Novel Approach to Acid Pit Lake Treatment and Management

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Abstract The onset of acidic pit lake conditions at Newmont's Lone Tree mine was rapid, and deteriorated to a problematic whole-lake chemistry. Complex geochemical predictions had been unsuccessful, and the acid load and geologic sources and transport mechanisms were unable to be quantified; this challenged remediation attempts, which ultimately exacerbated water quality issues. The paper relates to the successful quantification of acidity ingress, leading to compliant water quality through targeted treatment of surface water, and the development of a long term management plan in-line with company values and economic considerations relating to potential treatment design.

Introduction

Newmont Mining Corporation's Lone Tree Mine is located in Humboldt County, Nevada, approximately four miles northwest of the town of Valmy. Lone Tree Mine initiated production in 1991 with an open pit mine and has utilized various ore beneficiation methods that include heap leach, flotation and autoclave milling operations. The pre—mining groundwater elevation was approximately 50 feet below original topography. Active dewatering of the open pit area was required to facilitate mining and ceased in November 2006 at which time the open pit final depth of 3,570 ft. began filling with groundwater. Pit lake filling predictions anticipate the lake will achieve a maximum depth of 865 ft after 100 years, reaching 90% of its final depth in 2026 and 90% of its final volume in 2046 (ITASCA 2010). At its maximum depth the Lone Tree pit lake is a hydraulic sink and will not contribute to surface or ground water.

The pit consists of two zones separated by a saddle. Figure 1 presents a schematic cross-section of the Lone Tree pit prior to filling. The main sub-pit Section 11 is deepest in the south, with a final base elevation of 3,570 ft. Sub-pit 13 was back-filled with sulphide waste, encapsulated with oxide material to the north to create a 400-600ft buffer zone, and a 40ft vertical buffer zone.

There are four main lithological units that are of significance to the assessment of water quality in the pit lake.

Valmy Formation – A large percentage of the eastern portion of the pit shell. Mineralization occurs in breccias that have been partially cemented. Pyrite is present in fractures in the quartzite and coarser grained than the reduced Havallah Formation.

Wayne Zone – A large normal fault that is steeply dipping. Geologic units are downfaulted in excess of 1,000 ft. and this unit occurs from the surface to the bottom of the pit on the hanging and foot wall sides.

Alluvium –Limited alluvial deposits are net neutralising and only present in upper benches of the pit surface. This unit contributes minor groundwater flow compared to the bedrock units.

Havallah Formation – The sequence is made up of sandy limestones and conglomerate that has been decalcified.

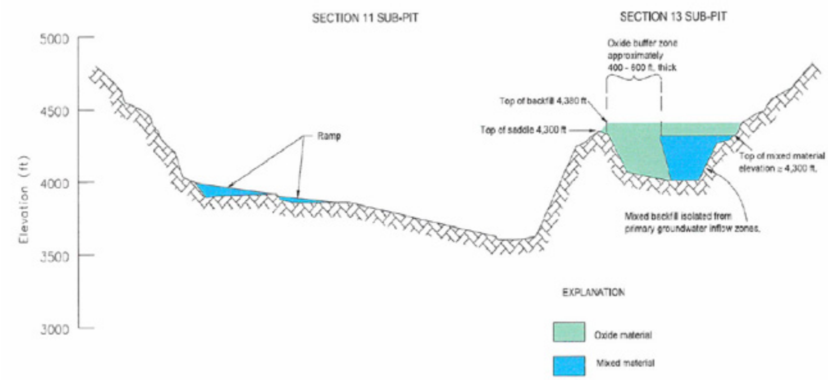


Figure 1 Cross-sectional schematic of Lone Tree pit and sub Section 13 backfill.

The waste rock is shown by major unit lithology in Figure 2, indicating the area of exposed material at the surface of the pit shell. The rock types that were classified as net acid generating, net acid neutralizing, and those as uncertain are shown. The data used to generate the classifications is presented in Table 1 and 2, from two independent geochemical classification activities.

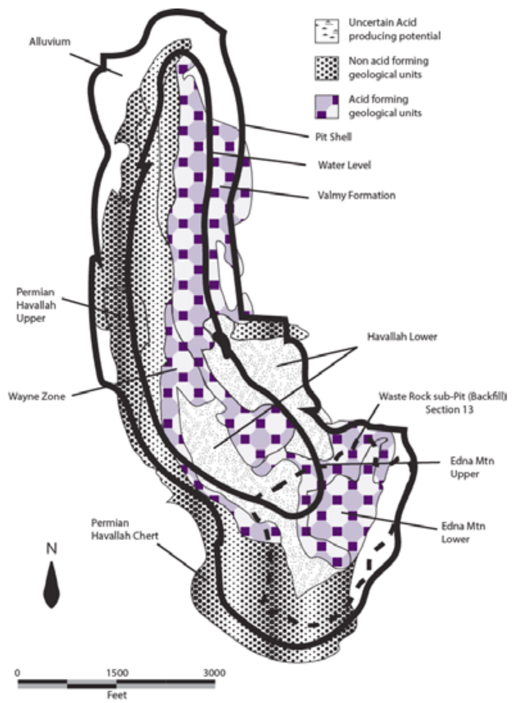


Figure 2 Map of major geological formations within Lone Tree pit lake

Table 1 *Summary of Geochemical testing data performed for Newmont in 1995.*

	Kinetic Tests					Static Tests	
Geologic Unit	Av NCV (% CO2)	Av ANP (% CO2)	AvAGP (% CO2)	HCT 20 wk pH	#HCT #	Static Tests Av. NCV	# Static tests #
Battle Mtn	-0.81	0.33	1.14	2.3	3	-1.24	23
Edna Mtn lower	-1.45	0.24	1.69	2.5	7	-0.87	30
Valmy	-1.66	0.27	1.93	2.4	4	-1.55	26
Havallah Lower Reduced	-5.67	1.17	7.20	6.2	2	0.16	50
Havallah Lower Oxide	-1.14	0.76	1.89	2.5	2		
Havallah Chert	2.45	2.56	0.10	6.7	2	0.53	48
Wayne Zone	-4.86	0.56	5.43	1.9	3	-3.8	7

Table 2 *Summary of Geochemical testing data performed for Newmont in 2010.*

Geologic Unit	AGP ppt $CaCO_3$	ANP ppt $CaCO_3$	Paste pH pH	HCT 20 wks pH
Havallah Chert	0.6	27.3	7.89	7.5
Alluvium	<0.3	210	7.76	8.1
Havallah Upper	<0.3	49	8.04	8.0
Havallah Lower	7.3	62.9	7.13	7.5
Edna Mountain Upper	31.9	33	6.09	3.2
Edna Mountain Lower	178	7.2	3.19	2.0
Valmy	38.4	<0.3	2.52	2.1

The geochemical characterization testwork undertaken represented the dominant material types of the Lone Tree pit lithology, and demonstrated a high propensity for net acid generation with rapid onset in the Valmy, Wayne Zone and Edna Mountain Formations, with some uncertainty around the Havallah formation. Based upon Figure 2 these lithology's have comprised up to 50% of the exposed wall rock during lake filling to date, and are expected to be approximately 30-35% of the wall rock exposed above the final pit lake elevation.

In 1994, these results (207 static tests and 24 20 week kinetic humidity cells) were used to estimate pit lake water quality using MINTEQA2. The resulting model predicted circum-neutral (pH 8.7) water quality with elevated TDS, antimony, fluoride, and nickel. A revision of the model in 1996 predicted a higher pH of 9.1. The rapid onset of acidic conditions in the pit lake suggests the modelling technique was incongruous.

Pit Lake Chemistry development

Upon cessation of dewatering operations at the Lone Tree Mine, the pH of the initial pit lake was circum-neutral in December 2006; the pit lake pH decreased in late 2007 declining to 3 to 3.5 by early 2008. Pit lake treatment in the form of alkalinity additions was initiated in 2008 to increase pH and reduce metal concentrations (Fig. 3). Beginning in 2011 the lake began to thermally stratify in the summer months. Treatment via caustic, followed by lime additions was conducted seasonally during summer and fall months. Alkalinity additions during stratification failed to improve the surface pH conditions, resulting in low pH (~3) in surface water (epilimnion), and high pH in the deeper water (hypolimnion). With the onset of lake mixing in the fall, high pH conditions were observed in the entire lake column (Fig. 3).

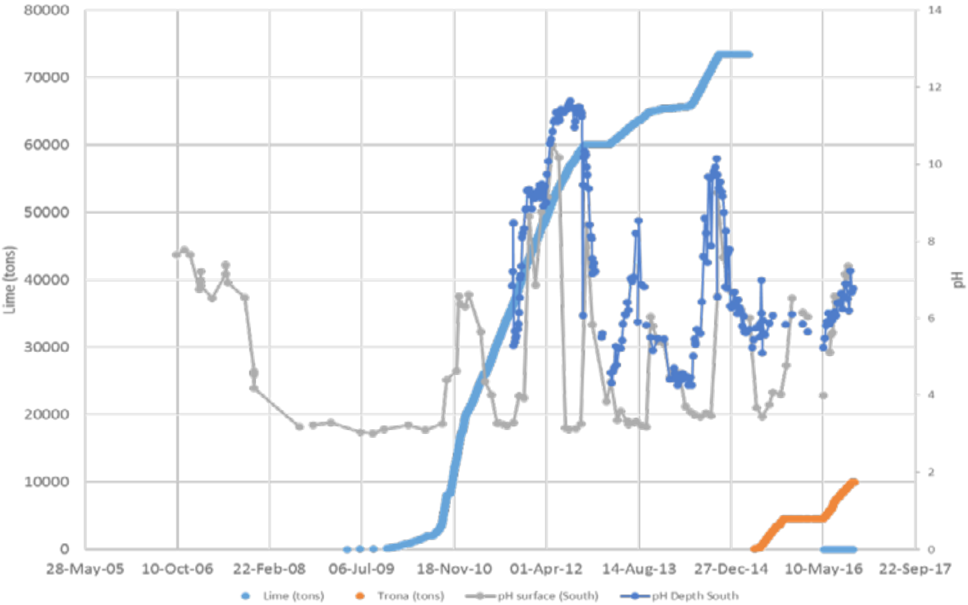


Figure 3 *Lime and Trona addition, south surface and depth pH.*

No relationship between surface pH and lime addition was evident (Fig. 3), and whole lake swings of pH from 3-10 were occurring with the onset and breakdown of stratification. It became evident that the lime was not dissolving in the surface waters, and there was no way to determine acid ingress or the utilization/efficiency of lime addition.

Once the initial assessment of lake neutrality was deemed to be incorrect, the site now had to re-evaluate and predict the likely lake condition for the future and hence the best way to maintain desirable pH conditions in the surface of the lake, all without any reliable data on the source and magnitude of acidity entering.

In 2014, Newmont Metallurgical Services was enlisted to determine a means to quantify the acidity ingress in order to evaluate the most effective and economically viable methods to control and maintain pit lake water quality. It was determined that lime solubility had prevented the efficient delivery of alkalinity, and that almost all of the alkalinity dosed in this manner was not utilized in the epilimnion prior to traversing to depth. Therefore a more soluble product would be desired.

Trona

Trona (sodium sesqui-carbonate) was selected as the sole source of alkalinity addition as maximum dissolution rates in the surface waters can be achieved. The rationale is to measure the alkalinity / acidity weekly as normal part of the monitory activity, and determine acidity ingress according to the following equation (Eqn. 1);

$$Acidity\ ingress = \frac{Alkalinity\ added - Acidity\ change}{Time\ interval}$$

Equation 1 *Acidity ingress calculation*

This calculation can be performed for each time frame between surface acidity measurements in summer months, during which time either no alkalinity source is dosed, or a soluble source is used. Incomplete dissolution of an alkalinity source leads to unusable results. *Alkalinity added* is derived from trona addition and epilimnion volume, and is in the units of (negative) grams of calcium carbonate per cubic meter of epilimnion. *Acidity change* is derived from the averaged measured values for acidity in surface water and is in the units of grams of calcium carbonate per cubic meter of epilimnion. *Acidity ingress* is then all acidity coming into the surface of the lake and is in the units of (negative) grams calcium carbonate per cubic meter of epilimnion for a given *Time interval* in days. Typically, the units of acidity are converted to grams sulfuric acid per day.

Results

After two years of data with trona as the sole alkalinity source, we have measured an average daily acid ingress of approximately 17 tonnes of sulfuric acid equivalent (Tab. 3).

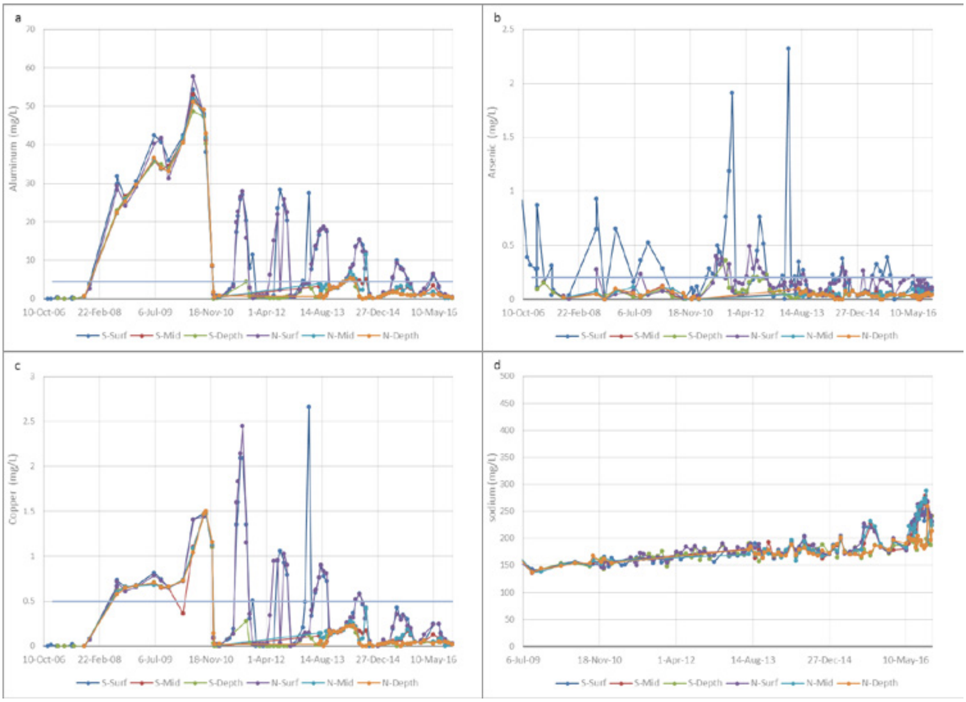
Table 3 *Summary of acidity ingress in (-) gCaCO3/m3 and tonnes H2SO4 / day*

Species	units	Year	June	July	August	September	Average
H_2SO_4	tonnes / day	2015	16.1	15.2	16.3	21.4	17.3
		2016	11.9	32.2	22.9	2.0	17.2

Lake amendment attempts have demonstrated a measurable improvement to water quality in the pit lake (Fig. 4a-d), and the extension to trona has not only yielded an understanding of acidity ingress, it has achieved the desired water quality.

Discussion

The calculated acidity ingress at Lone Tree is remarkably consistent for the time period measured, and provides a basis for the neutralization requirements in the near term. Further assessment of the acidity ingress (using trona) is required to develop long term trends, which will validate source terms and pathways and develop long term predictions required



Figures 4 a, b, c, d *Concentration of aluminium, arsenic, copper, and sodium, respectively, for each sampling point and depth.*

for capital investment purposes. Put simply; it is equally undesirable to over or under expend capital to solve this problem.

Trona *may* be the long term solution for this application, however sodium is the balancing ion within the trona molecule, and is conservative in a closed basin system such as Lone Tree. Continued addition of sodium will result in proportional total dissolved solids (TDS) increase, and is determined to be 6-8 mg/L per year (Na), which is acceptable on a short / medium term basis given the 2000 mg/L Na limit (Fig. 4d), and is largely dependent on the long term acidity ingress trend. The nature of sodium as compared to calcium in this case achieves two further benefits, making a longer term trial desirable; 1. Sodium concentration in the epilimnion allows for tracking of alkalinity distribution and, 2. Sodium concentration in the hypolimnion during stratification allows for the assessment of trona neutralisation efficiency, and can correct the acidity ingress calculation.

In addition to TDS, ultimately trona may not be an economic alkalinity source. Delivered, trona is about \$180/t, or in terms of alkalinity, \$280/t as $CaCO_3$. Quicklime (CaO) is about \$130/t, or in terms of alkalinity, \$75/t as $CaCO_3$. For this application, the economic and sustainable alkalinity source is most likely CaO. Both require capital investment for dosing and distribution; to overcome the solubility and distribution challenges already experienced.
Further to the empirical calculation and trend analysis for acidity at Lone Tree, reinterpre-

tation of the geochemical model based on the empirically derived acidity data as calibration, may yet yield a useful tool for the assessment of sources and pathways of acidity, and provide confidence in the water quality prediction long term. This recalibration, lessons learned and reassessment of the geochemical modelling approach, is likely to be useful for the wider industry. We intend to monitor and evaluate long term options over the next 5-7 years.

Summary

Geochemical modelling predicted neutral pit lake chemistry, instead acid conditions developed less than one year after pit filling began. Ad-hoc neutralization was attempted using caustic followed by quicklime, to some effect on overall lake chemistry. Lime dissolution and thermal lake stratification complicated reagent utilization assessments, and continued neutral conditions were not obtained. Sodium sesquicarbonate (trona) was used successfully over two stratification seasons, and acid ingress was quantified as 17 tonnes H_2SO_4 per day. The calibrated ingress is now being used to reassess the original model assumptions to better understand acidity source terms and potential long term trends to meet process design requirements for a water treatment system, and to inform other geochemical models.

References

(ITASCA 2010). 2010 update of numerical groundwater flow modeling for Newmont Mining corporation's lone tree mine Humboldt County, Nevada

This paper is solely based on internal reports of Newmont USA Limited's operation. This includes the geological data, history of the mine and chemical developments. As these reports are not available to the public, no references have been provided.