Combining Predictive Modeling and a Full-Scale Analog to Reduce Uncertainty

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Abstract

A proposed project in the Northern Territory, Australia currently has a partially developed open pit that has filled with water and must be partially dewatered before the future operations can begin. The water quality of the pit lake is poor and predictive modeling of the future ultimate pit shell suggest that during operations and in post closure, the pit walls will be a source of acid rock drainage and metal leaching (ARD/ML), resulting in the need to treat water collected within the pit. To allow discharge of the water being removed from the existing pit lake, in pit treatment using micronized lime was considered with the goal of raising the lake water pH to greater than 7.0 and precipitating key metals from solution.

In-pit micronized lime addition began at this site in 2012, to allow dewatering of the pit and to move the project toward operations. The in-pit micronized lime treatment has been successful in producing circum-neutral water with decreased metals concentrations, which has allowed for dewatering to commence and for safe discharge to local rivers without adverse impacts. Even with pumping over the last five years, the pit lake level remains high enough that much of the potentially acid generating (PAG) rock units of the pit wall are submerged and are under oxygen limited conditions. Water quality data and lake profiling were completed prior to the treatment and have continued since implementation of an in-situ treatment approach. The combined predictive modeling and the information gained during the in-pit treatment and monitoring has allowed for a higher degree of confidence that closure options can be implemented successfully.

Keywords: pit lake, case-study, in pit treatment

Introduction

Predictive modeling is often the best tool at our disposal to assess impacts from mining facilities and to develop closure plans. However, these models can be challenging to calibrate since the facilities are not constructed and the data is from tests on small sample sizes that must be scaled up. Having a test cell or local analog can provide a means to validate the modeling, but these too are often not available. A proposed project in the Northern Territory, Australia currently has a partially developed open pit that has filled with water, and which has been monitored and treated with lime for more than five years. This has allowed discharge of the water, but also has resulted in the development of a much-needed dataset that can be used as a means to validate a commonly proposed treatment method for post closure pit lakes.

Current Conditions and In-Situ Treatment

The mine site is located 56 km by road northwest of Katherine, and approximately 290 km southeast of Darwin in NT, Australia. The Project contains a number of known occurrences of gold, which have been explored and/or exploited to various degrees. The largest and best-known are the Batman and Quigleys deposits, both of which have had historic mining by prior operators. The Batman deposit has produced and been explored more extensively than the Quigley deposit.

The Project is designed to be a conventional, large open-pit mining operation that will use large-scale mining equipment in a blast/load/haul operation. Ore is planned to be processed in a large comminution circuit over the expected 13-year mine life. An open pit currently exists onsite from past mining activities, which has filled with water that is not of sufficient water quality to directly discharge to local waters.

In order for the Project to re-start mining activities, the water in the pit lake must be lowered to a level below where mining is scheduled to occur. The quality of the water onsite was not suitable for continuous discharge year-round to nearby streams, which are tributaries to the Edith River. However, in situ treatment of the pit lake water was predicted to result in concentrations that are sufficient for discharge during the wet season under the Project's water discharge license.

Micronized Lime treatment was investigated by Micronised Mineral Solutions Pty Ltd (MMS) to determine the treatment methodology, expected effectiveness, and expected cost to implement the in-situ treatment full-scale. This treatment technology utilizes very finely ground calcium carbonate (< 150 µm) and quicklime to raise the pH of the impacted water and precipitate metals. Utilization of the finely ground calcium carbonate (limestone) is the key to the treatment effectiveness, as the small grain size serves to extend the reactivity time of the particles by extending the time in which they are suspended in solution prior to settling to the bottom of the pit lake. This is achieved by the reaction between sulphuric acid, a component of the pit lake water, and the calcium carbonate particles. This reaction results in the production of carbon dioxide gas, which in turn provides buoyancy to the calcium carbonate particles. This extended settling time allows for a more efficient use of calcium carbonate and quicklime to raise the pH to the required levels. The treatment methodology includes raising the pH of the water within the pit lake to greater than pH 7.0 using calcium carbonate and quicklime in succession to capitalize on the capabilities of the low-cost limestone and minimize the quantity of quicklime required to attain a pH sufficient to precipitate additional metals. Raising the pH to greater than 7.0 results in the precipitation of the key metals of concern, including iron, aluminum, chromium, copper, lead, nickel, cadmium, and cobalt.

As such, in-situ treatment of the pit lake has been conducted by use of limestone and quicklime. Treatment began in late 2012 with the goal of producing water that can be discharged at rates that continue to protect the quality of the Edith River. In-situ treatment is being conducted as it allows for discharge of treated water in a suitable timeframe to meet with project schedule requirements. As of August 2015, it was estimated that between 12.7 giga liters of impacted water are currently on site with 79.8% is contained within the pit lake and balance from other sources across the site.

Water quality within the pit lake has historically varied in the past due to inputs from other ARD/ML sources. However, current site conditions route water such that the pit lake receives primarily fresh water. The pit walls are still mostly submerged, limiting additional oxidation of the wall rock and that ARD/ML source to the pit lake. Table 1 provides a summary of the average water quality within the pit lake prior to and since the implementation of micronized lime treatment.

The treatment has been most successful in reducing the copper concentration and raising the pH. Cadmium and aluminum have also been reduced. As would be expected, the calcium concentrations increased, as did the zinc due to its solubility at neutral pH. Sulphate, magnesium, potassium, and sodium were not changed as a result of the treatment. These results provide a means to assess the full scale implementation of the effectiveness of the in-situ treatment. This can be applied to the closure design as an analog to develop more effective closure designs.

Prediction of Post Closure Conditions

After the cessation of mining, it is expected that the Project water will have a post closure pit lake, and based on geochemical modeling the water will be equal to or worse in quality than the water present in the pit lake prior to beginning treatment in 2012. To accurately predict the on-site water chemistry and how treatment options will affect it, it is imperative that detailed geochemical characterization be conducted to determine the affinity

***Table 1** Summary of Pit Lake Water Quality Prior to and Since Treatment Began*

Analyte	Units	May 2011	April 2013	October 2014	August 2016	February 2017
pH-Field	std units	3.49	7.26	7.1	7.1	6.8
Electrical Conductivity	µS/cm	2,852	2,661	290	2,820	2,845
Temp	°C	-	26.9	29.8	23.7	32.8
Dissolved Oxygen	% sat.	-	91.8	-	88.6	103.5
Calcium	mg/L	167	440	373	397	400
Potassium	mg/L	6.5		8.5	9.1	8.3
Sodium	mg/L	45.1	49	56.5	67.7	59
Magnesium	mg/L	224	110	210	216	200
Hardness mg $CaCO_3$/L	mg/L	-	1,600	1,723	1,886	1,800
Total Alkalinity as $CaCO_3$	mg/L	-	37	53	36	22
Sulfate	mg/L	1,870	1,500	1,534	1,771	1,800
Chloride	mg/L	5.6	8	6	7	7
Total Dissolved Solids	mg/L	-	1,200	-	-	1,500
Total Suspended Solids	mg/L	-	<5	-	-	<5
Aluminum	µg/L	62.5	230	10.3	10	30
Cadmium	µg/L	146	5.1	82	33.1	29
Cobalt	µg/L	-	57	53	39	80
Copper	µg/L	11,700	27	108	1	5
Chromium	µg/L	-	1	1	1	<1
Iron	µg/L	-	<10	-	-	21
Lanthanum	µg/L	-	-	25.8	1.43	-
Lead	µg/L	-	1	1	1	<1
Manganese	µg/L	-	1,500	7,293	208	660
Mercury	µg/L	-	<0.05	-	-	-
Nickel	µg/L	-	64	669	256	230
Zinc	µg/L	42.5	210	16,194	2,186	2,000

of ARD/ML for the various rock types at the mine site. The detailed Project geochemical characterization program provided the foundation for the predictive water quality modeling. The understanding of site water flows is also critical to predicting impacts to water quality. It was determined that due to fracturing of the pit wall from blasting and mining activities, the surface runoff will be exposed to sulphides with unlimited atmospheric oxygen and water, thus having a strong affinity for acid generation. The ARD/ML reactions will be accelerated due to the long contact times anticipated in the immediate surface of the pit walls.

For purposes of this geochemical model, the post closure pit lake effluent was determined using surface area ratios of the different non-potentially acid generating (non-PAG), uncertain, and PAG materials that constitute the ultimate pit surface (UPS). Figure 1 presents the UPS with the three geochemical classifications assigned based on the geochemical characterization program. Estimated runoff from each of the materials was based on humidity cell leachate. These runoff chemistries were the only source term inputs used in the geochemical model. A filling rate and evaporation/precipitation components were not incorporated; only a fully filled pit lake was considered.

Geochemical Modeling

The geochemical modeling was conducted using the computer code PHREEQC (Parkhurst and Appelo, 1999), a reaction path

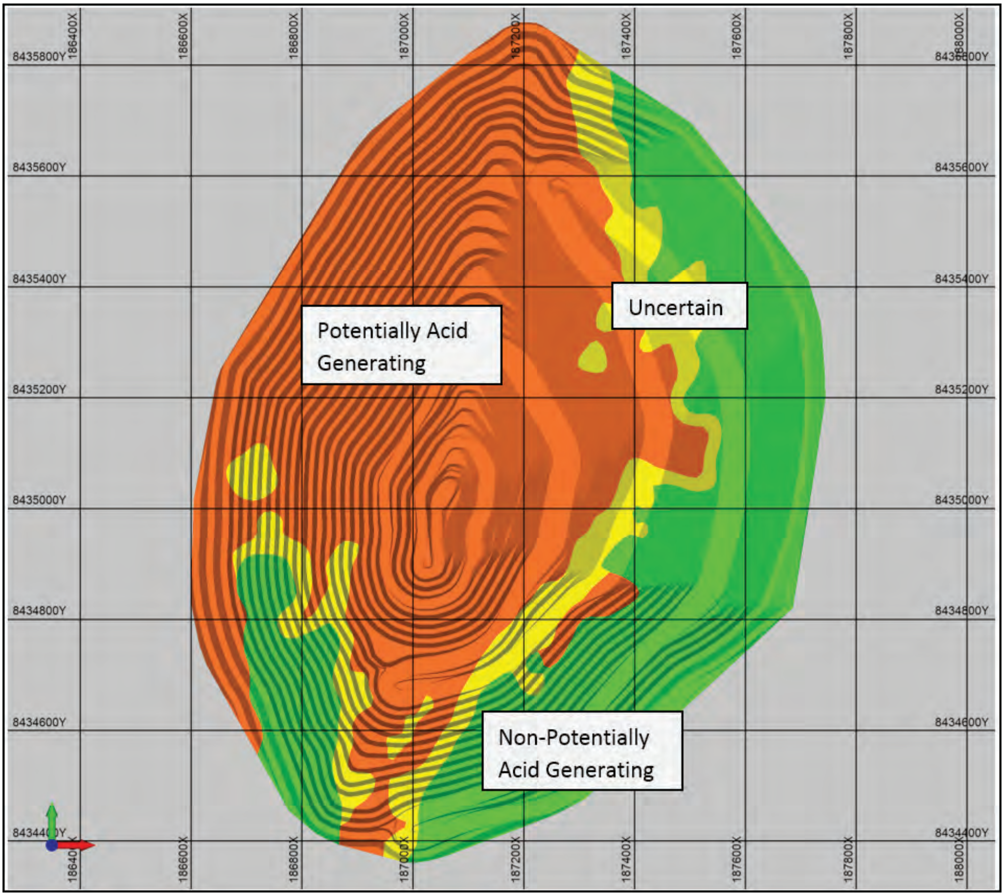

Figure 1 Ultimate Pit Surface with Color Coded ABA Criteria in Plan View. Orange represents potentially acid generating rock units, the yellow represents areas of uncertain acid generating potential, and the green represents the non-potentially acid generating rock units.

chemical equilibrium model supplied by the U.S. Geological Survey (USGS). PHREEQC is able to process multiple equilibrium and mixing reactions to produce the final chemical speciation. In addition to a computer code, geochemical modeling requires a database of the thermodynamic and kinetic parameters. For this study, the MINTEQ database (Allison et al, 1991) was chosen. However, this database does not include all of the relevant metals; therefore, to obtain a broader range of metals, data for Ti, Th, Bi were added from the Lawrence Livermore National Laboratory thermodynamic database (llnl.dat).

Some general assumptions were used throughout the geochemical modeling of the post closure pit lake. These general assumptions include:

- The precipitation source solution was limited to only hydrogen and oxygen, which were simulated as in equilibrium with atmospheric conditions;
- A six-month pyritic oxidation kinetic time step was used for the PAG wall rock units;
- Surface area proportions for the pit lake calculations were based on the UPS (i.e., the end of mine life); and
- Oxygen and carbon dioxide were assigned a steady-state concentration equal to atmospheric partial pressures.

Source Terms

To model the lithological units that comprise the UPS it was imperative to determine representative source terms for all the constituents. Source terms are stable leachate concentrations that represent long-term leachate quality. The selection of source terms was based on kinetic leachate concentrations.

Non-PAG source terms were based on the long-term kinetic metal leachate concentrations for each rock type. Several pertinent constituents were used in this determination. Each constituent's effluent concentrations were curve fitted, and assigned a point in time in which stable leachate concentrations were reached. Typically, stability was reached during the latter half of kinetic testing. Once stability ranges were acquired for the pertinent constituents, the curves were compared and a single flush (weekly) data point was chosen that represented the constant long-term leachate quality of the sample. The selection of a single flush (weekly) data point was necessary to satisfy the charge balance requirements for use in the geochemical modeling. This systematic process was repeated for each of the non-PAG rock types.

The uncertain source term was chosen based on the corresponding Round 2 humidity cell test sample results. Since this sample is trending towards acid generation after approximately two years, representative uncertain source terms were chosen before this onset. The most representative long-term leachate quality for the PAG lithologies is from the initial flush of the relevant humidity cells. These terms represent a higher metal load than the non-PAG samples. Unfortunately, only a single humidity cell has characteristics of ARD/ML generation and was terminated prior to reaching stable leachate concentrations. Thus, the most characteristic leachate quality for PAG material was from the initial flush. Its validity is due to the environmental conditions and subsequent extended contact time that water will have with PAG material in the UPS.

Surface area percentages and PAG classification for the rock types were based on the Project block model. Segregating the UPS based on lithologic composition and PAG criteria was accomplished by taking the individual pit slices from the block model and determining which blocks intersected the pit surface. When several blocks partially intersected the surface with the same x- and y-coordinates, the affected blocks were averaged and rounded up to the nearest ABA criterion (i.e., non-PAG, uncertain, PAG). These resulting blocks were used to contour the boundary strings and assign an ABA criterion to the UPS (Figure 1). Surface area ratios for the rock types and ABA designation were then calculated and used in the PHREEQC input file.

Figure 2 details the PHREEQC model construction for the post closure pit lake effluent. The chemical inputs for each of the lithologies from the non-PAG and uncertain material were mixed, respectively, based on their relative proportions of the UPS. The final PAG solution was developed by simulating the oxidation of pyrite for a six-month period. The three solutions (Solutions 8, 9, and 10 in Figure 2) were mixed in relation to their surface area percentages.

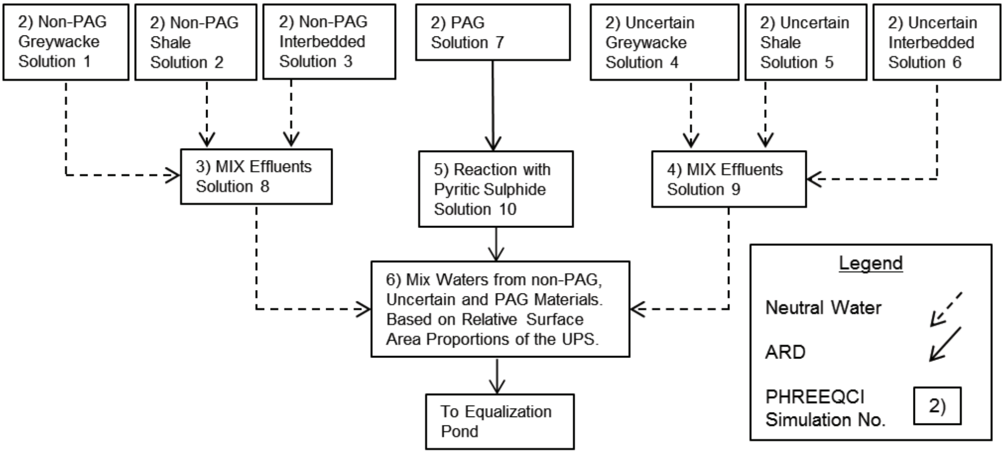

Figure 2 Pit Lake Geochemical Model Construction

Results and Conclusions

PAG material is estimated to compose approximately 55% of the UPS. As a result, the post closure pit lake is predicted to generate poor water quality. The predicted chemical effluent reporting from the post closure pit lake is similar to the poor water quality of the existing pit lake prior to treatment. The pH is predicted to be approximately 3.9, and the water will have elevated concentrations of most metals. Based on the experience and data gained from the in-situ treatment over the last five years of the existing pit lake, using a similar treatment option during closure will result in an increase of the pH and reduction of some key metals such as copper, iron, and aluminum, but may not result in full treatment of the water allowing discharge outside of the wet season. Raising the pH in the existing pit lake has resulted in an increase in the zinc concentration due to the solubility of this metal at pH 7 and has not changed the sulphate concentration, so other treatment options may be required if discharge is desired outside of the wet season. These issues may have been overlooked if the analog of the existing pit lake were not available for consideration as part of the Project closure planning.

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