically, the acidic water from Nero Lake has affected the water and sediment quality in Hanson Bay. As the acidic water was neutralized by alkalinity in Beaverlodge Lake, many of the metals dissolved in the Nero Lake water precipitated and settled in Hanson Bay. The elimination of acidity and metal loading to Hanson Bay was one of the risk reduction measures identified in the 2013 EIS.

RESULTS

Pilot Trial Results

Figure 6 shows the results of bench-scale titrations of Nero Lake water using lime. The results demonstrate that approximately 10 mg/L of lime (as CaO) is required to reach a pH of 7 and that about 40 mg/L is required to reach a pH of 10. The bench-scale titration results were used to define the lime dose used for the limnocorral tests.

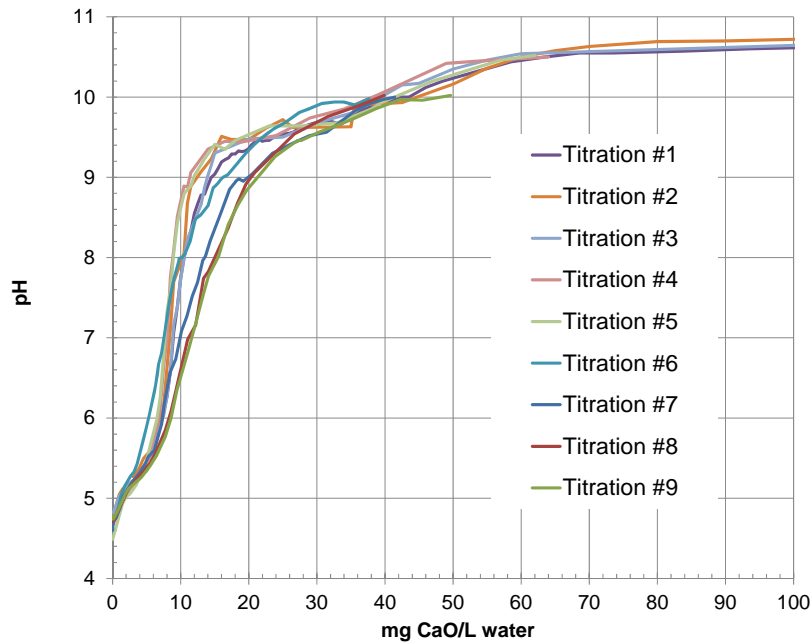


Figure 6 Titration of Nero Lake Water with Lime

Table 1 shows a summary of Nero Lake water quality (untreated) and corresponding Canadian Environmental Quality Guidelines for the Protection of Aquatic Life (CWQG). The comparison of water quality parameter concentrations to the CWQG are included here only as a reference. Treatment/neutralization of water in Nero Lake was intended to improve the lake water quality but was not specifically targeting the CWQG values. In 2013, the water in Nero Lake did not meet the CWQG for pH, aluminum, uranium, zinc and mercury. No other exceedances were noted.

Table 1 Raw Nero Lake Water Quality, July 2013

Parameter	Units	Untreated Water	CWQG
pH		4.3	6.5 - 9.0
Aluminum	mg/L	2.1	0.10
Uranium	µg/L	20	15
Zinc	mg/L	0.043	0.030
Mercury	µg/L	0.074	0.026

Besides pH, the effect of lime addition on the lake water quality was evaluated by measuring concentrations of the metals listed in Table 1. As lime is added to the lake water and pH increases, the metals listed in Table 1 precipitate as, or co-precipitate with, metal hydroxide. Figure 7 shows the effect of lime dose on concentrations of dissolved aluminum and uranium (log scale) in the limnocorrals 24 hours after the end of treatment. The results show that concentrations of dissolved uranium were reduced

significantly at lime doses greater than approximately 20 mg/L. Dissolved aluminum decreased by approximately a factor of 10 at a lime dose of 50 mg/L and was below the CWQG when the lime dose was greater than approximately 75 mg/L.

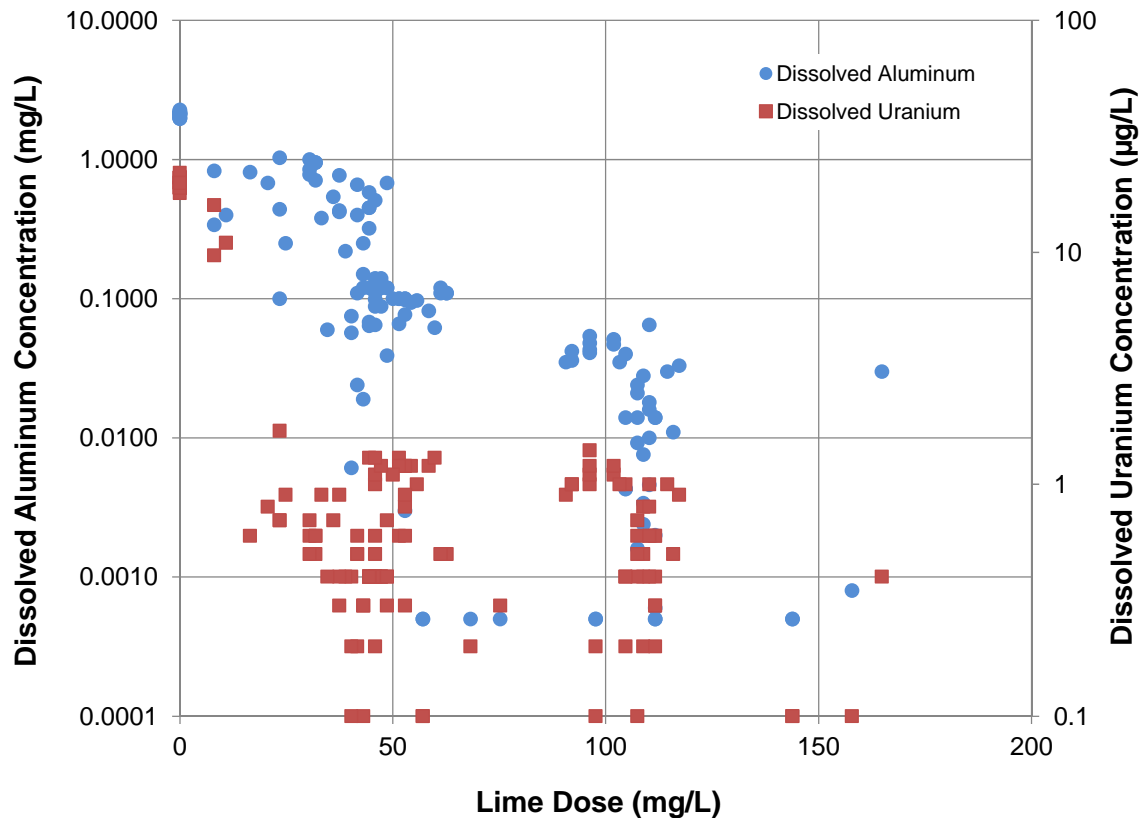


Figure 7 Concentrations of Dissolved Aluminum in Limnocorrals vs. Lime Dose

One objective of the pilot trial was to determine the requirement for mechanical mixing of lime in the lake. If dry lime or concentrated lime slurry were added directly to the lake a significant portion of the lime would likely settle unreacted to the bottom of the lake and would not be immediately available for neutralization. On the other hand, pumping and neutralizing the entire volume of the lake would require large pumps and treatment equipment with correspondingly high energy demand and cost. Therefore, the approach was to add the required quantity of lime to a fraction of the lake water volume, which would then mix with and neutralize the untreated volume.

The question of lime mixing was addressed in the pilot trial by adding the amount of lime required to treat the entire limnocorral to only a portion of the water, and then relying on passive mixing to uniformly mix the lime to the untreated water. Figure 8 shows a summary of the pilot trial results in which 5% to 25% of the limnocorral volume was treated. The results are expressed as dissolved aluminum and uranium concentrations in limnocorral water (post-treatment) vs. lime dose. In untreated lake water, the dissolved aluminum concentration was 2.1 mg/L and the dissolved uranium concentration was 20 µg/L. The results showed that treatment of 10% and 25% of the limnocorral volume resulted in similar performance as

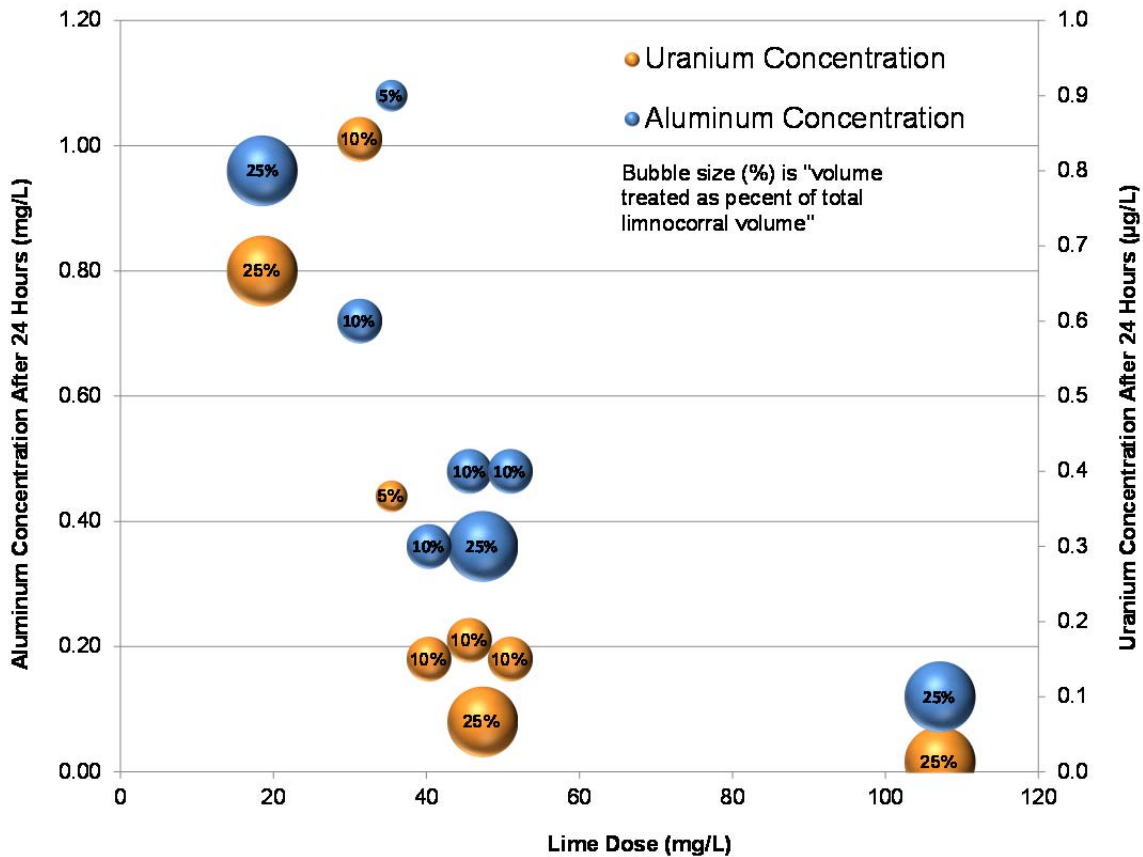


Figure 8 Aluminum and Uranium Concentrations in Limnocorrals vs. Lime Dose and Lake Fraction Treated

treating the entire limnocorral volume, and by inference the lime utilization¹ was similar. However, when the lime dose was added to only 5% of the limnocorral volume, the lime utilization appeared to be reduced. This was corroborated by the presence of settled lime in the bottom of the limnocorral after the trial run. Because of the large difference in scale, it was not possible to evaluate or predict the intensity of full-scale mixing in Nero Lake based on the pilot trial results. The mixing trials were intended to be a one-dimensional (i.e., depth) evaluation of the tendency of lime to settle unreacted to the bottom of the lake. However, depth profiles of temperature, conductivity, pH and Oxidation-Reduction Potential collected at several stations throughout the lake indicated that Nero Lake was well mixed, both laterally and vertically in the summer.

The effect of reactor (mix tank) residence time was also evaluated in the pilot trial. The results of the tests showed that lime utilization was similar when lake water was mixed with lime slurry in a reactor with 20 minutes residence time and when lime slurry simply was injected directly inline (data not shown).

¹ Here, lime utilization refers to the ratio of lime that dissolved into the lake water over the total quantity of lime added.

Water and Load Balance Results

Results of the water balance component for Nero Lake showed that the outflow from Nero Lake in a year with average annual precipitation and evaporation is approximately 360,000 m³. With a volume of 11,000,000 m³ the average hydrological residence time of the lake is approximately 30 years.

In the load balance model, inflows to Nero Lake (local runoff/groundwater and flow from Carney Lake) were assigned alkalinity concentrations that were typical of measured baseline concentrations. Historical estimates of acidity loadings from the tailings area were highly uncertain. Fortunately, historical lake water quality data dating back to 1978 were available. Because of this, the input of acidity to the lake could be established by varying acidity loading rates and comparing the model water quality predictions to the water quality measured over time.

Figure 9 shows the results of the acidity loadings sensitivity analysis that were completed for Nero Lake along with historical concentrations of acidity. Four different scenarios are shown here:

1. Acidity Input = Alkalinity Input. This scenario is the threshold situation where the lake would be neutral but would have no or little excess of alkalinity or acidity. If acidity loadings flowing to the lake are greater than alkalinity loadings, then the lake would become acidic over time.
2. Acidity input is half of the alkalinity input. In this scenario the lake would become neutral over time and remain neutral in the future.
3. Annual loadings of acidity to Nero Lake of 3.5 tonnes/year (best fit based on sensitivity analysis).
4. Decaying rates of acidity input to Nero Lake. This scenario assumed that annual loadings of acidity in 1978 were approximately 30 tonnes (as CaCO₃) but then gradually decreasing over time.

Comparing the measured acidity concentration to the modelling results shows that the annual loadings of acidity to Nero Lake likely are less than half of the alkalinity loadings reporting to the lake. Therefore, the observed reduction in acidity since 1978 is only possible if the lake receives a net surplus of alkalinity. Furthermore, the model results suggest that the effect on acidity concentration in Nero Lake is similar whether the acidity loadings have been constant or whether loading rates were relatively high in 1978 and decayed over time. The significance of this result is that the lake is unlikely to become acidic once the water has been neutralized.

Figure 10 shows the predicted effect of neutralizing the water in Nero Lake with varying lime doses. The results show that the addition of 150 tonnes of lime is sufficient to neutralize the lake, while addition of 800 tonnes of lime would bring the alkalinity concentration near to the expected long-term steady state concentration of about 75 mg/L of alkalinity (as CaCO₃).

Figure 11 shows the predicted effect of reducing acidity loadings by 0% to 95% by placing a tailings cover on the tailings beach or by other mitigation measures. The results show that a reduction in the current loadings of acidity from the tailings are likely insignificant in terms of effects to the water quality in Nero Lake.

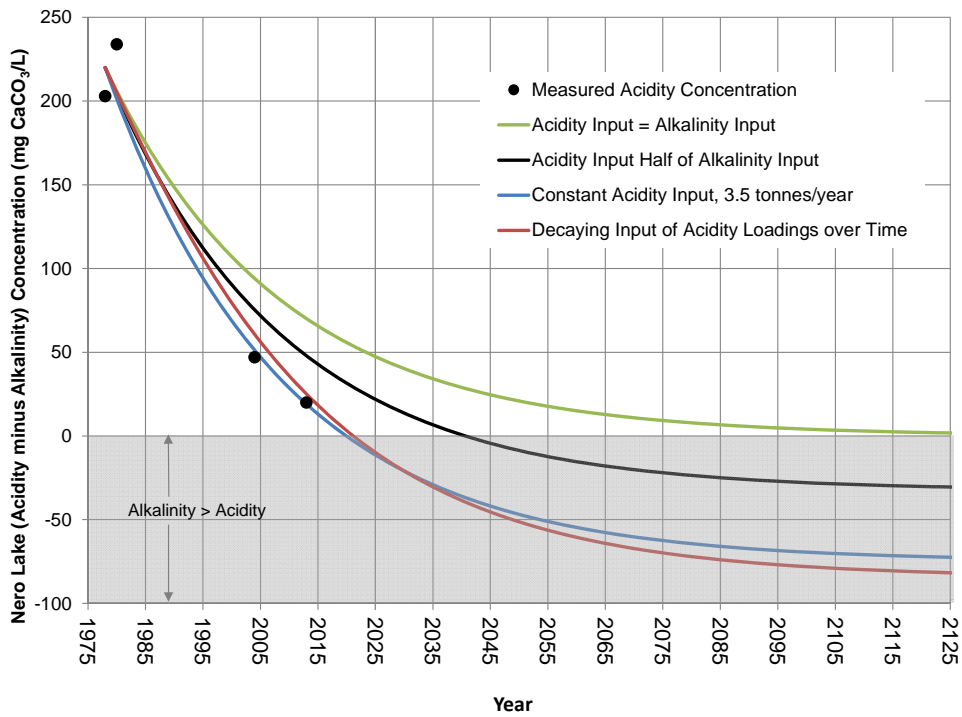


Figure 9 Sensitivity Analysis for the Acidity and Alkalinity Load Balance for Nero Lake

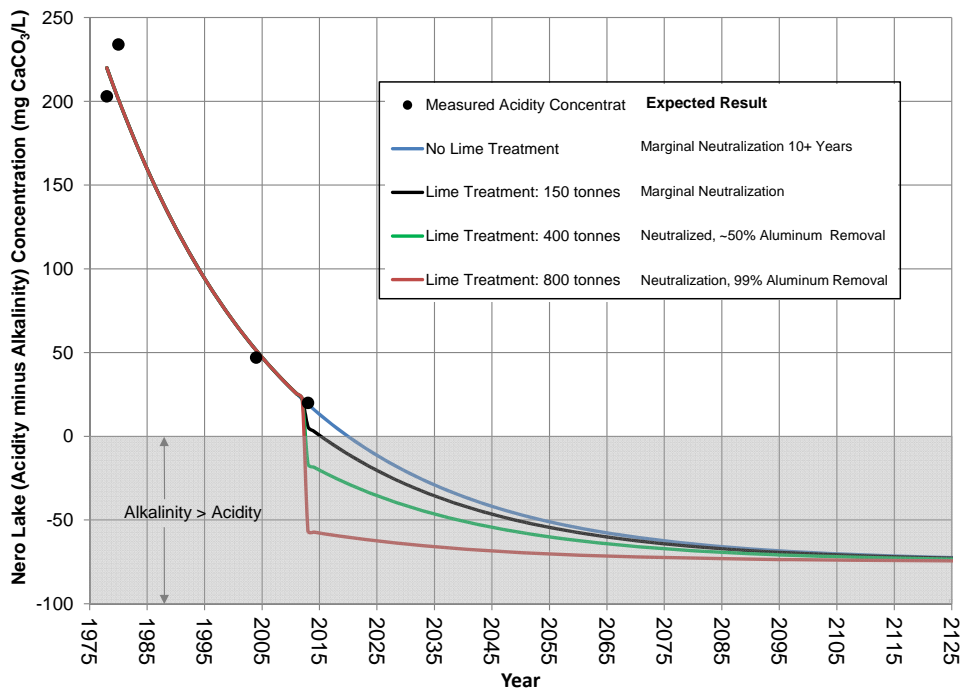


Figure 10 Predicted Effect of Lime Treatment on the Acidity and Alkalinity Load Balance for Nero Lake

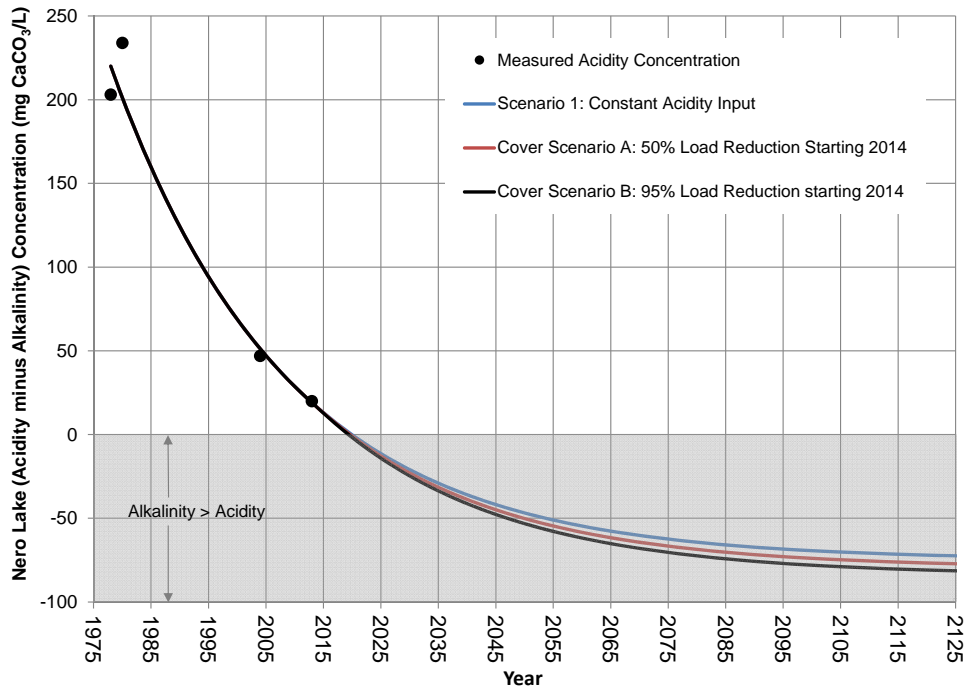


Figure 11 Predicted Effect of Tailings Cover on Nero Lake Water Quality

CONCLUSIONS

A pilot trial and a modelling study were used to develop the design basis for an in-situ treatment system for Nero Lake. Results from the pilot trial showed that:

- A lime dose of 20 mg/L to 75 mg/L would be required to treat the lake water depending on the desired treatment endpoint. A lime dose of 37 mg/L was recommended for the final design.
- The required lime dose can be delivered to the lake by circulating and dosing 10% to 20% of the lake volume without significant reduction in lime utilization. The final design recommendation was for 20% of the lake water to be circulated and dosed.
- A reactor for mixing lake water and lime slurry would not be required: in-line injection of lime slurry resulted in similar lime utilization as mixing slurry and lake water in a reactor tank.

The acidity and alkalinity load balance showed that:

- Since 1978, the annual load of alkalinity to Nero Lake has been greater than the annual load of acidity. This means that the lake will not become acidic following neutralization, assuming that no new and unanticipated sources of acidity appear.

- Any reduction in the current acidity loadings reporting to the lake is unlikely to significantly affect the long-term water quality of Nero Lake.

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