LIME DEMAND ESTIMATES FOR THE MANAGEMENT OF WATER QUALITY IN THE THOMPSON TAILINGS BASIN DURING OPERATIONS AND FOR CLOSURE PLANNING

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July 2015

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EXECUTIVE SUMMARY

A revised mine plan in 2014 at the Thompson mine-mill-smelter complex required an update to the tailings deposition plan. The ultimate goal for the Thompson tailings basin at closure is to have all material except parts of the existing South Beach submerged and protected from oxidation and subsequent acid generation. This will be achieved through a combination of subaqueous deposition of tailings and the raising of existing, and construction of new dams to flood tailings that will be temporarily deposited above existing water elevations. A site-wide water balance was developed to support the water level raising plan (WLRP) and to ensure flow requirements at the Weir are maintained (AMEC, 2014).

The WLRP was initiated in May 2013, in Areas 1 to 3, with a partial closure of the Narrow's Flow Gate (AMEC, 2014). The water level in Areas 1 to 3 was raised from 669 ft to 674 ft above sea level (asl) and the effects have been monitored by measuring flows at the weir and water levels in Areas 1 to 3. Following the water level raise, seepage was observed at the Narrows Dyke roadway and the water level was lowered to 672 ft to limit seepage.

Nickel concentrations in the basin were noted to increase following the water level raise in Areas 1 to 3, exceeding 0.5 mg/L at the CN Dam in June of 2014 while remaining below the compliance level of 0.5 mg/L at the Weir. Nickel concentrations were also observed to exceed the warning limit of 0.325 mg/L, during that period. In order to maintain acceptable metals concentrations at the Weir, lime is added to the basin as a slaked slurry in a 10,221 L (2,700 usgal) tanker truck at the Dredge, Narrows and the CN Dam with a delivery frequency of 6 truckloads per day on a schedule of 5 days per week. This equates to a lime delivery of 63 to 69 tonnes of lime per week to the basin, with each truck containing between 2.1 to 2.3 tonnes of lime.

In 2013 and 2014 there were some challenges with the delivery of lime combined with an increase in lime demand to control nickel levels in the Basin. Coincidentally, there was a planned water level raise in Areas 1 to 3 in 2013 by flow control at a constructed dyke at the Narrows. The observed changes in lime demand as well as additional planned water level raises in the future, as part of the closure planning process, suggested that the future lime demand requirements be assessed in order to confirm that the required lime did not exceed the lime delivery capacity in the future.

A water level raise in Area 4 is planned following the completion of the raise in Areas 1 to 3 as part of the WLRP. The raise in Area 4 will be completed with the progressive placement of stop logs at the Railway Dam Water Control Structure and will require the completion of the raise of Dam B in the South Arm of Area 4 (AMEC, 2014). It is understood that Vale, with the assistance of AMEC, is currently evaluating the potential options for a revised WLRP that includes a proposed delay in timing for the proposed Narrows and Dam B raises to the fall of 2017 (AMEC, 2014). The planned water level raises were scheduled to minimize acidity and nickel loadings from the exposed tailings, in order to meet discharge objectives at the Weir and to support a floating tailings delivery system in Area 4 in the future.

There are, however, time constraints for exposed tailings within the South Arm, to prevent excessive acidity loads to the basin. The South Beach tailings are at a mature stage of oxidation and acid generation and are expected to continue to release nickel and acidity until mitigation by constructing a proposed cover over the above-water tailings at closure. However, the freshly deposited tailings above water in Area 4 will also begin to generate acid and to become a source of metal loadings after a period of exposure above water. Because the loadings to the basin are a function of the total surface area of exposed and acid generating tailings, there is a need to understand the potential effects of the ongoing deposition and exposure of tailings in Area 4 on the lime demand in the basin required to control pH and nickel concentrations.

The objective of this assignment was to assess future lime requirements in the context of exposed tailings and planned water level raises in order to confirm that the required lime demand will not exceed the delivery rate of lime needed to control nickel concentrations in the Basin and remain compliant with discharge limits at the Weir.

Three focused questions were therefore developed regarding the proposed water level raises, and were addressed as part of this assessment:

1. Is a water level raise, from 672 to 674 ft asl, in Areas 1 to 3 required in 2015 to keep within the lime delivery constraints?
2. How will the planned water level raise in Area 4 from 669 to 674 ft asl in 2017 affect water quality and lime demand?
3. How will a one-year delay in the water level raise in Area 4 to 2018 affect water quality and liming requirements?

Tailings sampling in areas of exposed and flooded tailings was completed in September of 2014 to assess and verify the degree of oxidation and to better understand the relationship between exposure time and soluble loads of acid and nickel, as well as between submergence and flushing of acid and nickel from the tailings. These relationships provided a verification of exposure time before acid generation begins in areas where the tailings have been temporarily exposed before water level raises and permanent submergence.

A lime demand model for the Thompson tailings basin was developed and applied to assess the water quality and lime requirements during and after the planned water level raises in Areas 1 to 3 and the South Arm of Area 4. The results of the field sampling program were used to derive acidity and nickel loadings from, permanently exposed (Areas

1 to 3) and temporarily exposed (Areas 1 to 4) tailings as well as from recently flooded tailings (Area 1 to 3), as inputs to the model.

The overall results of this analysis showed that the lime demand for Areas 1 to 3 is less than but close to the current lime delivery rate of 46 tonnes of lime per week (4 trucks per day) for the area. The model results suggest that there will not be a material benefit with a water level raise in Areas 1 to 3 alone in 2015 and that the raise in Area 4 in 2017 or 2018 will result in a similar lime demand and mitigation results for Areas 1 to 3.

The water level raise in Area 4 in 2017 will result in an estimated peak lime demand that is similar to the current lime delivery rate of 23 tonnes per week (2 trucks per day) in that area, for loadings representing average conditions for the flooding of exposed tailings. Although a decline in lime demand is expected after an initial flush during submergence of the tailings, the peak values may be sustained for several months. This is the justification for construction of the splitter dyke that will allow lime addition to the flow from the South Arm into Area 4 prior to flow into Area 5.

The delay of a water level raise by one year to 2018 does not appear to represent a large incremental increase in lime demand for submergence of the tailings in the South Arm. However, the results from the upper bound scenario representing the 90th percentile loads from the temporarily exposed tailings during submergence suggest that there is a risk of exceeding the current lime delivery rate if the loadings are greater than those expected for average conditions or if more rapid flooding causes higher peak lime demand values than those predicted here. The risk associated with the peak lime demand resulting from a rapid flush event is the potential to exceed the lime delivery capacity and to experience non-compliance for nickel concentrations at the Weir. The water level raise will need to be managed at a rate that does not cause higher peak lime demand values. Monitoring at the outflow through the splitter dyke at the north end of the South Arm will be required to provide information for the lime requirements and lime should be added at that location to provide maximum benefits for pH and nickel control.

The conclusions from the model results have some uncertainties based on some assumptions used and the uncertainties associated with the historical lime usage in the Basin. Therefore, as a follow up to this assessment, it is recommended that a refinement to the estimated lime demand for the basin be completed using the most up to date records of lime delivery. In this way, the uncertainties surrounding historical lime delivery and consumption will be greatly reduced. This update will also allow for a clearer indication of lime requirements in terms of capacity and delivery restrictions to the basin that may become especially important during upset events or more rapid flooding of the basin. This refinement will reduce the uncertainty of the conclusions for the deferred raise of Dam B and therefore will reduce the risks associated with that decision.

The lime demand for water level raise events may also be affected by other processes in the Tailings Basin. Soda ash (sodium carbonate) and nitric acid, for example, are known to be discharged to the 48” sewer and to enter the basin. The lime that is added to Areas 1 to 3, to raise the pH above 8.5 and effectively control acidity and nickel that originate from the exposed South Beach tailings will need to be augmented by additional lime to counter these additional inputs from the sewer.

A review of the refinery inputs to the 48” sewer is recommended to overcome the residual uncertainties related to acidity and nickel loadings. This review should include the measurement of flow, as well as the analysis of acidity during routine sample collection. Also suggested is the estimation of additional sources of acidity to the sewer, including soda ash and the emptying of the acid tanks, in terms of relative contribution and frequency of events. An alternate to soda ash neutralization of the nitric acid tank discharge may be worth consideration in order to eliminate additional lime demand for soda ash precipitation when raising the pH above 8.2.

Additional characterization of the tailings effluent from D2 is also suggested for future work in order to reduce the uncertainty present in the model. Although the nickel and acidity concentrations are expected to be relatively small, the flow rate is a relatively large portion of the water balance in the Basin. The analysis of dissolved metals and alkalinity would improve the development of loadings sources to the Basin, during the beaching of tailings in the South Arm and the sub-aqueous disposal of tailings in Area 4.

Future opportunities for the evaluation of mitigation measures for the site include modelling scenarios that assess the sub-aqueous disposal of tailings in Area 4, the refinement of acidity and nickel loadings from the 48” sewer and the placement of covers on the exposed tailings areas. The release of nickel from the treatment solids in Area 1 and the sediments in Area 5, can be can be modelled in future iterations, in order to assess nickel loadings to the basin, lime demand requirements and predicted compliance at the Weir, during and post-closure.

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1.0 INTRODUCTION

The Vale Thompson nickel-copper operation is located in Thompson, MB, approximately 740 km north of Winnipeg. The mine-mill-smelter complex has been in operation since 1956 and has had both open pit and underground operations, with open pit extraction completed in 2005 (EcoMetrix and AMEC, 2006). The tailings basin includes five sub-basins, referred to as Areas 1 to 5 (**Figure 1.1**). Tailings have been discharged to and have filled most of Areas 1, 2 and 3 with discharge to Area 4 ongoing since 2011. Area 5 acts as a polishing pond immediately upstream of the outlet Weir that represents the compliance point.

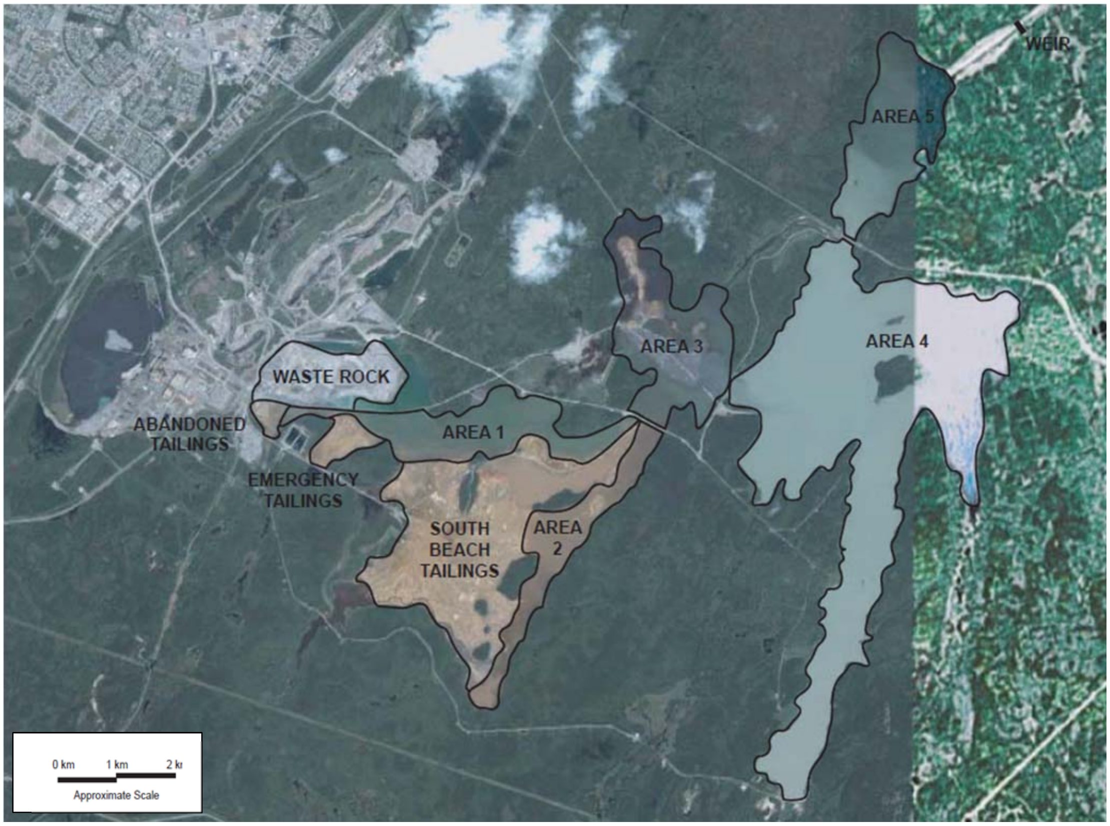
The tailings basin has been active since the mine began operations in 1956. Over 50 million tonnes of tailings have been deposited in the basin. The tailings have been deposited to form beaches in the water filled basins during operations and are intended to be temporarily exposed before raising water levels to form a water cover for mitigation of acid generation after closure. Some historic tailings were deposited at elevations above the planned final water elevation of 679 ft asl and will remain above water at closure. Those tailings will have soil covers constructed to mitigate acid drainage at closure. The above-water tailings are referred to as exposed tailings, and include the Emergency, Abandoned and South Beach tailings areas adjacent to Areas 1 and 2 as shown in **Figure 1.1**.

The discharge compliance point is the Weir at the outlet of Area 5. While there are several water quality parameters with established discharge limits, the focus of compliance is on nickel that has a limit of 0.5 mg/L. Experience has shown that if nickel remains below the discharge limit, all other water quality parameters will remain compliant. Nickel concentrations in the Basin increase with increased nickel loadings and also with decreased pH. The pH in the Basin decreases as a result of acidity loadings and increases in response to liming.

Nickel loadings to the basin originate from several sources. The runoff from older exposed, acidic tailings as well as temporarily exposed tailings that have developed acidic drainage after a few years of exposure are major sources of nickel and acidity loadings to the Basin. Other discharges to the basin, including mine water from the underground and process flows such as the 48 inch sewer also contribute nickel and acidity to the Basin. Since 2005 it has been necessary to add lime to the Basin, during periods of the year, in order to control nickel concentrations and to maintain compliance at the Weir.

It is understood that lime is added to the basin as a slaked slurry in 10,221 L (2,700 usgal) tanker trucks at the Dredge, Narrows and the CN Dam with a maximum practical delivery frequency of 6 truckloads per day, 5 days per week. This equates to a lime delivery of 63 to 69 tonnes of lime per week to the basin, with each truck containing between 2.1 to 2.3 tonnes of lime.

Figure 1.1: Schematic of the Thompson Tailings Basin



The tanker truck obtains the lime slurry from one of several sources, including the mill and two slakers present at the mill site. The mill source and slakers primary purpose is to supply lime to other components of the operation and therefore, there are some constraints on the availability of lime at the site for water treatment in the tailings basin. In 2013 and 2014 there were some challenges with the delivery of lime and at the same time, there was an increase in lime demand to the Basin to control nickel levels in the Basin. Coincidentally, there was a water level raise in Areas 1 to 3 in 2013 by controlling the flow at a constructed dyke at the Narrows. The observed changes in lime demand as well as additional planned water level raises in the future, as part of the tailings operation and closure planning process, suggested that the future lime demand requirements be estimated in order to effectively manage water quality in the future.

Two independent water level raises were planned, one in 2015 and one in 2017, before a final raise at closure. The first raise involves additional construction at the Narrows dyke to increase the water elevation in Areas 1 to 3 from 672 to 674 ft. The second raise involves additional construction of Dam B and control at the CN Dam to increase the water level in Area 4 to 674 ft.

Three focused questions were developed regarding proposed water level raises, and were addressed as part of this assessment:

1. Is a water level raise in Areas 1 to 3 from 672 to 674 ft asl required in 2015 to keep within the lime delivery constraints?

2. What will be the result of the planned water level raise in Area 4 from 669 to 674 ft asl in 2017, on water quality and lime demand?

3. What will be the result of a one-year delay in the water level raise in Area 4 if the raise does not occur until 2018?

1.1 Objectives and Scope

The objective of this assessment was to estimate future lime requirements in the context of exposed tailings and planned water level raises in order to effectively control nickel concentrations in the Basin and remain compliant with discharge limits at the Weir. Several tasks were required to meet the objective, including the following:

- Assess the overall effects of the flooding on water quality and lime demand, in terms of the relative loadings of acidity and soluble metals with and without a water level raise from 672 to 674 ft in Areas 1 to 3;

- Assess the evolution of acidity and soluble metals in the surface of the temporarily exposed tailings from Area 4, in order to better predict the loadings to the tailings basin during exposure and when the tailings become submerged as the water level is increased;

- Evaluate the water quality and lime demand required to maintain acceptable metals concentrations in the Weir discharge, associated with the water level raise from 669 to 674 ft in Area 4; and,

- Evaluate the effects of a delay in timing for the planned water level raise in Area 4.

Tailings sampling in areas of exposed tailings was completed to assess and verify the degree of oxidation and to better understand the relationship between exposure time and soluble loads. These relationships provided a verification of exposure time before acid generation begins in areas where the tailings have been temporarily exposed before final submergence after water level raises.

Areas of the Emergency, Abandoned, South Beach, Area 1 and Area 3 tailings that will also be flooded during the planned water level raise from 672 to 674 ft were also sampled to assess soluble loads. Samples of tailings that had become submerged during the water level raise to 672 ft in Areas 1 to 3 were also sampled in order to better understand the degree of flushing of acidity and metals from the tailings porewater to the overlying water.

A lime demand model for the Thompson tailings basin was developed and applied to assess the water quality and lime demand during and after the planned water level raises in Areas 1 to 3 and the South Arm of Area 4. The results of the field sampling program were used to derive acidity and nickel loadings from, permanently (Areas 1 to 3) and temporarily exposed (Areas 1 to 4) tailings as well as recently flooded tailings (Area 1 to 3), as inputs to the model.

1.2 Report Structure

Following this introductory section, the report is organized as follows:

- Section 2.0 provides background information related to the project, including an overview of water quality results from the Tailings Basin and a summary of the proposed water level raises;
- Section 3.0 describes the results from the field sampling program that was completed by EcoMetrix in 2014;
- Section 4.0 provides an interpretation of results within the context of relative loadings from the exposed and submerged tailings source areas;
- Section 5.0 provides an interpretation of results within the context of lime demand requirements for compliance at the Weir pre- and post-water level raises ;
- Section 6.0 provides the overall conclusions and recommendations of the investigation, and
- Section 7.0 provides a list of the reference materials that were used in the preparation of this report.

The complete results of the chemical analyses of samples collected during the 2014 work program are attached in **Appendix 1.**

2.0 BACKGROUND

Previous investigations of water quality in the Thompson tailings facility have shown that exposed and acidic tailings in Areas 1 to 3 were major sources of acidity and nickel to the basin (EcoMetrix, 2006, 2007, and 2011). Other sources of acidity and/or nickel are associated with discharges to Areas 1 and 3 that include the 48 and 42 inch sewers as well as those from the underground mines, 1D and T1. The tailings process water from D2 has relatively low nickel concentrations but also represents a source of loadings because of the relatively high flow rates (EcoMetrix, 2007). In the past, the 48 inch sewer was estimated to be a major potential source of nickel loadings. The 48 inch sewer receives discharges from the refinery, including regular effluent streams, upset releases, nitric acid tank contents and soda ash.

In the mid 2000s, comparing the monitoring results to the water quality modelling predictions in the Basin identified a major unknown source of dissolved nickel that was traced back to upset conditions for the smelter return that delivered large loadings to the D2 pump box and then to the basin with the tailings process water (EcoMetrix, 2007). The smelter return flows were rerouted to the 48 inch sewer in 2007) to provide a capability to add lime to the flows as a means of removing dissolved nickel before the water entered the basin.

A revised mine plan in 2014 at the Thompson mine-mill-smelter complex required an update to the tailings deposition plan. The ultimate goal for the Thompson tailings basin at closure is to have all material except parts of the existing South Beach submerged and protected from oxidation and subsequent acid generation. This will be achieved through a combination of underwater deposition of tailings and the raising of existing, and construction of new, dams to allow flooding of that material that will be temporarily deposited above existing water elevations. A site-wide water balance was developed to support the water level raising plan (WLRP) and to maintain the flow requirements at the Weir (AMEC, 2014).

The tailings basin is being managed to control nickel concentrations and to maintain compliance at the Weir by addition of lime to the Basin. There are several sources of acidity and nickel loadings to the Basin that, cumulatively, necessitate the use of lime to maintain pH values above 8 in the Basin to control nickel concentrations so that values remain below the discharge limit of 0.5 mg/L at the Weir. A major ongoing source of acidity and nickel loadings to Areas 1 and 2 is runoff from the exposed tailings at the South Beach. While runoff from exposed tailings at the Emergency and Abandoned and Area 3 contributed acidity and nickel loadings prior to 2013, the majority of those tailings areas were submerged when the water level was raised to 672 ft in 2013 and loadings have been greatly reduced from those sources. After submergence of the temporarily exposed tailings in Areas 1 to 3, the newly flooded areas will represent a smaller source of loadings that will diminish to negligible values over time. Other areas of temporarily exposed tailings, including those in the South Arm are expected to represent a source of acidity and nickel loadings that will increase with exposure time.

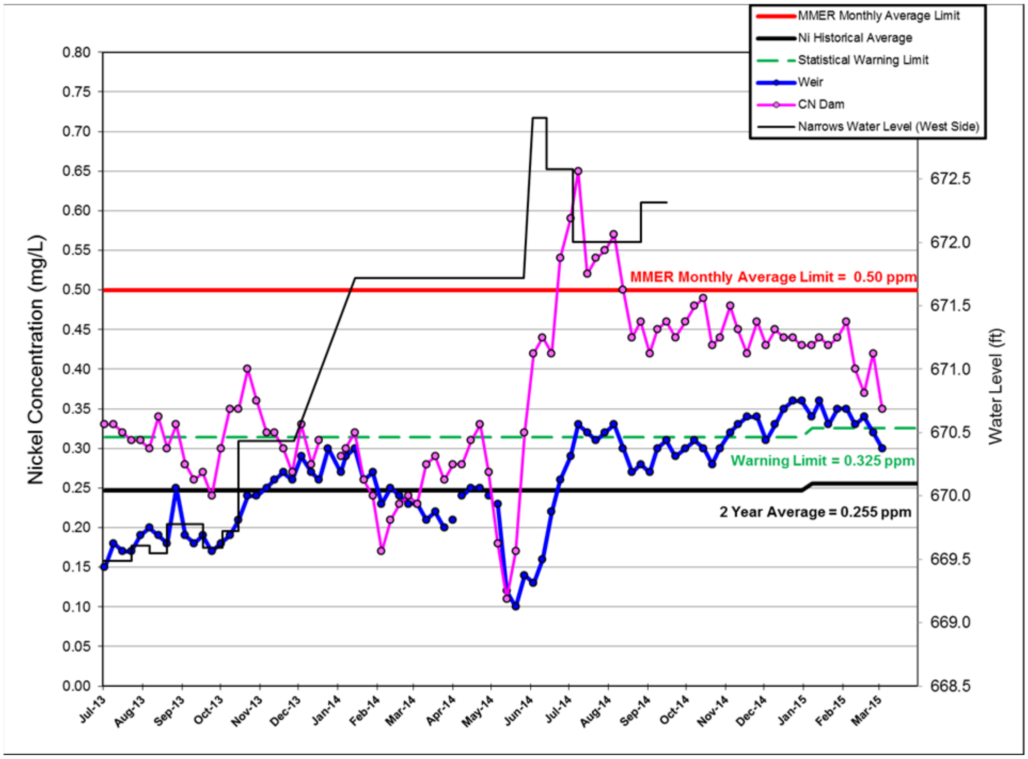
There are, however, time constraints for exposed tailings to prevent excessive acidity and nickel loadings to the basin. The ongoing loadings from the South Beach tailings are at a mature stage of oxidation and acid generation and the loadings are expected to continue until closure when the loadings will be mitigated by construction of a cover over the tailings that will remain above water. Lime delivery to the basin is adequate to control the acidity and nickel loadings from the South Beach. However, freshly deposited tailings that will be temporarily above water will begin to generate acid after sufficient exposure time. The temporarily exposed tailings need to be considered in the management of water quality in the basin to ensure that adequate quantities of lime can be added to the basin in order to maintain pH levels that will control metal concentrations to meet compliance levels at the basin discharge.

Previous studies (EcoMetrix, 2012a) have suggested that the tailings will begin to generate acid and metal loadings to the basin within 4 years of deposition and exposure above water. The total loadings from exposed tailings are a function of the exposed area and exposure time and therefore, loadings are expected to increase as the exposed area of tailings and the exposure time increases. The temporary exposure or beaching of tailings prior to final flooding requires consideration to avoid excessive acid and nickel loadings to the basin that could lead to elevated concentrations of nickel, and potentially other metals, above compliance levels at the Weir.

As an interim measure, a dyke was raised at the Narrows in order to flood the temporarily exposed tailings in Areas 1 to 3 in order to stop the acidity and metal loadings from the above water tailings. The WLRP was initiated in May 2013, in Areas 1 to 3, with a partial closure of the Narrow’s Flow Gate (AMEC, 2014). The water level in Areas 1 to 3 was raised from 669 ft to 674 ft above mean sea level (asl) and has been continually monitored based on observed flows at the weir and the measured water levels in the basin. Following this water level raise, seepage was observed at the Narrows Dyke roadway several months later and the water level was lowered to 672 ft to limit seepage. During the water level raise in 2013-2014, and with ongoing deposition of temporarily exposed tailings in Area4, there was an increase in lime demand in the basin in order to control pH and nickel concentrations at the Weir. An increase in nickel concentrations at the CN Dam and at the Weir after the water level raise suggested that flushing of the exposed tailings in Areas 1 and 3 had contributed to the higher than anticipated nickel levels during the water level raise.

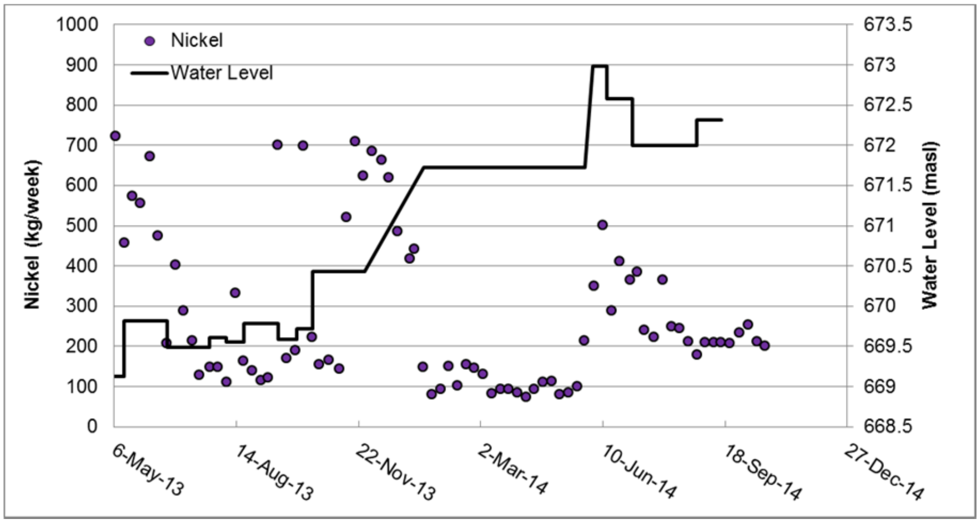
Nickel concentrations in the basin were noted to increase following the water level raise in Areas 1 to 3, exceeding 0.5 mg/L at the CN Dam in June of 2014 (**Figure 2.1**) while remaining below the compliance level of 0.5 mg/L at the Weir. Nickel concentrations were also observed to exceed the warning limit of 0.325 mg/L, during that period. In order to maintain acceptable metals concentrations at the Weir, lime has been delivered to the basin at several key locations in Areas 1 to 3, including the Dredge, Narrows and CN Dam. Those locations receive a total of 63 to 69 tonnes of CaO per week, equivalent to two trucks daily at each of the three locations on a schedule of 5 days per week. It is understood that the delivery of lime is currently at a maximum due to the infrastructure available at the site and represents an important variable and potential constraint for consideration during this assessment.

Figure 2.1: Thompson Tailings Basin Nickel Trends for the Period 2013 to 2015



Nickel loadings were also noted to increase at the Narrows following the water level raise in Areas 1 to 3 (**Figure 2.2**). Nickel loadings were estimated using the measured concentrations at the Narrows monitoring station and the estimated outflow from Areas 1 to 3 as determined by previous modelling iterations (EcoMetrix, 2012b and 2007). Following the water level raise from 669 ft to almost 670 ft in May, 2013, an “initial flush” was observed and again from almost 670 to just over 671.5 ft, resulting in peak nickel loadings to the basin. Loadings were observed to decrease over a period of 10 weeks post flooding to over 671.5 ft. A secondary flush was also observed during the raise from just under 672 ft to 673 ft in June 2014 before the water level was dropped to 672 ft.

Figure 2.2: Nickel Loadings at the Narrows during the Water Level Raise in Areas 1 to 3 from 669 to 673 ft asl



A water level raise in Area 4 is planned following the completion of the raise in Areas 1 to 3 as part of the WLRP. The raise in Area 4 will be completed with the progressive placement of stop logs at the Railway Dam Water Control Structure and will require the completion of the raise of Dam B in the South Arm of Area 4 (AMEC, 2014). It is understood that Vale, with the assistance of AMEC, is currently evaluating the potential options for a revised WLRP that includes a proposed delay in timing for the required Narrows and Dam B raises to the fall of 2017 (AMEC, 2014). The planned water level raises are required to minimize acidity and nickel loadings from the exposed tailings, in order to meet discharge objectives at the Weir and to support a floating tailings delivery system in Area 4 in the future.

There are, however, time constraints for exposed tailings within the South Arm, to prevent excessive acidity loads to the basin. Loadings from the South Beach tailings are at a mature stage of oxidation and acid generation and are expected to continue until mitigation by constructing a cover over the above-water area at closure. However, the freshly deposited tailings above water will begin to generate acid and to become a source of metal loadings after a period of exposure above water. Because the loadings to the basin are a function of the total area of exposed and acid generating tailings, there is a need to understand the potential effects of the ongoing deposition and exposure of tailings in Area 4 to the lime demand in the basin to control pH and nickel concentrations.

Previous studies (EcoMetrix, 2012a) suggested that the time for exposure of exposed tailings was about four years to the onset of acid generation. The temporary exposure or beaching of tailings prior to final flooding requires consideration to avoid excessive acid and nickel loadings to the basin that could lead to elevated nickel concentrations at the Weir prior to a water level raise and potentially during a raise event.

3.0 FIELD SAMPLING AND LABORATORY TESTING

The following sections describe the methods used to complete the tailings sampling program and the short-term leaching tests.

3.1 Field Sampling

3.1.1 Sampling Locations

A total of 42 surficial tailings samples and 7 submerged tailings core samples were collected from the basin. The approximate locations of each sampling station are illustrated on **Figure 3.1** and **Figure 3.2**.

Abandoned Tailings

Tailings were deposited in the Abandoned Tailings area during the 1970s and represent an area of historical tailings deposition (Klohn-Crippen, 1994).

Three sampling stations (AT-01, AT-02 and AT-03) were located within the Abandoned tailings area (**Figure 3.1**). Location AT-01 represents a sampling station that had been previously flooded during the water level raise in 2013, but was exposed during the time of sample collection. Locations AT-02 and AT-03 represent tailings from areas that will remain exposed upon flooding of Areas 1 and 3 to 674 ft asl.

In addition to the collection of these surficial tailings samples, a core of submerged tailings was also collected from location AT-C01. Tailings from this core represent previously exposed tailings that were flooded during the 2013 water level raise in Areas 1 to 3. The submerged tailings samples were intended to provide information on the potential release of acidity and metals from the porewater near the surface of the tailings during and after the flooding event.

Emergency Tailings

Two sampling stations (ET-01 to ET-C01) were located within the Emergency tailings in area (**Figure 3.1**). Station ET-01 was located within an area that will remain exposed upon flooding, while station ET-C01 represents a tailings core from an area of submerged tailings. These tailings were deposited in the 1980s and represent an area of historical tailings deposition (Klohn-Crippen, 1994).

South Beach Tailings

Two sampling stations (SB-C01 and SB-01) were located within the South Beach tailings area (**Figure 3.1**). Station SB-01 was located within an area that will remain exposed upon flooding, while station SB-C01 represents a tailings core from an area of submerged tailings. These tailings were placed between approximately 1970 and 1992 and represent a variety of depositional ages (EcoMetrix and AMEC, 2006).

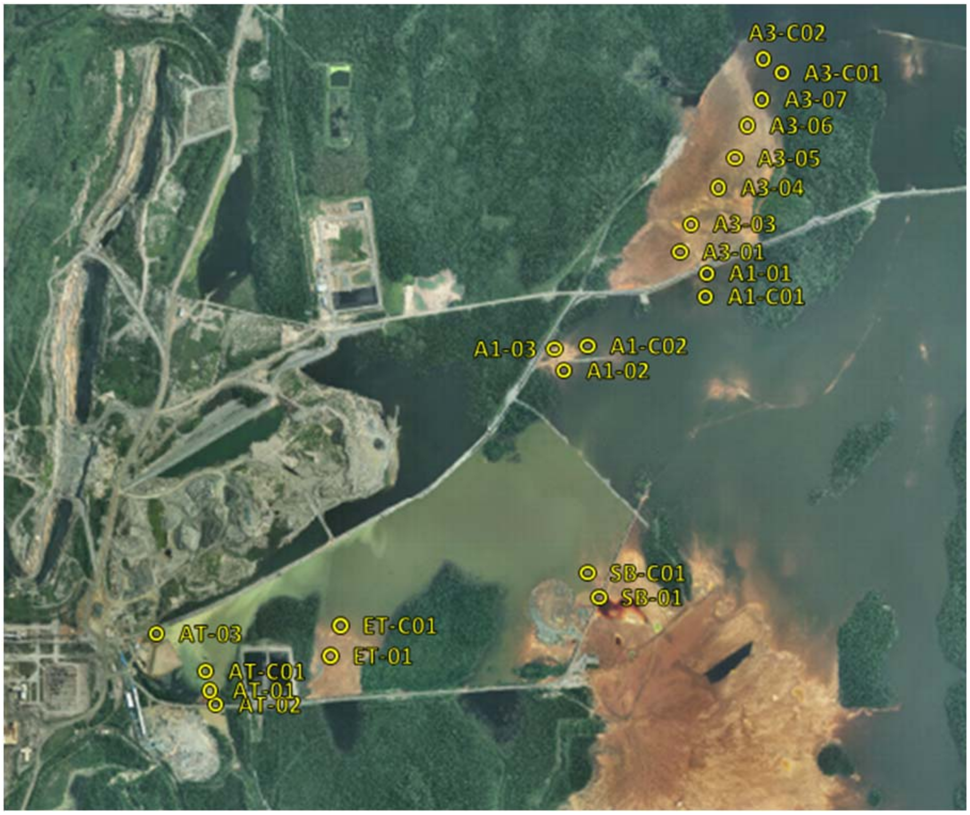
Area 1

Five sampling stations (A1-01, A1-02, A1-03, A1-C01 and A1-C02) were located within Area 1 (**Figure 3.1**). Locations A1-01 to A1-03 represents tailings from areas that had been previously submerged during the flooding of Areas 1 to 3, but were exposed at the time of sample collection. Locations A1-C01 and A1-C02 represent submerged tailings cores that had been exposed prior to flooding. These tailings were deposited between 1960 and 1993 and represent a variety of depositional ages (Sherriff et al., 2004).

Area 3

Seven surficial tailings samples (A3-01 to A3-07) and 2 underwater tailings core samples (A3-C01 and A3-C02) were collected from Area 3 (**Figure 3.1**). Sample locations A3-01 to A3-07 represent a transect of exposed tailings that had been previously flooded during the 2013 water level raise, but were exposed at the time of sampling. Location A3-02 represents an area of tailings that will remain exposed once the water level raise is complete and is located near the southwest perimeter of the basin.

Figure 3.1: Approximate Locations of Sample Stations in Areas 1 to 3

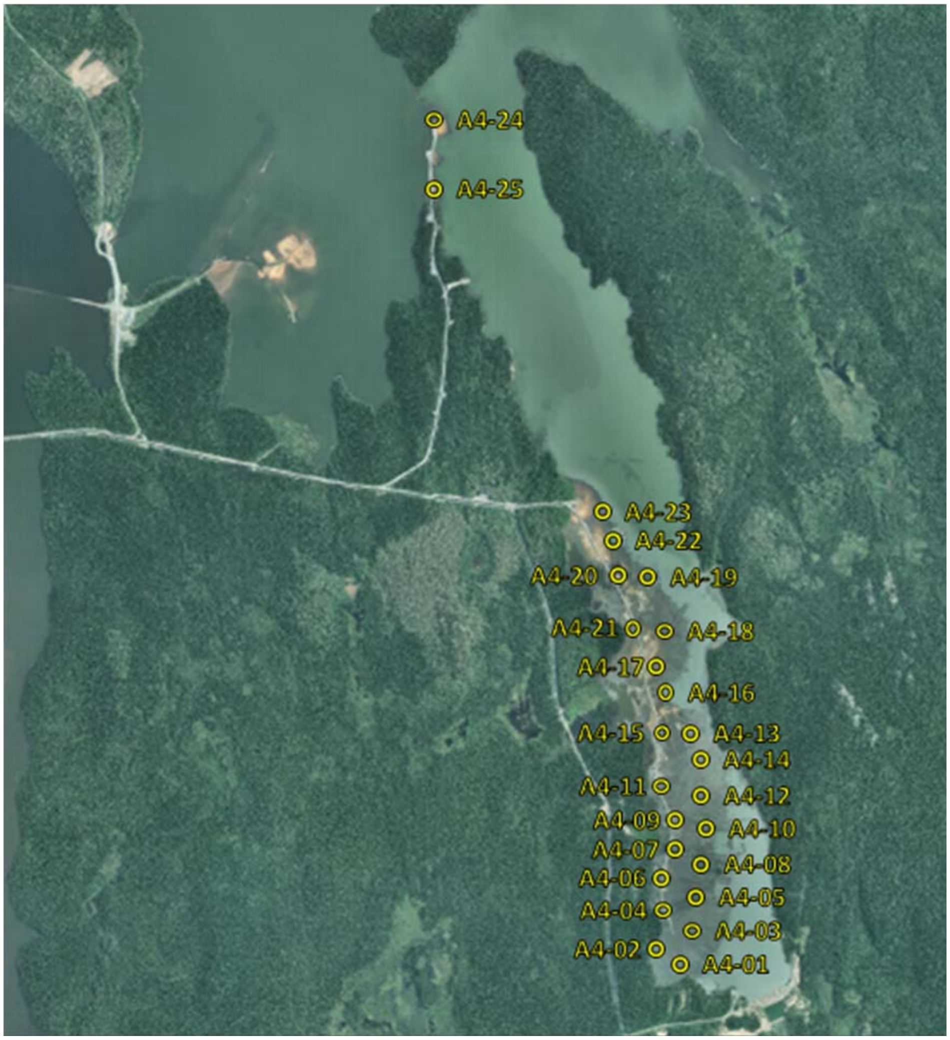


Area 4

Twenty-five sampling stations (A4-01 to A4-25) were located within the Area 4 tailings. Stations A4-01 to A4-23 were located within the southern arm of the tailings, representing tailings that were deposited during the period 2011 to 2014 (**Figure 3.2**). Samples were collected along a south-north transect of tailings, at intervals of approximately 150 m in length, corresponding with historical end of pipe discharge within the arm.

Tailings present in the northern portion of Area 4 were deposited over the period 2010 and 2011 (**Figure 3.2**). Two sampling stations, A4-24 and A4-25, were located in the northern portion of Area 4 and were exposed at the time of sampling.

Figure 3.2: Approximate Locations of Sample Stations in Area 4



3.1.2 Sample Collection Methods

Shallow sampling of the tailings was completed to assess the metal loadings from the tailings to the basin. Shallow samples provide an indication of the soluble acid and metal loads that can be readily flushed from the tailings during rainfall events and also potentially during flooding. Experience at other sites has shown that the top 10 to 20 cm typically represents the majority of the “flushable” soluble load that can be released to surface water during rainfall events (EcoMetrix, 2012a). Therefore, samples were collected with a hand auger at depths from 0-10 cm and 10-20 cm.

In addition, core samples were collected from selected areas within the basin to assess the behaviour of soluble loadings during the water level raise in Areas 1 to 3 from 669 to 673 ft asl.

Core samples were collected using a 2 inch (5 cm) diameter KB-Coring tube. At each location a total of two cores were collected to achieve sufficient sample volume for porewater extraction from the tailings. The cores were sectioned into increments of 0 to 5 cm, 5 to 10 cm, 10 to 20 cm and 20 to 25 cm. The intervals from each sampling location were composited, placed into dedicated Ziploc bags and stored at 4°C until further analysis.

The physical characteristics of the sampling location and the tailings samples were noted at the time of sample collection. Chemical characteristics including rinse pH and conductivity measurements were also determined at the time of sample collection. Samples were then shipped to the EcoMetrix Laboratory in Mississauga, ON for further processing.

3.2 Laboratory Testing Methods

Short-term porewater extraction (PWE) tests using distilled water were completed on the tailings samples. The tests were completed to evaluate the effects of dissolution of soluble metals and to estimate the potential inventories available for release to the tailings basin through porewater flushing and surface runoff.

The leach tests used a 1:3 water:solids ratio with distilled water (approximately 100 mL water to 300 g of equivalent dry tailings). This ratio was used to minimize the dilution and potential dissolution of solids during the extraction of the porewater. The samples were shaken for approximately 1 minute prior to sampling of the leachate. After shaking, leachate samples were filtered (0.45 µm) and pH and conductivity were measured. Samples were subsequently acidified with HNO_3 prior to submission to ALS Waterloo for analysis. The leaching test methods were generally consistent with those described in the *Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia* (Price, 1997) and the *Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials* (Price, 2009).

3.3 FIELD PROGRAM RESULTS

Leachate water from the PWE tests was analyzed for dissolved metals and acidity. The sulphate concentrations were calculated from the results of the sulphur analysis in the ICP scan. The results were used to estimate the inventories of soluble metals and acidity in the tailings. Results for all parameters are summarized in Attachment 1 and are presented for both the original leachate chemistry (mg/L) and as soluble concentrations (mg/kg). The original leachate chemistry (mg/L) was converted to mg/kg of dry tailings using the sample mass and measured moisture contents.

3.3.1 Surficial Tailings Samples

3.3.1.1 Area 1, Abandoned, Emergency and South Beach

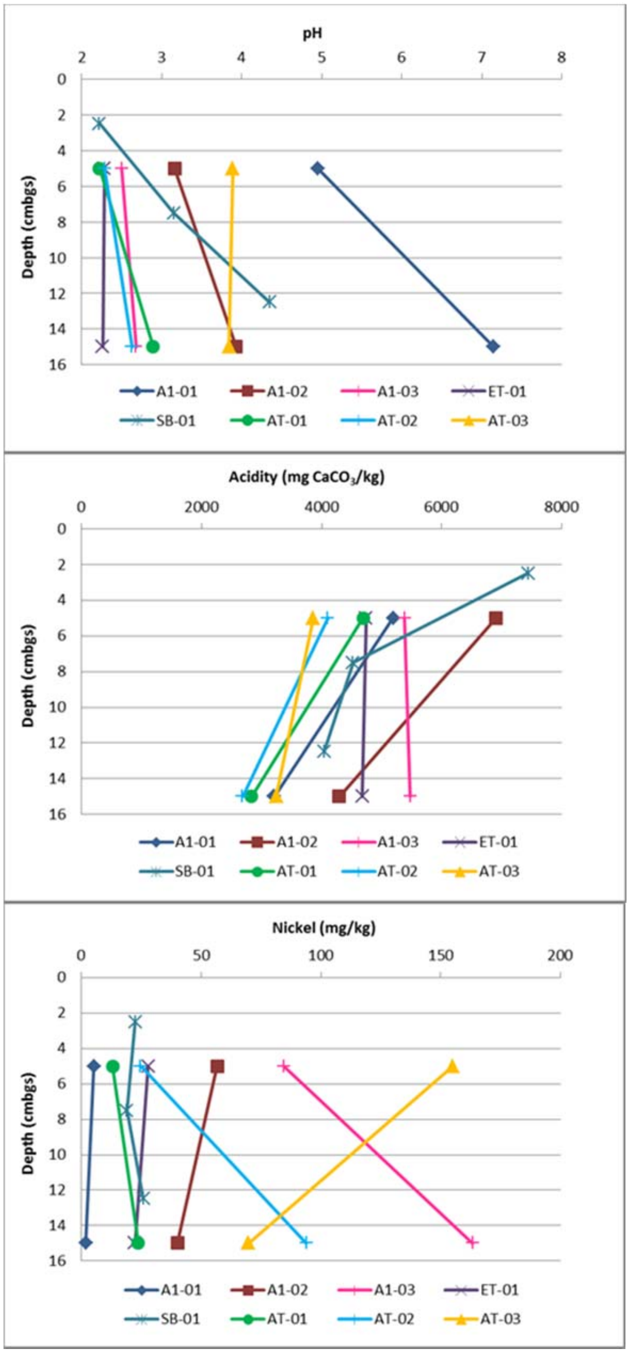
Depth profiles for pH values, as well as acidity and nickel concentrations in the tailings porewater are shown in **Figure 3.3** for the surficial tailings samples. Tailings samples were collected at depths from 0-10 cm and 10-20 cm, represented by the median depth interval in **Figure 3.3**. The results for other selected constituents were also compiled and are summarized in Attachment 2.

The pH values of the tailings porewater ranged between values of 2 to 7, with the lowest values measured in the Emergency and South Beach tailings and the highest values measured in Area 1 (**Figure 3.3**). Tailings from Area 1 exhibited variable pH values, ranging from 3 to 5 at the surface and from 4 to 7 in the deeper samples. Samples collected from A1-01 had been submerged during the water level raise in Areas 1 to 3 from 669 to 673 ft asl, and were saturated at the time of sampling. The higher pH values associated with these samples suggested that some of the soluble acidity had been rinsed from the samples during the flooding and draining events compared to the lower pH values observed in the exposed samples from A1-02.

Acidity concentrations in the porewater were relatively similar between areas, with values ranging between 3,900 and 7,400 mg CaCO3/kg at surface, and between 2,700 and 5,500 mg CaCO3/kg in the deeper samples (Figure 4.1). Concentrations of soluble acidity were generally higher at surface and lower in the deeper samples.

Nickel concentrations in the porewater ranged from values of 5 mg/kg in tailings from A1-01 to as high as 155 mg/kg in tailings from the AT-03 (Figure 4.1).

Figure 3.3: Summary of pH, Acidity and Nickel Concentrations with Depth in the Tailings Porewater from Area 1



The lowest nickel concentrations, on the order of 20 mg/kg, were associated with samples A1-01, AT-01, SB-01 and ET-01, that had been flooded during the initial water level raise in Areas 1 to 3 from 669 to 673 ft asl and then re-exposed when water levels declined again in 2014 to 672 ft asl.

Concentrations of nickel on the order of 100 mg/kg were observed in the porewater from exposed tailings that will remain above 674 ft. The much lower values observed in the surficial tailings from stations A1-02, A1-03 and AT-03 and suggest that rinsing of shallow tailings porewater had occurred during the water level raise from 669 to 673 ft asl and the subsequent flooding of Areas 1 to 3.

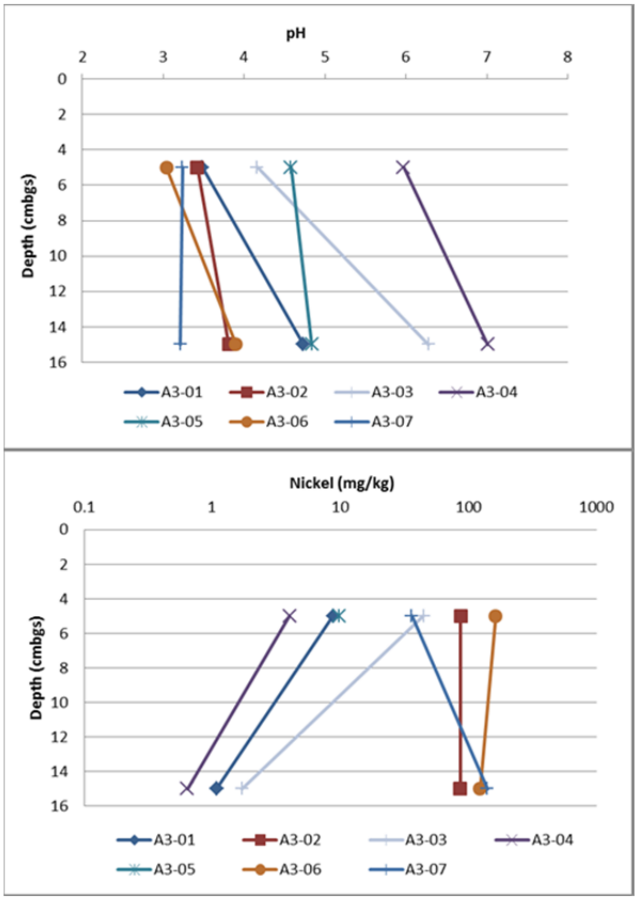
3.3.1.2 Area 3

Depth profiles for pH and nickel concentrations in the tailings porewater are shown in **Figure 3.4** for the surficial tailings samples. Tailings samples were collected at depths of 0-10 cm and 10-20 cm, represented by the median depth interval in **Figure 3.4.** The results for the submerged tailings, as collected from the core samples are presented in **Section 4.2**. The results for other selected constituents were also compiled and are summarized in **Attachment 2**.

The pH values of the tailings porewater from Area 3 were variable, ranging from values of 2.8 to 7 (**Figure 3.4**). The pH values were generally lower at the surface of the tailings and higher in the deeper samples. No clear trends were observed for pH values along the exposed tailings transect, A3-03 to A3-07 that had been flooded during the initial water level raise from 669 to 673 ft asl

Nickel concentrations in the porewater exhibited values ranging from 4 mg/kg to 160 mg/kg (**Figure 3.4**). The elevated nickel concentrations in the porewater from the surface of the tailings were noted to reflect the lower pH values observed in the shallower samples.

Figure 3.4: Summary of pH Values and Nickel Concentrations in Porewater from the Area 3 Tailings



3.3.2 South Arm of Area 4

Depth profiles for pH, acidity and nickel concentrations in the tailings porewater from the South Arm of Area 4 are shown in **Figure 3.5** for the surficial tailings samples. Tailings samples were collected at depths of 0-10 cm and 10-20 cm, represented by the median depth interval in **Figure 3.5.**

In general, the results of the short term leach tests indicate that for most locations in the South Arm, soluble metal concentrations are similar in the 0-10 and 10-20 cm intervals (**Figure 3.5**).

The pH values of the tailings porewater from Area 4 were highly variable, with values ranging from 3 to 8.5 (**Figure 3.5**). Rinse pH values were slightly higher in the 10-20 cm depth intervals, but generally follow a similar trend to those for the 0-10 cm depth intervals.

A trend of decreased rinse pH was noted with increased time since deposition, within the northernmost section of the South Arm.

Acidity concentrations in the porewater were highly variable, with values ranging between 20 and almost 700 mg CaCO3/kg at surface, and between 10 and almost 800 mg CaCO3/kg in the deeper samples (**Figure 3.5**). Concentrations of acidity were generally higher at surface and lower in the deeper samples, although some reversal of this was observed at some locations.

Nickel concentrations in the porewater exhibited a wide range in values, with values of 0.001 mg/kg in the most recently deposited tailings nearest to Dam B and reaching 300 mg/kg in oldest tailings from the northernmost sections of the South Arm (**Figure 3.5**). A trend of increased nickel concentrations in the porewater was noted with decreased rinse pH values. The evolution of nickel concentrations with time since deposition in the South Arm is discussed in the following sections.

3.4 Tailings Cores

Depth profiles of acidity and nickel concentrations in the porewater from the tailings cores are shown in **Figure 3.6**. Core samples were collected from selected areas within the basin to assess the behaviour of soluble loadings during the water level raise in Areas 1 to 3 from 669 ft to 673 ft. The cores were sectioned into increments of 0 to 5 cm, 5 to 10 cm, 10 to 20 cm and 20 to 25 cm. and are represented by the median interval on all figures.

Acidity concentrations in the tailings porewater exhibited values on the order of 200 mg $CaCO_3$/kg at the tailings surface and relative maximum values on the order of 1,500 mg $CaCO_3$/kg at depths of 10 to 15 cm below the surface of the tailings. At depths greater than 15 cm, acidity concentrations were observed to decrease, with values on the order of 200 mg $CaCO_3$/kg.

Nickel concentrations in the tailings porewater exhibited similar trends with depth to that of acidity. Peak concentrations were associated with depths between 10 and 15 cm below the surface of the tailings, with lower concentrations above and below these depths.

Figure 3.5: Summary of pH Values, Acidity and Nickel Concentrations in the Tailings Porewater from the South Arm of Area 4

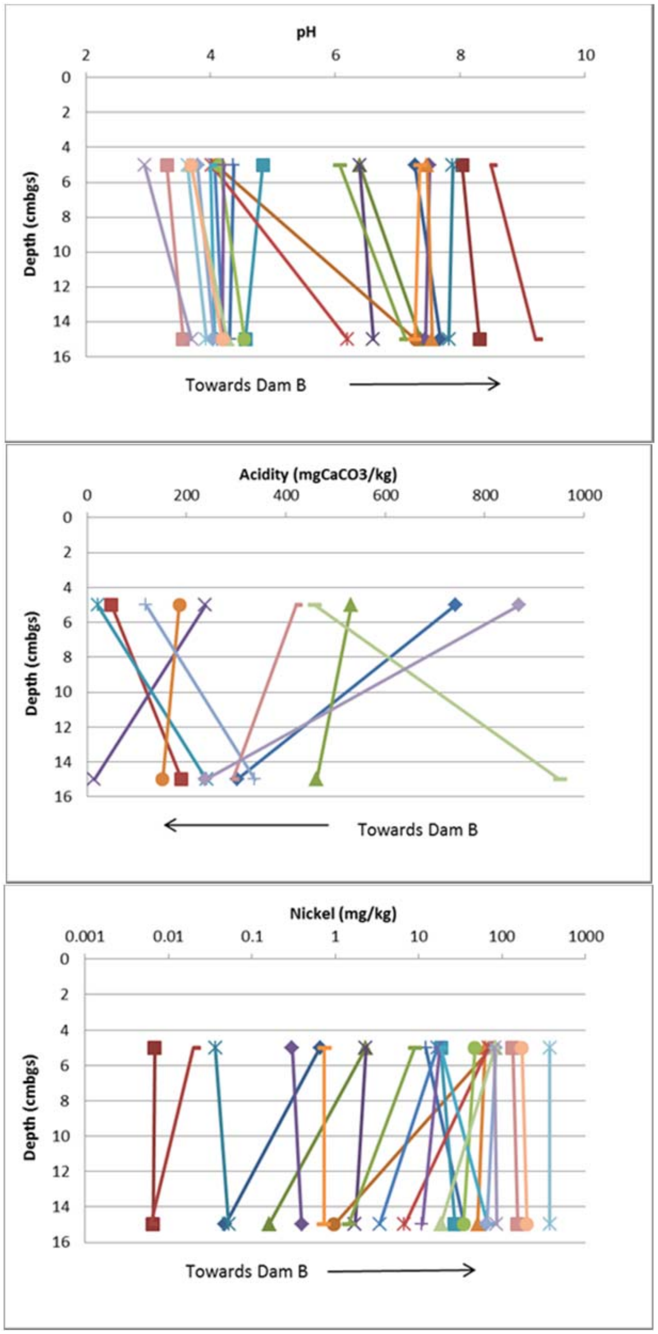
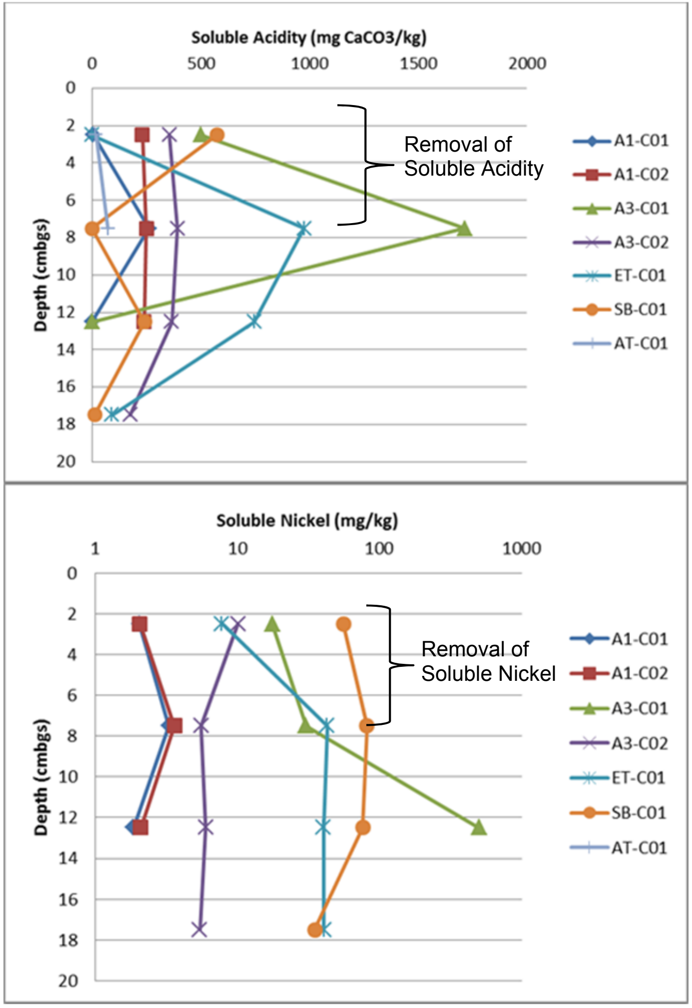


Figure 3.6: Acidity and Nickel Concentrations in the Tailings Porewater from Areas 1 to 3 with Depth in the Core Samples



The depth profiles within the tailings cores indicate that removal of soluble constituents from the porewater had occurred within the uppermost 5 cm of tailings. Tailings cores were collected from recently flooded areas and suggest that the decreases in concentrations in the near surface was the result of flushing of soluble mass during the water level raise event. On average, a difference of approximately 50% in soluble mass was observed between the 0- 5 cm and 5-10 cm depths. These results were used in the development of mass loadings for the submerged tailings as described in further detail in **Section 5.2**.

3.5 Effect of Exposure Time on Porewater

Tailings were deposited in the South Arm of Area 4 beginning in 2010, to a planned elevation of 674 ft-asl or about 5 ft above the water level. The area of exposed above-water tailings grew as the end of pipe was moved in a southerly direction, along the western side of the South Arm. In September of 2014, the tailings spigot was located within the southeastern corner of the Arm, a few hundred metres from Dam B. It is understood that once the tailings reach the southernmost edge of the Arm at Dam B, tailings will then be deposited in a northerly direction, along the eastern side of the Arm. It was estimated that tailings will completely fill the South Arm in 2017, according to the latest survey information and the Tailings Basin Management Plan (AMEC, 2013).

Tailings samples were collected at various locations within the Arm, representing different deposition dates, as determined by the approximate spigot locations and dates provided by Vale. The evolution of pH, acidity and nickel concentrations in the tailings porewater over time is discussed in the following sections.

A summary of rinse pH values exhibited by the tailings porewater is presented in **Figure 3.7**, in relation to the approximate date of deposition. A similar plot is provided in **Figure 3.8**, illustrating the decrease in rinse pH values with increasing exposure time in the South Arm.

The pH of the tailings porewater was observed to decrease with tailings age, with pH values around 8.5 for the more recently deposited tailings and decreasing to values between 3 and 5 in the oldest tailings in the South Arm. These results suggest that the onset of acidic conditions occurred within 2 years of deposition within the basin. An apparent steady-state pH value of 3.5 was observed after 2 years of exposure that is shown to approach the average pH value in the South Beach Tailings porewater (EcoMetrix, 2012a) represented by the dashed line in **Figure 3.7**. The South Beach represents a mature tailings condition, with tailings deposition over the period 1970 and 1993.

These results suggest that the onset of acidic conditions occurs about 2 years earlier than the previous estimate of 4 years given in the EcoMetrix (2012a) report. Higher resolution sampling in the South Arm of Area 4, including freshly deposited tailings, allowed for better estimates of acidity generation as part of this assessment.

Figure 3.7: pH values in the Tailings Porewater from the South Arm of Area 4 according to Relative Deposition Date

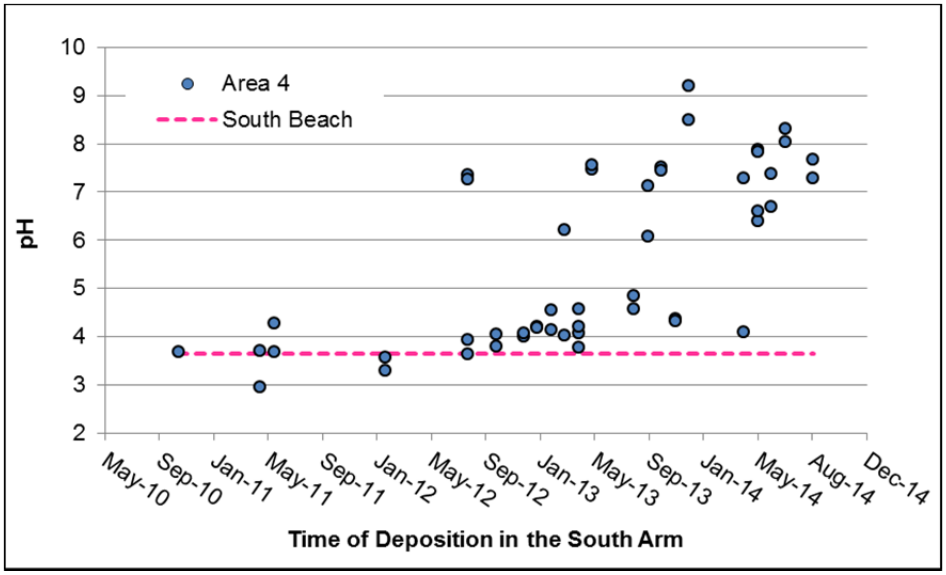
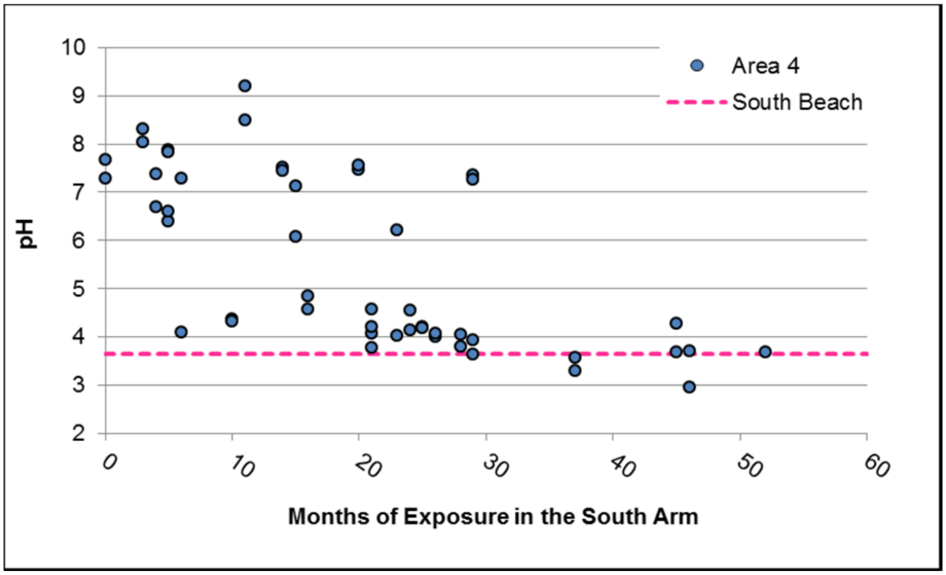


Figure 3.8: pH values in the Tailings Porewater from the South Arm of Area 4 according to Months of Exposure



An increase in soluble acidity values exhibited by the tailings porewater was observed with tailings age, as illustrated in **Figure 3.9**. Soluble acidity values in fresh tailings were on the order of 1 mg $CaCO_3$/kg, increasing to a maximum value of 800 mg $CaCO_3$/kg in the oldest tailings samples. Soluble acidity values are shown to approach those exhibited by the South Beach Tailings of 2,300 mg $CaCO_3$/kg. However, these results suggest that soluble acidity load in the surface tailings from the South Arm may continue to evolve with time to conditions similar to those at the South Beach that have been exposed for decades and are assumed to be at steady state with respect to soluble loads.

Nickel concentrations in the tailings porewater exhibited an inverse trend to that of pH, with the lowest values observed in the fresh tailings and the highest values in the oldest tailings (**Figure 3.10**). Nickel concentrations in the tailings porewater were on the order of 0.01 mg/kg in the fresh tailings samples and increased to values of 70 mg/kg in the oldest tailings. The oldest tailings exhibited nickel concentrations that approach those of the South Beach and indicate that concentrations may still evolve over time as the tailings continue to produce acidity during maturation.

Figure 3.9: Acidity Concentrations in Tailings Porewater in the South Arm of Area 4 according to Relative Deposition Date and Months of Exposure

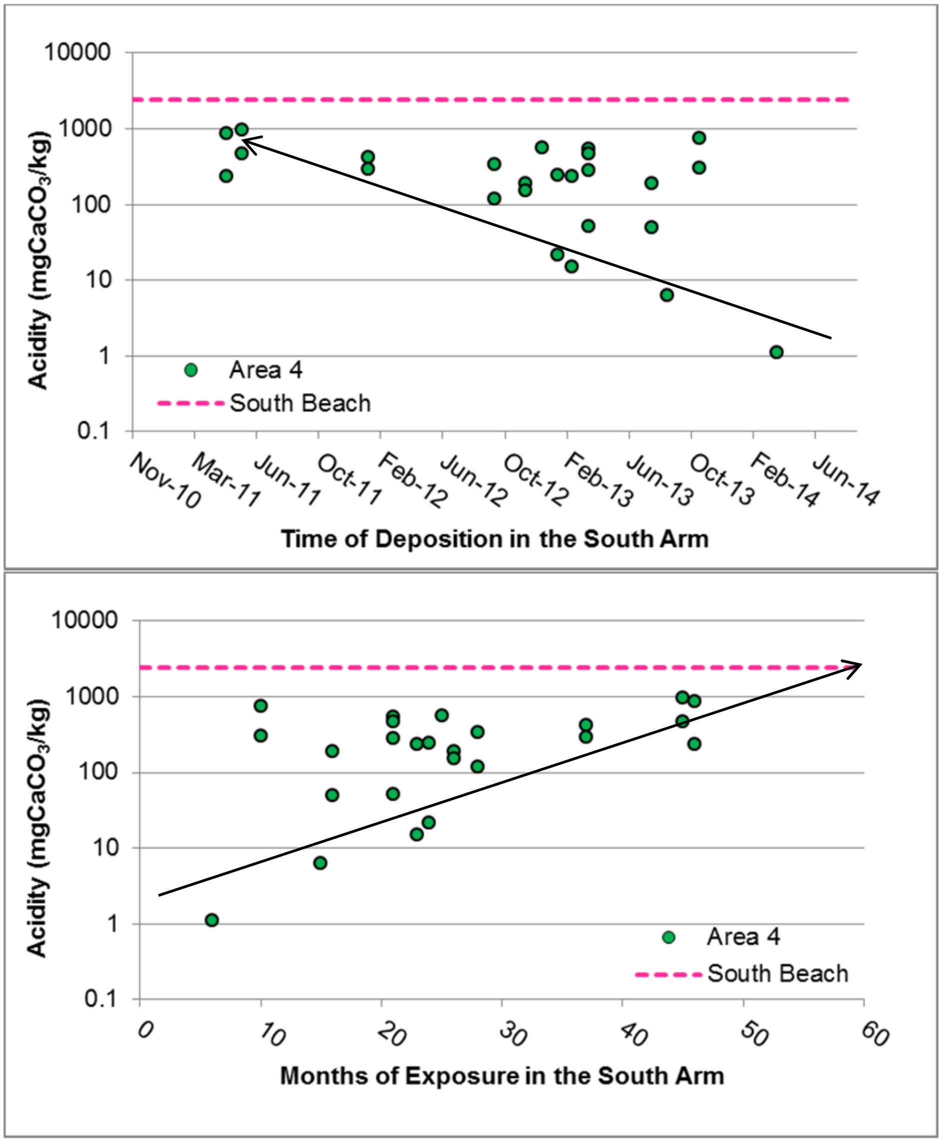
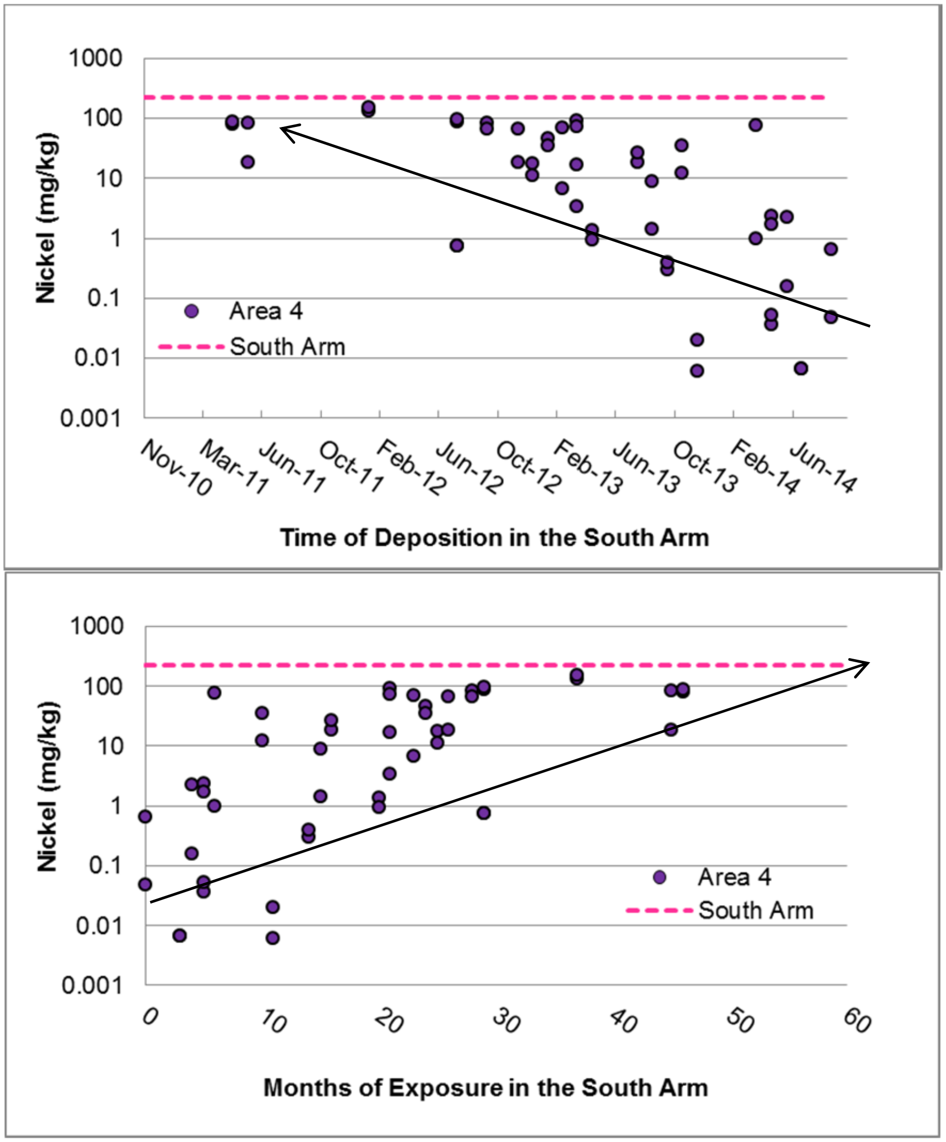


Figure 3.10: Nickel Concentrations in the Tailings Porewater in the South Arm of Area 4 according to Relative Deposition Date and Months of Exposure



4.0 ESTIMATION OF LOADINGS FROM THE TAILINGS

Loadings were estimated for the exposed tailings that will remain above a water level of 674ft, as well as for tailings that will be submerged following the water level raise to 674ft. The estimate loading rates presented in the following sections were applied in development of a lime demand model, described in **Section 5.0**. Modelling exercises were completed to evaluate the lime demand required for the tailings basin that would maintain compliance at the Weir (**Section 5.0**).

Loadings associated with the waste rock stockpile have been previously estimated by EcoMetrix (2007). Waste rock loading rates were estimated to be approximately 10% of those from the exposed tailings within the South Beach and did not represent an important source of annual loadings to the basin. The waste rock loadings were also estimated at a time when the stockpile was at a maximum capacity and therefore represented maximum potential loading rates. It is understood that waste rock is being removed from the stockpile location for use as backfill, at the time of this report. As a result, the waste rock inventory is quite small compared to that in the past and therefore was not included as a source term in this assessment.

4.1 Surficial Tailings

4.1.1 Conceptual Loadings Model

Sulphide tailings oxidize from the surface to relatively shallow depths and the rate of oxidation depends predominantly on the sulphide content and the moisture retaining characteristics of the tailings. Evaporation and warmer surface temperature during the summer months promotes lower water contents and increased oxidation rates within the upper few centimeters of the tailings and results in an accumulation of soluble oxidation products. The soluble metals and acidity that are produced during oxidation reside in the tailings porewater and can migrate to the environment via different pathways. Due to the low hydraulic conductivity of mine tailings, runoff is generally a major component of the water balance during heavier precipitation events because there is insufficient time to infiltrate to the groundwater table that is found within the tailings. During rainfall events on uncovered tailings, experience has shown that the greatest contribution to loadings from reactive bare or uncovered tailings is commonly associated with the rinsing or flushing of shallow tailings porewaters during rainfall events. This phenomenon has been observed at other tailings facilities that exhibit acid generation and metal leaching behaviour (Nicholson et al, 2000).

Other pathways, such as groundwater flow, through and out of the tailings, generally represent much smaller contributions to the total loadings of dissolved constituents from tailings. Although migration of tailings porewater through infiltration and groundwater pathways can and does occur, the loads associated with groundwater transport are generally lower than those associated with shallow flushing from uncovered tailings because the flow rates through tailings are relatively low and the source of soluble oxidation products is the shallow tailings porewater that gets flushed and removed to runoff regularly by rainfall during the non-frozen period.

In climate conditions like central to northern Manitoba, the most important period for flushing is expected to occur during the autumn rains when moisture levels in the tailings are higher and soluble oxidation products have accumulated during the preceding warmer summer months when the most significant degree of oxidation typically occurs. Therefore, metal loadings from tailings, via the groundwater pathway, are expected to be substantially smaller than those for the runoff pathway during shallow porewater flushing. It can be concluded that the loadings from tailings are dominated by the shallow flooding and therefore, the area of exposed and acid generating tailings is a key variable in the estimation of loadings to the tailings basin.

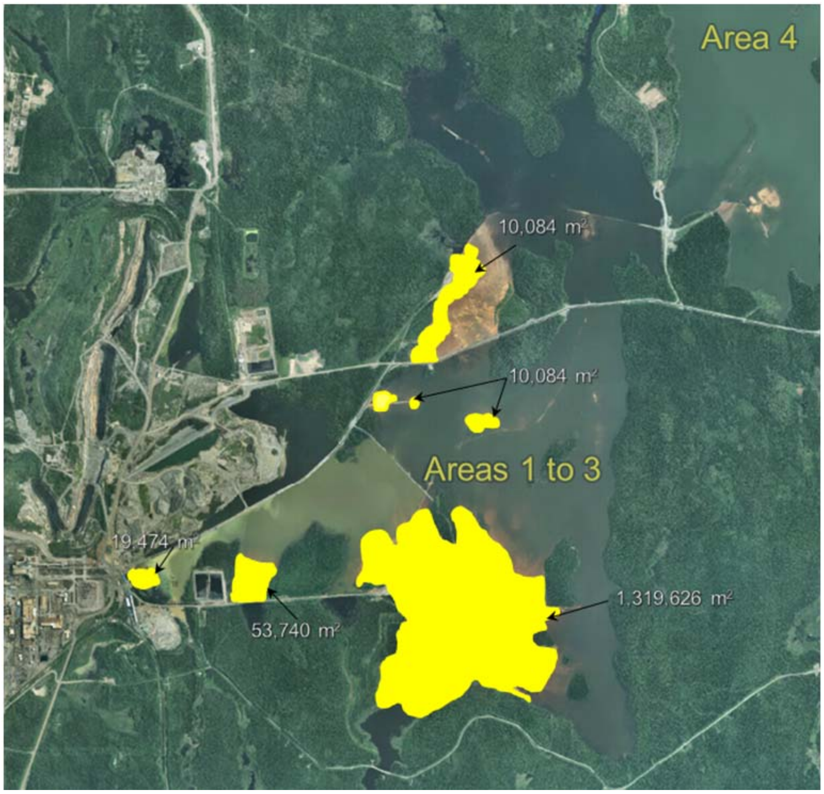
4.1.2 Estimated Loading Rates for Exposed Tailings

The area of tailings that will remain exposed in Areas 1 to 3 once a final water level of 674 ft is established, are presented in **Table 4.1** and are illustrated by the areas that are shaded red in **Figure 4.1**.

Table 4-1: Summary of Tailings Areas that will Remain Exposed Above an Elevation of 674 ft upon Flooding of Areas 1 to 3 (Provided by AMEC)

Tailings	Exposed Tailings Area at 674 ft asl	
	m2	ft2
South Beach	1,319,626	14,204,341
Abandoned	19,474	209,621
Emergency	53,740	578,450
Area 1	10,084	108,548
Area 3	56,009	602,877
Total	**1,458,934**	**15,703,837**

Figure 4.1: Tailings Areas that will Remain Exposed to an Elevation of 674 ft upon Flooding in Areas 1 to 3 (Illustrated by Yellow Shading) (Modified from AMEC)

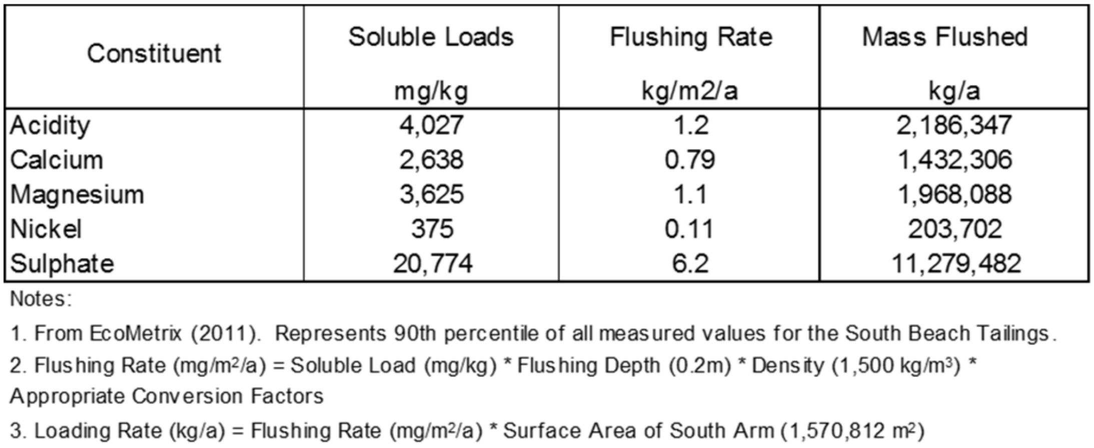


The results of the short term leaching tests on samples from the South Beach, Abandoned and Emergency tailings areas were used to calculate the potential loadings from the ongoing flushing of shallow porewater from the exposed tailings areas after the water level raise in Areas 1 to 3 (**Table 4.2**). Short term leach test results from the South Beach tailings were assumed to be representative of a mature tailings condition. Soluble loads from the South Beach tailings were used to derive loading rates for the exposed tailings in Areas 1 to 3 and the South Arm of Area 4. The calculations assume an average tailings density of 1,500 kg/m^3 and a flushing depth of 20 cm.

The 90th percentile values for South Beach soluble loads were used in the calculation of loading rates and represent a conservative assumption (**Table 4.3**). The calculation of maximum loadings from the South Arm assumed that the entire arm had exposed tailings at the same stage of oxidation maturity as those of the South Beach in order to compare the magnitude of maximum potential loadings in the basin. The loadings associated with exposed tailings in Area 4 in **Table 4.3** were calculated using the entire surface area of the South Arm of 849,871 m^2.

The estimated acidity and nickel loadings from the exposed tailings in Areas 1 to 3 are about 2000 t-CaCO$_3$/a and 200 t-Ni/a, respectively. The total annual lime demand from both areas is about 2300 t-CaO/a or about 6.4 t-CaO/day, 365 days/a.

Table 4-2: Summary of On-going Runoff Loadings from Areas 1 to 3

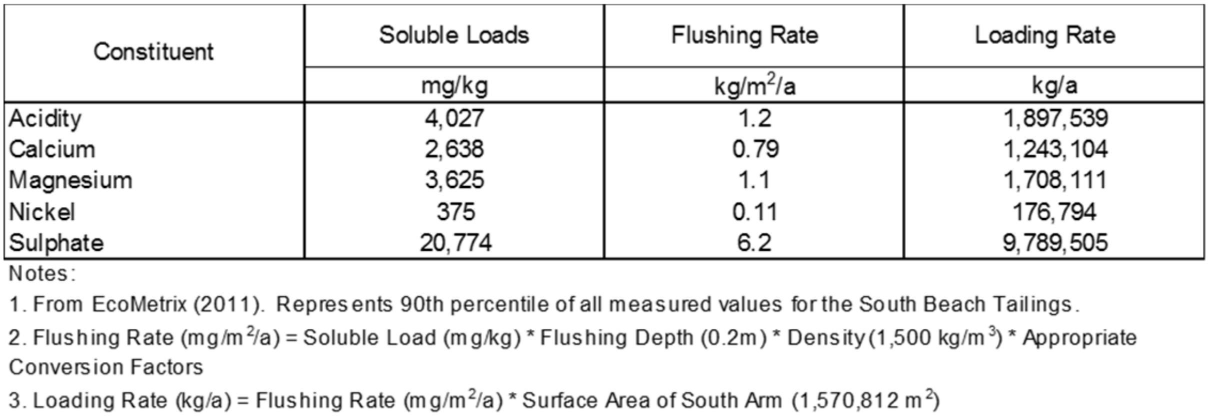


Constituent	Soluble Loads mg/kg	Flushing Rate kg/m2/a	Mass Flushed kg/a
Acidity	4,027	1.2	2,186,347
Calcium	2,638	0.79	1,432,306
Magnesium	3,625	1.1	1,968,088
Nickel	375	0.11	203,702
Sulphate	20,774	6.2	11,279,482

Notes:

1. From EcoMetrix (2011). Represents 90th percentile of all measured values for the South Beach Tailings.
2. Flushing Rate (mg/m^2/a) = Soluble Load (mg/kg) * Flushing Depth (0.2m) * Density (1,500 kg/m^3) * Appropriate Conversion Factors
3. Loading Rate (kg/a) = Flushing Rate (mg/m^2/a) * Surface Area of South Arm (1,570,812 m^2)

Table 4-3: Summary of On-going Runoff Loadings from the South Arm of Area 4



Constituent	Soluble Loads	Flushing Rate	Loading Rate
	mg/kg	kg/m^2/a	kg/a
Acidity	4,027	1.2	1,897,539
Calcium	2,638	0.79	1,243,104
Magnesium	3,625	1.1	1,708,111
Nickel	375	0.11	176,794
Sulphate	20,774	6.2	9,789,505

Notes:

1. From EcoMetrix (2011). Represents 90th percentile of all measured values for the South Beach Tailings.
2. Flushing Rate (mg/m^2/a) = Soluble Load (mg/kg) * Flushing Depth (0.2m) * Density (1,500 kg/m^3) * Appropriate Conversion Factors
3. Loading Rate (kg/a) = Flushing Rate (mg/m^2/a) * Surface Area of South Arm (1,570,812 m^2)

4.2 Submerged Tailings

4.2.1 Conceptual Loadings Model

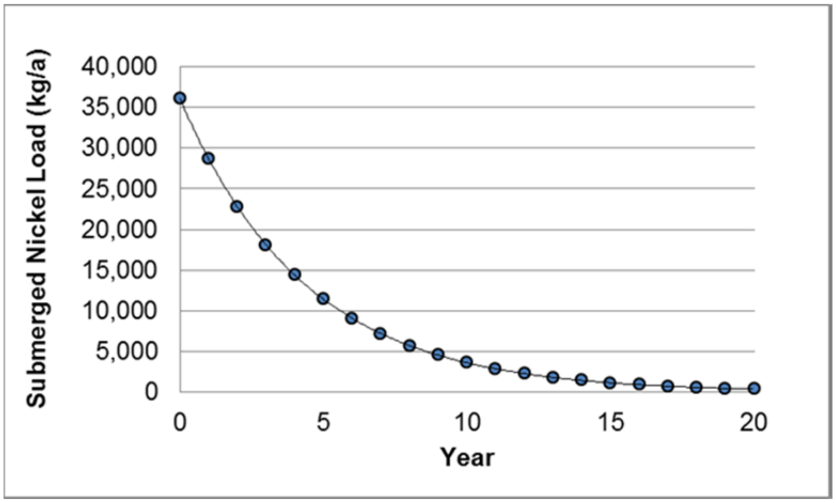
At closure, the transfer of constituents from the submerged tailings to the overlying water column will be primarily driven by two mechanisms, the initial flushing of soluble oxidation products from the surficial tailings followed by diffusion of porewater to the overlying water column over an indefinite period.

When the tailings flood, some oxidation products present in the near-surface porewater will be released by an “initial flush”, resulting from agitation and wave movement during the water level raise. This flushing is expected to diminish after flooding is complete and mechanical and hydraulic agitation ceases. The concentrations in the porewater of the flooded tailings are expected to exceed the concentrations in the overlying water. The differences in concentrations between the porewater and overlying water represents the concentration gradient that is the driving force that controls the upward transport of acidity and other dissolved constituents by diffusion from the flooded tailings to the overlying water in the basin.

Following the flooding of tailings underwater, the concentration gradient between the porewater and overlying water will be the highest. As a result, the highest loadings are expected immediately following a water level raise and the cessation of mechanical flushing. Over time, the concentration gradient between the porewater and overlying water will decrease as a result of the loss of dissolved mass from the porewater as well as the accumulation of organic and inorganic matter on the surface of the submerged tailings that will reduce the diffusive flux from the tailings.

Previous experience with the modelling of constituent transport from submerged mine materials, has shown that the diffusive flux can decrease by approximately 99%, over a period of 20 years. An exponential decrease in the estimated loading rate for nickel from submerged tailings in Areas 1 to 3, is illustrated in **Figure 4.2**, for a period of 20 years after initial flooding. This decline of 99% over 20 years in the diffusive transport from the porewater of the flooded tailings to the overlying water was applied in the model for the estimated loadings.

Figure 4.2: Decrease in Nickel Loadings from Submerged Tailings to the Basin over a Period of 20 years



4.2.2 Estimated Loading Rates for Submerged Tailings

Average values from the short term leach tests completed for the core samples, were used to estimate the porewater concentrations present in the submerged tailings from Areas 1 to 3 (**Table 4.4**). A moisture content of 0.2 L/kg of dry tailings was used for these calculations to represent the saturated underwater tailings, representing a volumetric water content of 0.3 L-water/L-tailings.

Table 4-4: Summary of Average Soluble Mass and Porewater Concentration for the Tailings Cores collected from Area 1 to 3

Constituent	Soluble Mass from Core[1]	Porewater[2]
	mg/kg	mg/L
Acidity	671	3,353
Calcium	271	1,354
Magnesium	553	2,767
Nickel	33	164
Sulphate	6,100	30,502

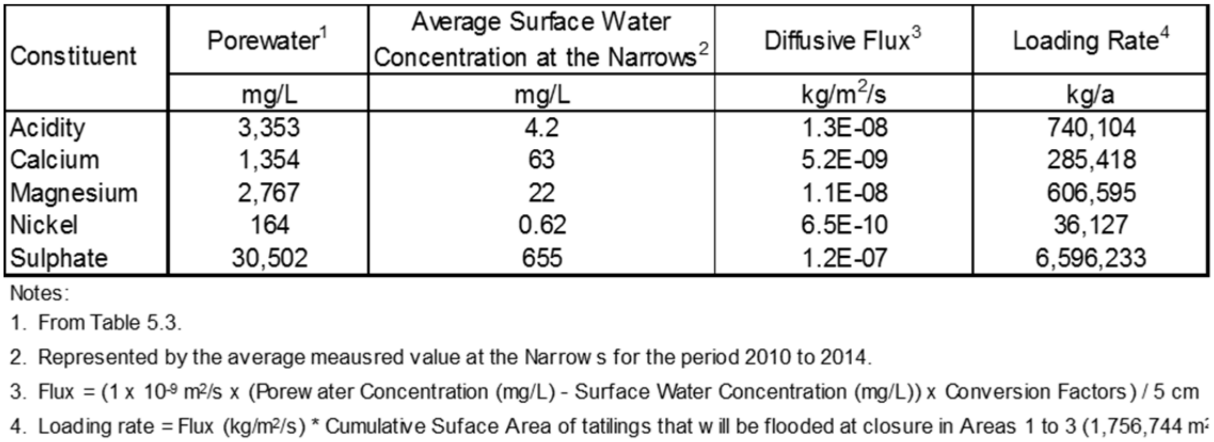
Notes:
1. Represents the average soluble mass in the uppermost 5 to 10 cm of the tailings cores.
2. Estimated using the soluble mass and an average measured moisture content of 0.2 L/kg.

The calculation of the diffusive flux from the porewater to the overlying water column assumed that overlying water will initially have constituent concentrations that are represented by the average measured value at the Narrows (**Table 4.5**). The diffusion coefficient for water is typically about $1x10^{-9}$ m^2/s. The estimated flux of dissolved constituents from the tailings porewater to the overlying water can be calculated assuming a diffusion thickness of 5 cm. The diffusion thickness is an estimated value that represents the near surface zone that will likely get mixed and washed by water as flooding of the tailings occurs.

The initial loadings to the tailings basin from the submerged tailings were estimated from the relative surface areas of submerged tailings in Areas 1 to 3 and the estimated flux values (**Table 4.5**). These estimated loading rates were applied in the lime demand model, as described in **Section 5.1.2,** to represent the maximum relative loadings contribution from the underwater tailings. The acidity loading rate of 740,000 kg $CaCO_3$/a is equivalent to a lime demand of about 410 t-CaO/a or 1.1 t-CaO/day.

It is expected that over time, the subsurface flushing and the releases of oxidation products will decrease and this will be reflected by decreased concentrations in the overlying surface water. For modelling purposes, the diffusive flux was decreased from the initial values by approximately 99%, over a period of 20 years, as described in **Section 4.2.1** above.

Table 4-5: Estimated Loading Rates for Submerged Tailings in Areas 1 to 3



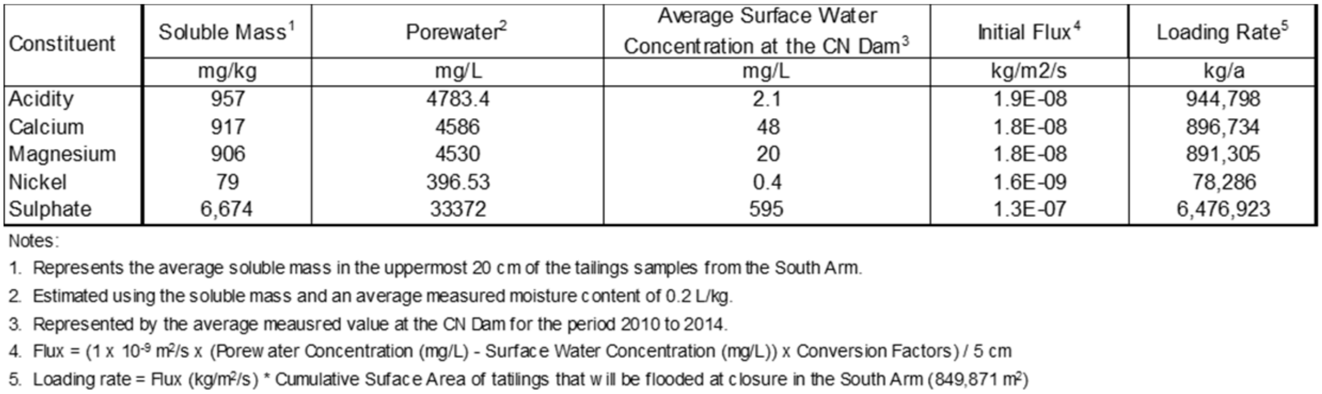
Constituent	Porewater[1]	Average Surface Water Concentration at the Narrows[2]	Diffusive Flux[3]	Loading Rate[4]
	mg/L	mg/L	kg/m^2/s	kg/a
Acidity	3,353	4.2	1.3E-08	740,104
Calcium	1,354	63	5.2E-09	285,418
Magnesium	2,767	22	1.1E-08	606,595
Nickel	164	0.62	6.5E-10	36,127
Sulphate	30,502	655	1.2E-07	6,596,233

Notes:

1. From Table 5.3.
2. Represented by the average meausred value at the Narrows for the period 2010 to 2014.
3. Flux = (1 x 10^{-9} m^2/s x (Porewater Concentration (mg/L) - Surface Water Concentration (mg/L)) x Conversion Factors) / 5 cm
4. Loading rate = Flux (kg/m^2/s) * Cumulative Suface Area of tatilings that will be flooded at closure in Areas 1 to 3 (1,756,744 m

Loading rates from submerged tailings in the South Arm of Area 4 were also estimated for select constituents. Loading rates were developed using the average values from the short term leach tests and assumed that 50% of the soluble mass would be removed during the initial flush (**Table 4.6**). This assumption was supported by the results from the tailings cores collected in Areas 1 to 3, that exhibited soluble constituent concentrations in the uppermost 5 cm that were roughly half those observed in the deeper tailings samples (**Section 3.2**). The initial calculated acidity loading rate of about 940,000 kg $CaCO_3$/a is equivalent to a lime demand of approximately 530 t-CaO/a or 1.4 t-CaO/day.

Table 4-6: Estimated Loading Rates for Submerged Tailings in the South Arm



Constituent	Soluble Mass[1]	Porewater[2]	Average Surface Water Concentration at the CN Dam[3]	Initial Flux[4]	Loading Rate[5]
	mg/kg	mg/L	mg/L	kg/m2/s	kg/a
Acidity	957	4783.4	2.1	1.9E-08	944,798
Calcium	917	4586	48	1.8E-08	896,734
Magnesium	906	4530	20	1.8E-08	891,305
Nickel	79	396.53	0.4	1.6E-09	78,286
Sulphate	6,674	33372	595	1.3E-07	6,476,923

Notes:

1. Represents the average soluble mass in the uppermost 20 cm of the tailings samples from the South Arm.
2. Estimated using the soluble mass and an average measured moisture content of 0.2 L/kg.
3. Represented by the average meausred value at the CN Dam for the period 2010 to 2014.
4. Flux = (1 x 10^{-9} m^2/s x (Porewater Concentration (mg/L) - Surface Water Concentration (mg/L)) x Conversion Factors) / 5 cm
5. Loading rate = Flux (kg/m^2/s) * Cumulative Suface Area of tatilings that will be flooded at closure in the South Arm (849,871 m^2)

4.3 Relative Loadings Comparison

A summary of potential loadings to the Thompson tailings basin is provided in **Table 4.7**. As shown by this comparison, the highest relative loadings contribution to the basin is associated with the ongoing surface runoff from the exposed tailings. Loadings from the underwater tailings in Areas 1 to 3 represented a fraction of those from the surface runoff, on the order of 20%.

Loadings from the submerged tailings in the South Arm, associated with the diffusive transport of oxidation products, represented a greater portion of the surface runoff loadings on the order of 55%. The initial flush to the overlying water column from the rinsing of soluble products upon flooding was also shown to be a significant contributor of loadings to the basin. The initial flush represents a one-time event, whereas the initial diffusive flux represents a maximum estimate that is expected to decrease with time.

Table 4-7: Comparison of Estimated Loadings Rates for the Thompson Tailings

Source Location	Constituent	Initial Flush	Initial Diffusive Flush	Surface Runoff	Diffusive / Runoff
		kg/a	kg/a	kg/a	%
Areas 1 to 3	Acidity	740,104	370,929	1,078,144	34%
	Calcium	285,418	143,047	1,183,183	12%
	Magnesium	606,595	304,016	1,956,906	16%
	Nickel	36,127	18,106	99,939	18%
	Sulphate	6,596,233	3,305,933	10,522,983	31%
South Arm of Area 4	Acidity	948,769	944,798	1,897,539	50%
	Calcium	621,552	896,734	1,243,104	72%
	Magnesium	854,055	891,305	1,708,111	52%
	Nickel	88,397	78,286	176,794	44%
	Sulphate	4,894,753	6,476,923	9,789,505	66%

5.0 LIME DEMAND MODELLING

A lime demand model for the Thompson tailings basin was developed, in order to assess the lime demand required to mitigate acidity and nickel loadings to the basin, during and after the planned water level raises in Areas 1 to 3 and the South Arm of Area 4.

The model objectives for Areas 1 to 3 were to:

- Compare the predicted lime required to mitigate acidity and nickel loadings to actual usage up to 2014; and;
- Assess the timing requirements for a water level raise at the Narrows from 672 to 674 ft asl in terms of lime demand.

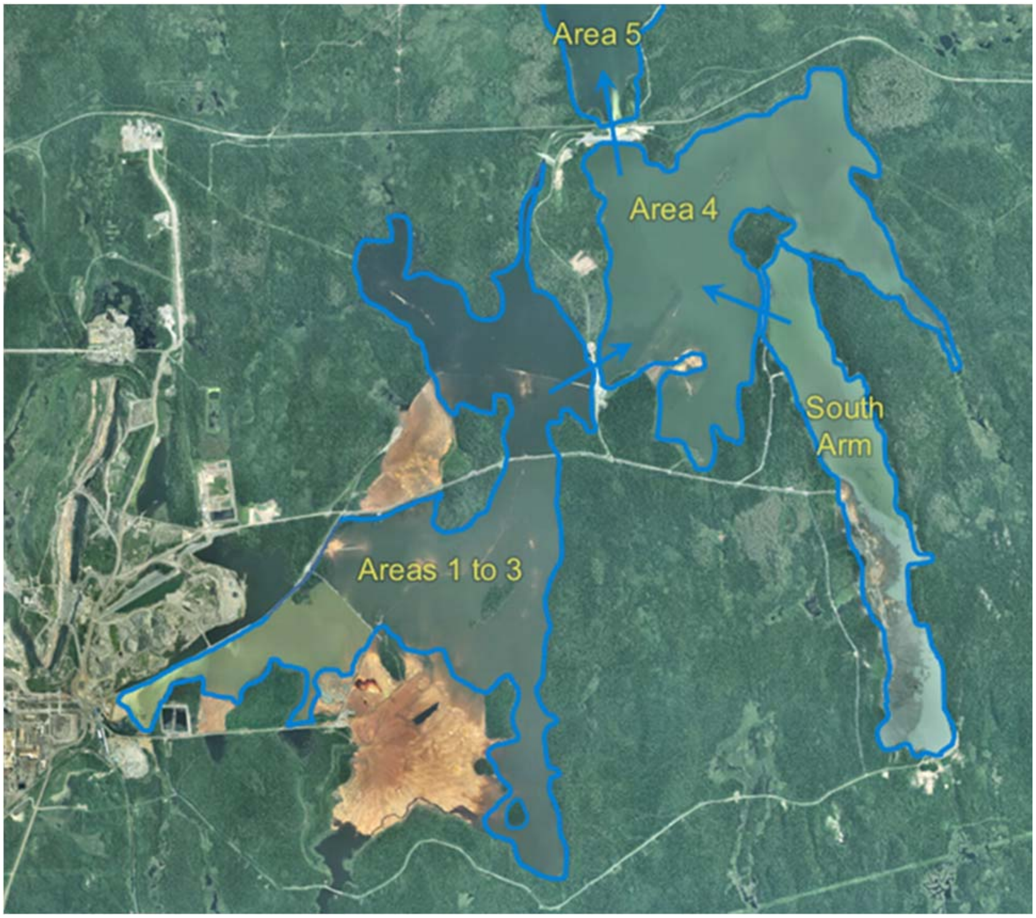
The objectives for the South Arm of Area 4 were to:

- Assess the lime requirements for the mitigation of loadings as tailings are continually deposited and temporarily exposed in the South Arm; and;
- Assess the timing requirements for a water level raise from 669 to 674 ft asl in the South Arm in terms of lime demand and compliance at the Weir.

5.1 Model Development

In order to provide estimates of lime demand for the Thompson tailings basin, EcoMetrix developed a transient mass balance model in MineMod^{TM}. This model is based on our proprietary Inco Tailings Basin Model, with which lime demand estimates had been derived in 2011 and 2012, and which does not reflect the current (2015) tailings basin configuration at Thompson. Conceptually, the basin is modeled as four connected compartments (Areas 1-3, Area 4, South Arm, and Area 5), with divisions between compartments situated at current and planned dam locations to allow future water level raises to be accurately represented (**Figure 5.1**). The model tracks nickel, acidity, calcium, magnesium, carbonate species, and sulphate in solid and aqueous phases throughout the tailings basin. The model was calibrated using available data for magnesium that behaves as a conservative chemical constituent and is only affected by dilution in the basin. The model was run for a period of 30 years beginning in 2010, in order to investigate the behaviour of the predicted nickel concentrations at the Weir.

Figure 5.1: Conceptual Layout of the Thompson Tailings Basin for the Lime Demand Model



5.1.1 Process Flows and Chemistry

Natural inflows to each of the waterbodies in the basin, as well as estimated process inflows such as from the 48” Sewer, 42” Sewer, T1, and 1D, are included in the model to develop a water balance for the tailings basin. Process inputs to the tailings basin were maintained at constant values until 2018, at which time loadings associated with the 48” Sewer were assumed to decline to zero to reflect the planned closure of the refinery in that year. For modelling purposes, all process flows were assumed to decline to zero in 2030 to reflect the closure of the Thompson Mine.

A summary of flows and associated chemistry for each of the process inflows is presented in **Table 5.1**.

Table 5-1: Summary of Process Inflows and Chemistry

Source Location	Flow[1]	Nickel[2]	Acidity[3]
	m3/a	mg/L	mg CaCO3/L
48" Sewer	7.8E+06	3.3	55
42" Sewer	9.9E+05	2.3	27
T1	1.2E+06	6.0	23
1D	1.9E+04	56	656
D2 Tailings Effluent	1.3E+07	-	-

Notes:

1. Flow values were taken from EcoMetrix (2006) with the exception of D2 that was updated to reflect the annual average flow rate of 11,000 USGPM.

2. Represents an average of water quality monitoring data from 2014. Values for T1 were not available and were assumed to be equal to historic data from EcoMetrix (2006).

3. Calculated from the available surface water monitoring data from 2014. Calculated values for T1 were represent an average of monitoring data for the 2007 calendar year.

With the exception of D2, process flows were taken from the EcoMetrix (2007) model update. The flow rate associated with the D2 Tailings effluent was updated for the 2015 model update, represented by an average value of 1.3 x 10^{-7} m^3/a, or 6,530 USGPM.

Acidity and nickel concentrations within the process flows are represented by annual average values for the period 2010 to 2014. Acidity is not directly measured within each process stream and these values were calculated based on the available chemistry at each monitoring station. Chemical data for T1 and D2 process flows were unavailable within the operations database. Values for acidity and nickel concentrations were estimated from historically measured values used in the EcoMetrix (2007) modelling assessment.

The 48” sewer represents the largest process flow rates into the basin and is known to be a source of nickel and acidity to Areas 1 to 3. Previous modelling investigations completed in the mid 2000s relied on measured flows and monitored concentrations from the sewer to estimate nickel loadings. While concentrations of nickel and many other constituents are measured weekly in the sewer outfall, there are no measurements of acidity. Also, there are no recent measurements of flow from the sewer and the absence of these data represent a major source of uncertainty in the total acidity loadings from the sewer and therefore, a major source of uncertainty in the lime demand required to treat the acidity from the sewer.

Due to the large contribution of loadings from the 48” sewer to the tailings basin, the process chemistry from the operations database was reviewed in greater detail to highlight any uncertainties that may affect model results.

A summary of measured pH values at the exit of the 48” sewer is shown in **Figure 5.2**. The measured pH values in the process water range from values of 7.5 to 12 and indicate discrete events of elevated nickel concentrations. These results also suggest that lime added to the 48” sewer is typically consumed before discharge enters the basin in Area 1. The lime consumption within the 48” sewer is consistent with the observed trends for nickel concentrations (**Figure 5.3**) that exhibit the highest values at the lowest pH values. These data show that some samples had elevated nickel concentrations that were not treated by raising the pH with lime addition. However, when lime was added and pH increased to values greater than about 8.5, the treatment was effective at removing nickel from the 48” sewer discharge.

Figure 5.2: Measured pH Values in the Outlet from the 48” Sewer

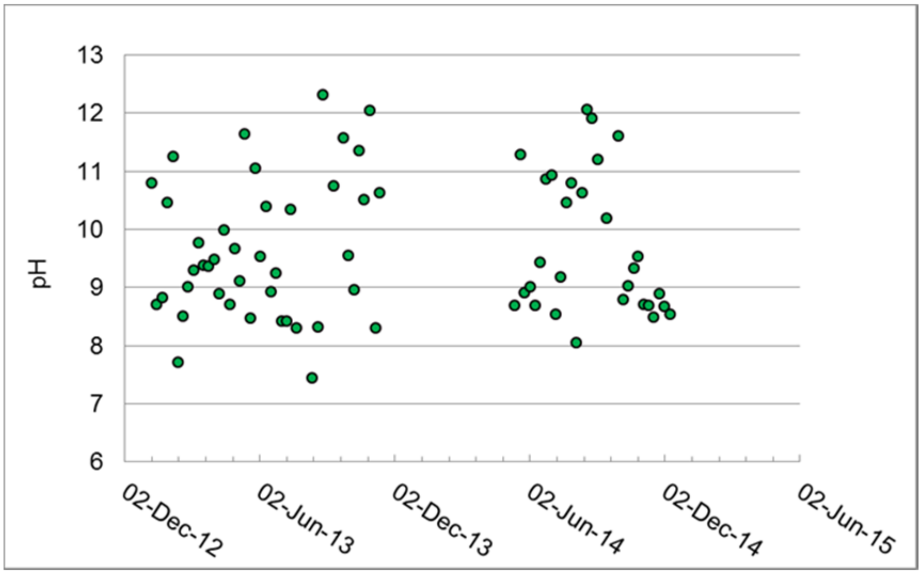
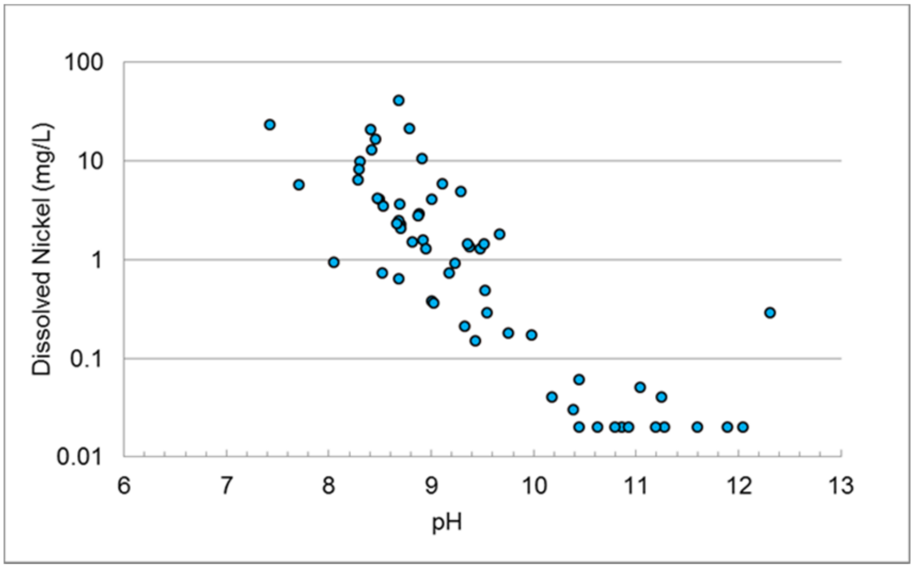


Figure 5.3: Concentrations of Dissolved Nickel with pH in the Outlet of the 48” Sewer



From discussion with Vale staff, it is understood that some of the observed lime consumption and potential source of acidity to the basin may be attributed to the emptying of the nitric acid tanks into the 48” sewer. It is also understood that the soda ash (Na_2CO_3) is added to the sewer when the acid tanks are emptied to the sewer in order to neutralize the acid. There may be other sources of elevated nickel to the sewer from the refinery that may warrant further consideration to mitigate nickel loadings to the basin. The potential for the acid tank evacuation events to represent substantial nickel loadings to the Basin, as well as the absence of measured flow rates, indicate that the 48” sewer represents a potentially important source of uncertainty within the lime demand model and for pH and nickel concentration control in the Basin.

As an aside to the lime demand modelling, it should be noted that the addition of soda ash to the Basin through the 48” discharge represents additional lime demand in the Basin. A pH of 8.5 or higher is needed for effective removal of nickel in the Basin. The presence of dissolved carbonate (CO_3^{2-}), originating as soda ash, causes the consumption of lime (CaO) as calcium carbonate ($CaCO_3$) precipitate when the pH is raised to about 8.2. Further addition of lime is required until all of the carbonate is removed from the water by precipitation. Only after the carbonate has been removed will the pH rise above 8.5 with addition of lime. An alternate approach to neutralization of the nitric acid tank discharge may be worth consideration in order to eliminate the lime requirements for soda ash removal in the Basin.

5.1.2 Tailings Source Terms

Present and future above water and flooded tailings are both represented in the model, which allows for variation in exposed and flooded areas over time. The model also includes representations of geochemical processes based on these varying areas. These include runoff from exposed tailings, an initial flush and an ongoing diffusive flux from flooded tailings. The processes that move the constituents of concern from tailings to the water in the Basin are summarized in **Table 4.7**.

The model accounts for acidification of above-water exposed tailings over time, including algorithms for estimating and summing relative contributions of each of the constituents of concern from areas of different tailings ages within each compartment to allow acidity loadings to be estimated for each time step. For this assessment, it was assumed that acidification of the tailings within the South Arm begins immediately upon deposition, increasing in a linear fashion to a maximum loading rate equal to that of the mature South Beach tailings in 6 years.

The projected mine plan was used as the basis for the model inputs concerning tailings deposition in Area 4. It was assumed that 99% of the available volume in the South Arm would be filled in by tailings over the time period 2011 to 2017. Partitioning of nickel from the water to Basin sediments is also implemented in the model, using a partition coefficient (K_d) approach.

5.2 Model Results

The lime demand for the tailings basin was estimated by summing lime demand results for two geochemical processes – the deposition of dissolved nickel as nickel hydroxide ($Ni(OH)_2$) and the raising of pH in each compartment. More specifically, stoichiometric amounts of lime were estimated in each time step to reach “ideal” conditions, bringing dissolved nickel to 0.1 mg/L and the pH to 8.5 in the context of carbonate species equilibria. The total lime demand across the basin is therefore expected to be representative of the amount of lime required to keep these “ideal” conditions in the basin, regardless of where in the basin the lime is actually applied. An efficiency factor for lime of 80% was assumed within the model to account for the percentage of CaO in delivered lime (92%) as well the losses during mixing within the Basin and slaker efficiencies.

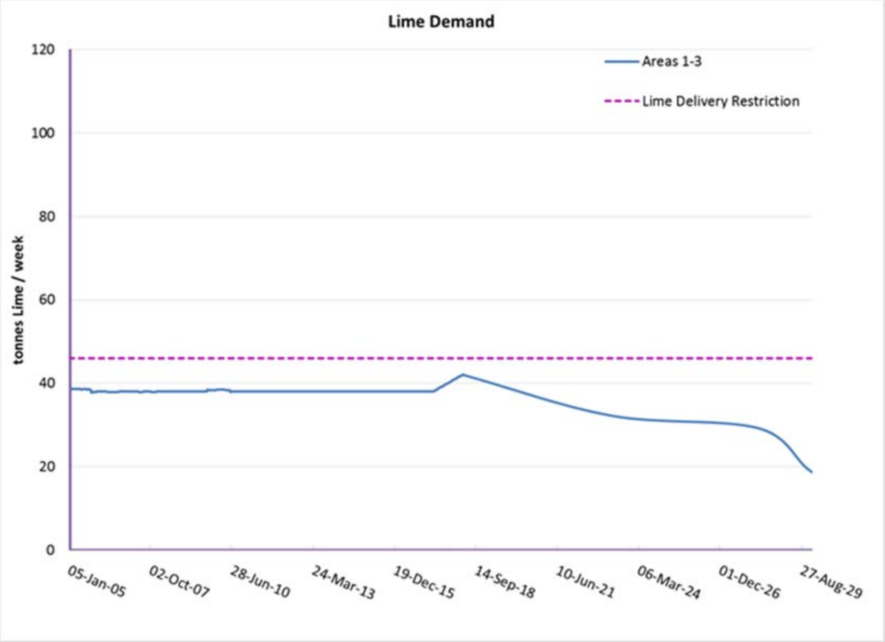
5.2.1 Areas 1 to 3

It is understood that lime is added to Areas 1 to 3 as a slaked slurry in 10,221 L (2,700 usgal) tanker trucks at the Dredge and the Narrows with at a delivery frequency of 4 truckloads per day, 5 days per week. This equates to a lime delivery rate for Areas 1 to 3 of 42 to 46 tonnes of lime per week, with each truck containing between 2.1 to 2.3 tonnes of lime. The weekly lime delivery for Areas 1 to 3 has been illustrated alongside model predictions for reference.

Prior to 2013, the water level in Areas 1 to 3 was 669 ft asl. Between May 2013 and March 2014, the water level increased to 672 ft, covering most of the exposed tailings in Area 3 as well as some other exposed tailings in Areas 1 and 2. An initial increase in lime demand was observed during and after the water level raise, as expected, before declining after the tailings were submerged to an elevation of 672 ft.

The lime demand model was run to determine the lime demand after the water level raise from 669 to 672 ft and the results are plotted in **Figure 5.4**. The lime demand prior to the water level raise in 2013 was about 38 tonnes of lime per week. During the water level raise, the lime demand increased to a peak of about 43 tonnes per week and then was predicted to decline to a value near 30 tonnes per week in 2025.

Figure 5.4: Predicted Lime Demand Requirement for Areas 1 to 3 with the Water Level Raise from 669 to 672 ft asl in 2013 Only

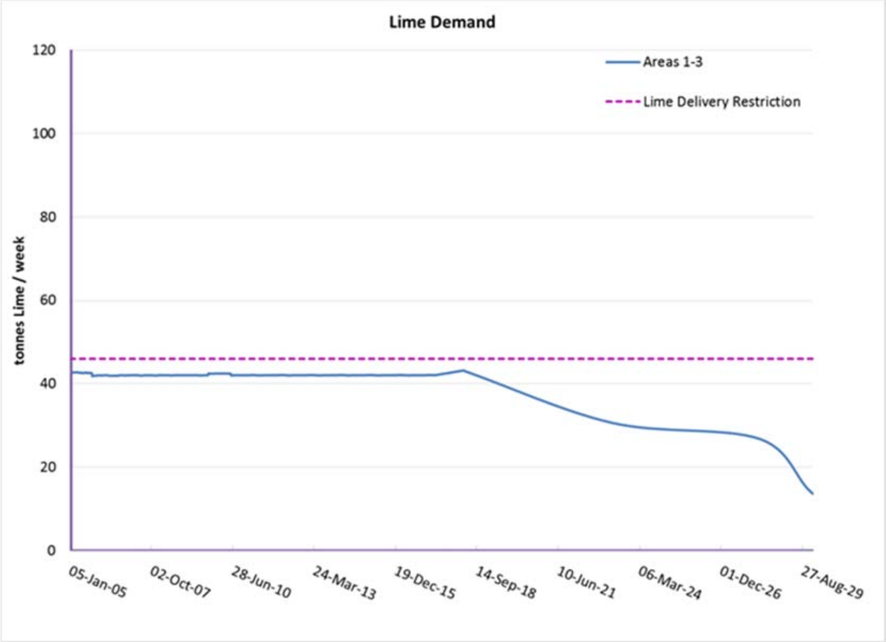


The sharp decrease in lime demand at 2018 represents a “switching-off” of the 48 inch sewer loadings and is shown for illustration only in this figure. This “switching-off” of the 48” sewer was included as a sensitivity exercise to assess the relative contribution of loadings associated with this source. The lime demand in Areas 1 to 3 for the sewer discharge was estimated to be about 10 tonnes of lime per week. This result suggests that the 48” sewer represents an important source of acidity to the basin that could materially affect the lime demand. The uncertainties surrounding this source are discussed in more detail in the following sections.

It is our understanding that the majority of potential acid and nickel loadings from the sewer are associated with the refinery that will be closed in the future. Following the closure of the refinery, the loadings associated with the sewer are expected to decline although other discharges may remain due to on-site drainage. The lime demand is therefore expected to decline by 10 tonnes per week after the refinery is closed and there are no longer any important sources of acidity and nickel in the sewer discharge. This decrease would be expected to start as soon as the loadings to the sewer were mitigated.

The model was also run to calculate the lime demand for a water level raise from 672 to 674 ft in order to determine the incremental difference attributed to the 2 foot raise planned in 2015. The predicted lime addition requirement for Areas 1 to 3, without a planned water level raise from 672 to 674 ft asl, is approximately 40 tonnes lime per week as shown in **Figure 5.5**. The simulated raise in water level from 672 to 674 ft resulted in a small increase in the calculated lime demand to about 43 tonnes per week as a result of the flushing of the existing acidity in the exposed tailings before decreasing to a value near 30 tonnes of lime per week in 2025 as shown in **Figure 5.5**. The difference in lime demand with and without the raise from 672 to 674 ft asl is about 5 tonnes of lime per week or about 3 trucks per week.

Figure 5.5: Predicted Lime Demand Requirement for Areas 1 to 3 with a Planned Water Level Raise in 2015 from 672 to 674 ft asl



The predicted lime demand with or without the water level raise to 674 ft falls within the delivery rate of 46 t-CaO/week to Areas 1 to 3. Therefore, given the current understanding of the acidity loadings to Areas 1 to 3, there is no material benefit to raising the water level in Areas 1 to 3 to 674 ft in 2015. However, it is evident that the maximum lime demand values are relatively close to the delivery capacity and there are uncertainties related to the acidity loadings to the Basin that should also be considered as discussed below.

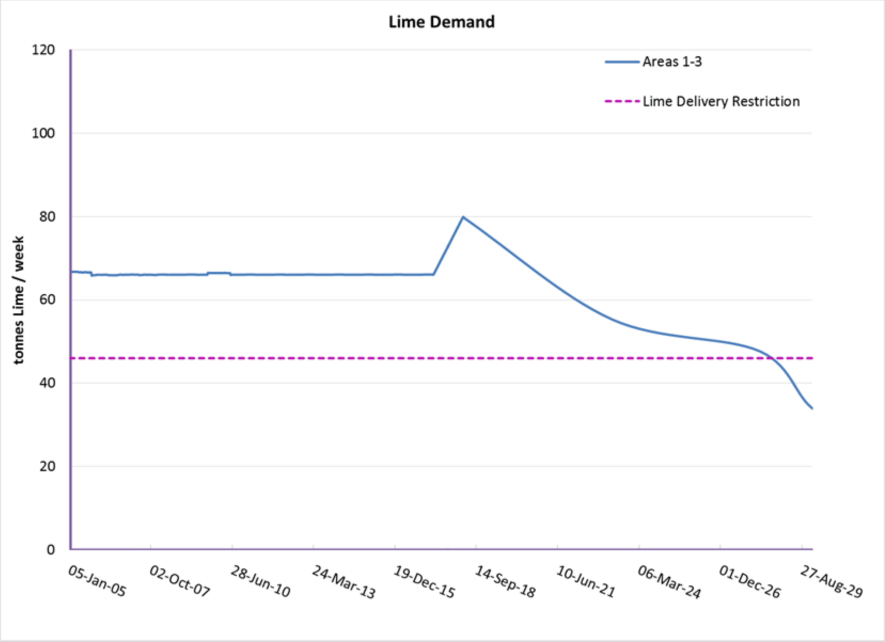
The lime demand estimates in **Figures 5.4** and **5.5** assume that; 1) the estimated acidity loadings from the top 10 cm of the exposed tailings are represented by “average” soluble loads measured in the field in 2014 and 2) the estimated acidity loading from the 48 inch sewer, based on measured flows in the mid 2000s, are reasonably reflective of conditions into the future.

The acidity loadings from exposed tailings in Areas 1 to 3 were considered in a sensitivity scenario with soluble acidity loads represented by the 90th percentile of the measured values from the field rather than the average values. The results for this upper bound acidity loading from the exposed tailings are shown in **Figure 5.6**. The maximum lime demand is predicted to be about 82 tonnes per week, exceeding the lime delivery for Areas 1 to 3 as well as the total lime delivery for the tailings Basin of 69 tonnes per week.

The 90th percentile loadings from the exposed tailings are not anticipated but there can be variations annually that can be above and below the average value used for the predictions shown in **Figures 5.4** and **5.5**. The results from this upper bound scenario suggest that the lime demand could exceed the delivery rate of 46 tonnes of lime per week in Areas 1 to 3 for extreme seasonal conditions for the exposed tailings.

In addition, if the acidity loadings from the 48 inch sewer were 50% greater than that estimated in the model, the lime delivery capacity to Areas 1 to 3 of 46 tonnes per week could be exceeded by 2 tonnes per week. Therefore, the sewer also represents an important uncertainty that can materially affect the lime demand and water quality management in the Basin.

Figure 5.6: Predicted Maximum Lime Demand Requirement for Areas 1 to 3 with a Planned Water Level Raise in 2015 from 672 to 674 ft asl



It is strongly recommended that the confidence in acidity loadings from the 48 inch sewer be increased by:

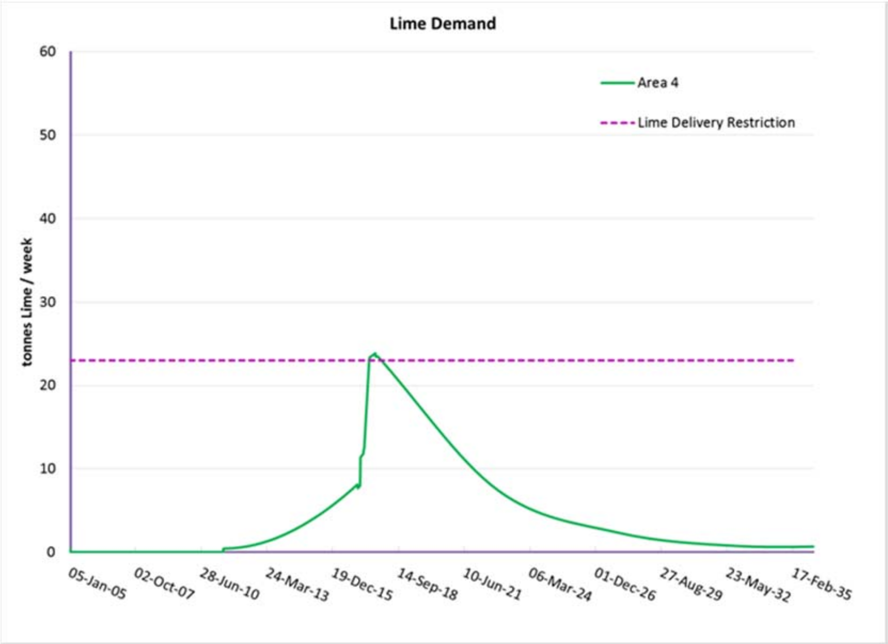
1. Adding acidity to the list of constituents in the weekly monitoring program and;
2. Measuring the flow rate from the 48 inch sewer.

5.2.2 South Arm of Area 4

It is understood that lime is added to Area 4 as a slaked slurry in 10,221 L (2,700 usgal) tanker trucks at the CN Dam with a delivery frequency of 2 truckloads per day, 5 days per week. This equates to a lime delivery for Area 4 of 21 to 23 tonnes of lime per week, with each truck containing between 2.1 to 2.3 tonnes of lime. This lime delivery has been illustrated alongside model predictions for the South Arm of Area 4 for reference.

The predicted lime demand for the South Arm of Area 4, before the planned water level raise from 669 to 674 ft asl, is approximately 8 tonnes of lime per week in 2017 as shown in **Figure 5.7**. When the tailings are submerged in 2017, there will be a rapid increase in lime demand as a result of flushing of the soluble acidity from the surface of the acidic tailings. The peak lime demand was predicted to be slightly more than the lime delivery of 23 tonnes per week, followed by a decline to a value near 5 tonnes per week in 2025.

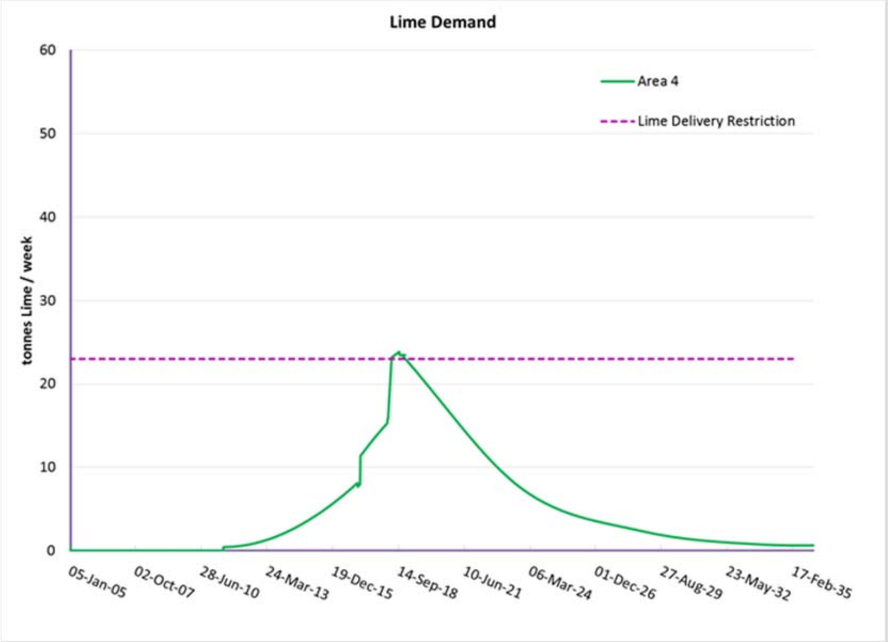
Figure 5.7: Predicted Lime Demand Requirement for Area 4 with the Planned Water Level Raise from 669 to 674 ft asl in 2017



With a maximum lime demand of about 40 tonnes per week in Areas 1 to 3, the total maximum lime delivery requirement for the tailings basin will be about 63 tonnes per week or just less than the total lime delivery of 69 tonnes per week.

A delay in the water level raise to 2018 in Area 4 will increase the peak lime demand by 2 tonnes of lime per week, following a water level raise from 669 to 674 ft asl, as shown in **Figure 5.8**. This one-year delay will however, increase lime delivery requirements associated with the ongoing exposure of the tailings in the South Arm before the water level raise from 8 to 15 tonnes per week, or 3 trucks per week before the water level raise in 2018.

Figure 5.8: Predicted Lime Demand Requirement for Area 4 with a Planned Water Level Raise from 669 to 674 ft asl in 2018

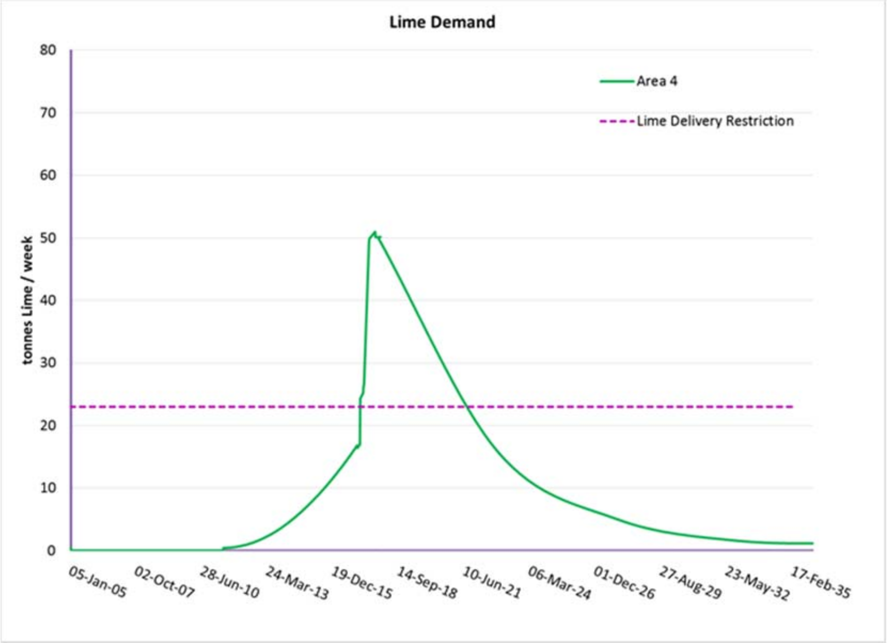


For the purposes of this modelling assessment, it was assumed that the one-time flushing event associated with the flooding of exposed tailings would take place over a one-week time period for the incremental area that was submerged each week. This assumption is somewhat conservative in that the actual lime demand may vary over the initial flushing period and may take place over a longer period as suggested by monitoring data at the Narrows, post-flooding. However, the rate of submergence of the tailings is not known with precision because the final geometry of the tailings in the South Arm is not yet known as it was for the exposed tailings in Areas 1 to 3. Therefore, a faster rate of submergence could result in a more rapid flushing of the tailings surface and a higher peak lime demand than those predicted in **Figures 5.7** and **5.8**. In any case, it was considered prudent to design for peak events in order to remain compliant at the Weir and therefore, this assumption of one week to flush newly submerged tailings was not considered to be too conservative.

One implication for the lime demand from the South Arm tailings is the need to add lime to the water leaving the South Arm rather than allowing the acidity and nickel to enter Area 4 and adding lime at the railway flow control structure. Adding lime at the outlet of Area 4 will result in the accumulation of treatment solids in Area5. Those treatment solids represent a potential future risk of increasing nickel concentrations at the Weir when the Basin is closed and the pH in the basin decreases to near neutral values. The objective is to treat the South Arm nickel and acidity loadings at a splitter dyke at the north end of the South Arm to allow treatment solids to settle in Area 4 where they will be entrained in subaqueously deposited tailings in the future. This is a key consideration for closure planning and implies that a splitter dyke will need to be in place prior to the water level raise in Area 4.

As with Areas 1 to 3, there may be uncertainties with loadings from the exposed tailings in the South Arm. The predicted lime demand in **Figures 5.7** and **5.8** assume "average" soluble loads from the temporarily exposed tailings. An upper bound lime demand was calculated for the 90th percentile loads and the results are shown in **Figure 5.9**. The peak lime demand for the upper bound scenario is 50 tonnes of lime per week and exceeds the lime delivery constraint of 23 tonnes per week in Area 4. If the "average" lime demand in Areas 1 to 3 of about 40 tonnes per week are added to the upper bound value of 50 tonnes per week in the South Arm, a total lime requirement of 90 tonnes per week would exceed the total delivery rate of 69 tonnes per week for the basin. And although this upper bound value is not anticipated for average conditions, the results suggest that seasonal extremes could result in lime demand rates that may approach or exceed the current lime delivery constraints for the tailings basin.

Figure 5.9: Predicted Maximum Lime Demand Requirement for Area 4 with a Planned Water Level Raise from 669 to 674 ft asl in 2017



A detailed discussion of the estimated lime demand for the Thompson tailings basin and the risks associated with deferment of the water level raise in Areas 1 to 3 and the South Arm of Area 4 is presented in **Section 6.0**.

6.0 SUMMARY

The lime demand and quantitative loadings model developed for the Thompson Tailings Basin represents a tool that can predict water quality during the operation and closure of the site. The loadings model developed herein represents an iterative process that can be updated to incorporate the optimization and design of the water level raises, in terms of timing requirements and exposed tailings runoff and mine schedule in order to represent the most effective mine water management strategy for the Thompson mining life cycle. The model can also be used to identify gaps or uncertainties related to the management of water quality at the Thompson site.

The overall results of this analysis showed that the estimated lime demand for Areas 1 to 3 is less than, but close to, the current delivery rate of 46 tonnes of lime per week 4 trucks per day) for the area. The model results suggest that there will not be a material benefit with a water level raise in Areas 1 to 3 alone in 2015 and that the raise in Area 4 in 2017 or 2018 will result in a similar lime demand and mitigation effects for Areas 1 to 3.

The water level raise in Area 4 in 2017 will result in an estimated peak lime demand that is similar to the current delivery rate of 23 tonnes per week in that area, for loadings representing average conditions for the submergence of exposed tailings. Although a decline in lime demand is expected after an initial flush during submergence of the tailings, the peak values may be sustained for several months. This is the justification for construction of the splitter dyke that will allow lime addition to the flow from the South Arm into Area 4 prior to flow into Area 5.

The delay of a water level raise by one year to 2018 does not appear to represent a large incremental increase in lime demand for submergence of the tailings in the South Arm. However, the results from the upper bound scenario representing the 90th percentile loads from the temporarily exposed tailings during submergence suggest that there is a risk of exceeding the current lime delivery rate if the loadings are greater than those expected for average conditions or if more rapid flooding causes higher peak lime demand values than those predicted here. The risk associated with the peak lime demand resulting from a rapid flush event is the potential to exceed the lime delivery rate and to experience non-compliance for nickel concentrations at the Weir. The water level raise will need to be managed at a rate that does not cause higher peak lime demand values. Monitoring at the outflow through the splitter dyke at the north end of the South Arm will be required to provide information for the lime requirements and lime should be added at that location to provide maximum benefits for pH and nickel control.

Future opportunities for the evaluation of mitigation measures for the site include modelling scenarios that assess the sub-aqueous disposal of tailings in Area 4, the refinement of acidity and nickel loadings from the 48” sewer and the placement of covers on the exposed tailings areas. The release of nickel from the treatment solids in Area 1 and the sediments in Area 5, can be modelled in future iterations, in order to assess nickel loadings to the basin, lime demand requirements and predicted compliance at the Weir, during and post-closure.

7.0 RECOMMENDATIONS

A review of the historical lime delivery rates to the basin for the period 2010 through 2014 was undertaken by AMEC (2015). This review included an assessment of the purchased quantities, slaker production and concentrations of lime in solution from each source. It was noted that there had been some historical uncertainty in the source of lime delivered to the basin, as well as frequency of delivery. It was also noted that the records of lime delivery and frequency for the 2014 calendar year provided a clearer representation of actual conditions.

It is understood that lime is added to the basin as a slaked slurry in a 10,221 L (2,700 usgal) tanker truck at the Dredge, Narrows and the CN Dam with a maximum practical delivery frequency of 6 truckloads per day on a schedule of 5 days per week. This equates to a lime delivery of 63 to 69 tonnes of lime per week to the basin, with each truck containing between 2.1 to 2.3 tonnes of lime.

The conclusions from the model results have some uncertainties based on some assumptions used and the uncertainties associated with the historical lime usage in the Basin. Therefore, as a follow up to this assessment, it is recommended that a refinement to the estimated lime demand for the basin be completed using the most up to date records of lime delivery. In this way, the uncertainties surrounding historical lime delivery and consumption will be greatly reduced. This update will also allow for a clearer indication of lime requirements in terms of capacity and delivery restrictions to the basin that may become especially important during upset events or more rapid flooding of the basin. This refinement will reduce the uncertainty of the conclusions for the deferred raise of Dam B and therefore will reduce the risks associated with that decision.

The overall conclusion from the tailings basin model is that pH control will be required for compliance during operation until the acid and nickel loadings from the 48” sewer, from the system upsets and from the South Beach have been substantially mitigated.

The lime demand for water level raise events may also be affected by other processes in the Tailings Basin. Soda ash (sodium carbonate) and nitric acid, for example, are known to be discharged to the 48” sewer and to enter the basin. The lime that is added to Areas 1 to 3, to raise the pH above 8.5 and effectively control acidity and nickel that originate from the exposed South Beach tailings will need to be augmented by additional lime to counter these additional inputs from the sewer.

A review of the monitoring data for the 48” sewer indicated that some samples had elevated nickel concentrations that were not treated by raising the pH with lime addition. This observed lime consumption and potential source of acidity to the basin may be attributed to the emptying of the nitric acid tanks with release to the 48” sewer. It is also understood that soda ash (Na_2CO_3) is added when the acid tanks are emptied to the sewer in order to neutralize the acid. Although soda ash represents a source of alkalinity, the carbonate must be precipitated by additional lime to raise the basin water pH to values above 8.2. Therefore the soda ash also represents a source of lime demand when the pH in the basin is raised to values between 8.5 and 9 to remove nickel.

There may be other sources of nickel to the sewer from the refinery that may warrant further consideration to mitigate nickel loadings to the basin. The potential for the acid tank evacuation events to represent substantial nickel loadings to the Basin, as well as the absence of measured flow rates, indicate that the 48” sewer represents a potentially important source of uncertainty in the lime demand model results and for pH and nickel concentration control in the Basin.

To overcome these residual uncertainties and to refine the lime demand requirements for the Basin, a review of the refinery inputs to the 48” sewer is recommended. This review should include the measurement of flow, as well as the analysis of acidity during routine sample collection. Also suggested is the estimation of additional sources of acidity to the sewer, including soda ash and the emptying of the acid tanks, in terms of relative contribution and frequency of events. An alternate to soda ash neutralization of the nitric acid tank discharge may be worth consideration in order to eliminate additional lime demand for soda ash precipitation when raising the pH above 8.2.

The reduction of loadings from the sewer during operation has the added benefit of reducing the nickel inventories in the sediment in the basin and therefore, decreasing the peak concentrations, as well as the length of time required for water management after closure.

Additional chemical characterization of the tailings effluent from D2 is also suggested for future work in order to reduce the uncertainty present in the model. Although the nickel and acidity concentrations are expected to be relatively small, the flow rate is a relatively large portion of the water balance in the Basin. The analysis of dissolved metals and alkalinity would improve the development of loadings sources to the Basin, during the beaching of tailings in the South Arm and the sub-aqueous disposal of tailings in Area 4.

8.0 References

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