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Predicted Post-Closure Contaminant Loads and Water Quality Conditions in Myra Creek, Nyrstar Myra Falls, Canada

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Abstract

Nyrstar Myra Falls (NMF) is an underground zinc mine on Vancouver Island, British Columbia, Canada. In 2016, Robertson GeoConsultants Inc. (RGC) developed a water and contaminant load balance model to support the closure planning for the Old Tailings Disposal Facility (TDF) and a closure cover design for the embankment berm of the active Lynx TDF. The model was used to (i) simulate current impacts to groundwater and Myra Creek by Metal Leaching (ML) and Acid Rock Drainage (ARD) and (ii) predict future, post-closure water quality conditions as closure and progressive reclamation proceeds.

This paper will describe RGC's conceptual load balance model and a numerical load balance model that was developed with the software GoldSim. The numerical model was calibrated to daily zinc (Zn) loads in Myra Creek from 2012 to mid-2016, and water quality data was collected from within the mine site. Once calibrated, the model was used to simulate the improvement in water quality conditions in Myra Creek during the future operation of the Lynx Seepage Interception System (SIS) and after the Old TDF has been closed and the Lynx TDF berm has been raised to its final height and covered.

Introduction

In 2016, Nyrstar Myra Falls (NMF) submitted a permit-level closure plan for the Old TDF, a closure cover design for the Lynx TDF embankment berm, and a conceptual design for the Lynx Seepage Interception System (SIS). Detailed closure engineering was completed by Amec Foster Wheeler, the Engineer of Record for the TDFs (see Amec Foster Wheeler, 2016a; 2016b).

Robertson GeoConsultants Inc. (RGC) developed and calibrated a numerical contaminant load balance in the software GoldSim. The model was then used to predict future Zn loads in groundwater and to Myra Creek once the Lynx SIS was operational and closure measures have been implemented.

Background

Site Location and Physical Setting

NMF is in the lower reaches of the Myra Valley about 90 km from the City of Campbell River within Strathcona Provincial Park. Myra Creek flows eastward through the site before discharging into Buttle Lake about 1.5 km downstream of the Old TDF. Mean annual precipitation (MAP) is 2480 mm and monthly average temperatures range from 2°C in January to 25°C in August.

Myra Valley contains sequences of glaciofluvial and glaciolacustrine sediments that were deposited during last glaciation. Rock slides, rock falls, and debris flows have produced local colluvial deposits that overlie these glacial sediments. Alluvial sediments have also been deposited more recently by Myra Creek and its tributaries. These glacial and alluvial sediments comprise the Myra Valley aquifer (MVA) that is the focus of this paper.

General Mine Arrangement

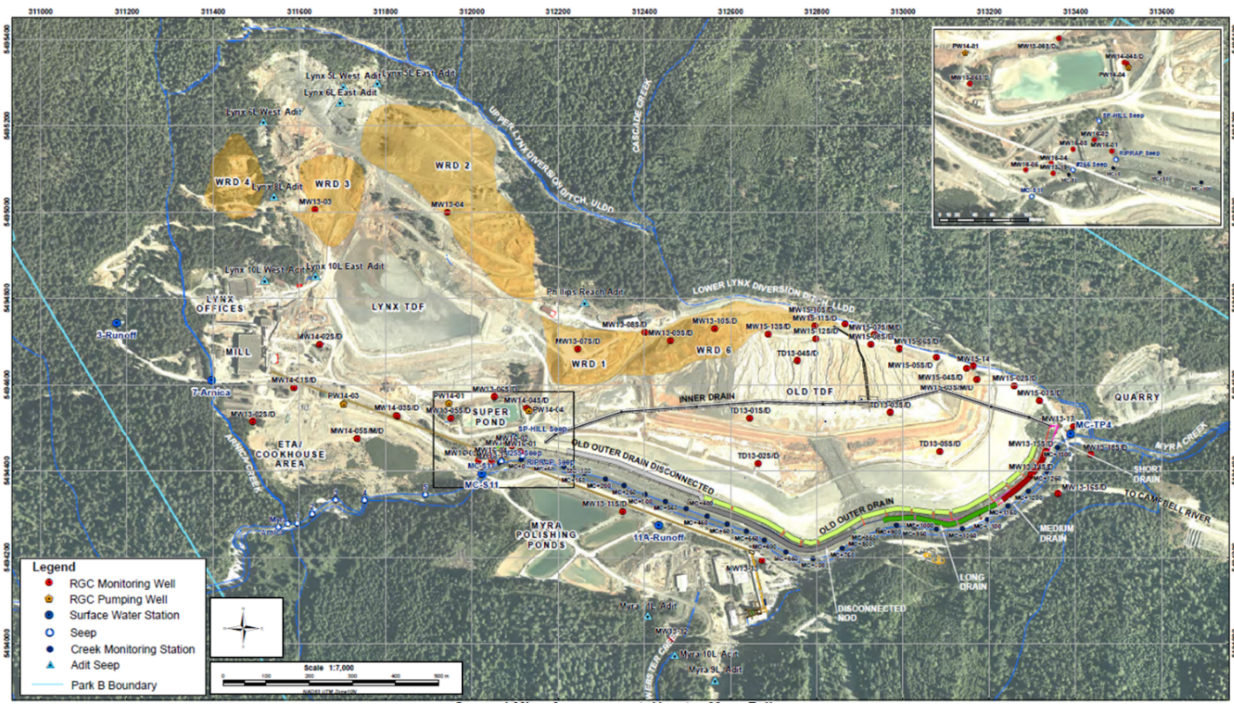

Figure 1: General mine arrangement and monitoring locations, Nyrstar Myra Falls

Key surface features at NMF are shown in Figure 1, including the Lynx TDF (around the former open pit), the Old TDF, Lower Lynx Diversion Ditch (LLDD), the historic WRDs, and the water treatment system (i.e. the Super Pond and Polishing Ponds). Underground workings (not shown) are extensive within Myra Valley and extend to Thelwood Valley. The Old TDF under-drain system near Myra Creek is shown in Figure 1 and described further below.

Groundwater and Surface Water Monitoring Network

There is a network of fifty-seven groundwater monitoring wells at NMF. Forty-one of these wells were installed in 2013 as part of RGC's environmental drilling program ("MW13" and "TD13" well series). Monitoring wells were also installed in 2014 and 2016 near the Lynx TDF to support the design of the Lynx SIS.

Surface water is routinely monitored at stations along Myra Creek. Daily composite samples are also collected using an auto-sampler at station MC-TP4. Monthly water quality surveys are also conducted at thirty locations along Myra Creek adjacent to the Old TDF (Figure 1). Flows in Myra Creek are recorded by a streamflow gauge underneath the carbridge. Zn and Cu concentrations in treated effluent are measured with an auto-sampler at station "Runoff 11A" near a Parshall flume.

Current Water Management and Treatment System

The Old TDF under-drains collect impacted groundwater near Myra Creek and direct it to Pumphouse #4. From Pumphouse #4, groundwater is pumped back to the Super Pond where it is treated. The Inner Drain and Area II Outer Drain are operational but it is the New Outer Drain (NOD) that is the most effective component of the Old TDF under-drain system and consists of a system of three separate drain sections referred to as (i) Short Drain, (ii) Medium Drain and (iii) Long Drain (see RGC, 2016c and Figure 1).

Flows of impacted groundwater, mine water, and surface water report to a Low-Density Sludge (LDS) water treatment system. Flows from the NOD account for about 50% of the total flow to the Super Pond.

Water Quality Guidelines (WQGs) and Objectives

Provincial WQGs for the protection of aquatic life in Myra Creek are discussed in Nautilus Environmental Inc. (2016). For Zn, the maximum and 30-day average WQGs at a water hardness of less than 90 mg/L as $CaCO_3$ are 0.033 mg/L Zn and 0.0075 mg/L Zn, respectively.

Water Quality Impacts

Groundwater at NMF is impacted by Acid Rock Drainage (ARD) from sulphidic, Potentially Acid Generating (PAG) waste rock and Neutral Mine Drainage (NMD) that flows from the upper levels of the Lynx and Myra mine workings. Most of the waste rock at surface is in the historic WRDs (i.e. WRD#1, #2, #3, and #4) and in the Lynx TDF embankment berm. The historic WRDs also contain Non-PAG waste rock and non-sulphidic waste rock.

Conceptual Site-Wide Load Balance

RGC developed a conceptual contaminant load balance model for groundwater in the MVA in 2014 (RGC, 2014). Mass loads of SO_4, Cd, Cu, and Zn were simulated in Excel using a monthly time step. The model was calibrated to the estimated Zn load (56.1 t Zn) to groundwater in the MVA in 2012. This Zn load is the sum of the Zn load recovered by the Old TDF under-drains via Pumphouse #4 (45.3 t Zn) and the Zn load in Myra Creek downstream of the site at MC-TP4 (10.8 t Zn).

For the TDFs and WRDs, loads were estimated as the product of monthly net percolation rates from O'Kane Consultants Inc. (2014) and constant Zn concentrations that were inferred from leach tests and historic groundwater quality data. Other Zn loads to groundwater in the MVA were estimated from mine water and surface water quality and measured flows (where available).

Key findings from that model are summarized here:

- Sources in the Old TDF Reach accounted for about two-thirds of the annual Zn load to groundwater in 2012. 65% of this Zn load is from WRD#1 and the other 35% was from WRD#6.
- Sources in the Lynx TDF Reach accounted for one-third of the annual Zn load to the MVA.
- Tailings are not currently a major source of Zn to groundwater in the MVA because tailings pore water at the base of the tailings profile consists of process water that is alkaline and characterized by low concentrations of metals.

In RGC (2016a), the conceptual load balance was updated as summarized below.

Hydrological Model for Myra Valley

A hydrological model was developed in GoldSim to simulate daily flows in Myra Creek from 2012 to mid-2016. Simulated flows from the model were used to estimate Zn loads in Myra Creek and Zn loads from un-gauged catchments in Myra Valley (namely, Arnica Creek, and Webster Creek). The hydrological model is a simplified version of the UBC Watershed Model that simulates the daily runoff hydrograph for Myra Creek. Simulated flows from the hydrological model are shown in Figure 2, with observed and simulated Zn concentrations in Myra Creek at MC+50 m, MC+800 m and MC-TP4, and provincial WQGs for Zn.

Zn Loads in Myra Creek

To estimate incremental Zn loads to Myra Creek from the major site reaches during low flow and high flow conditions, thirty-three sampling campaigns were undertaken from 2012 to mid-2016.

The following "reaches" of Myra Creek were identified from the monitoring data:

- Lynx Reach; extends from Arnica Creek (upstream of the Mill Reach) to station MC+50 m.

- Upper Old TDF Reach; extends from MC+100 m to the rock outcrop near MC+850 m.
- Lower Old TDF Reach; extends from MC+850 to MC+1350 m.

Daily Zn loads in Myra Creek during low flow and high flow periods are shown in Figure 2.

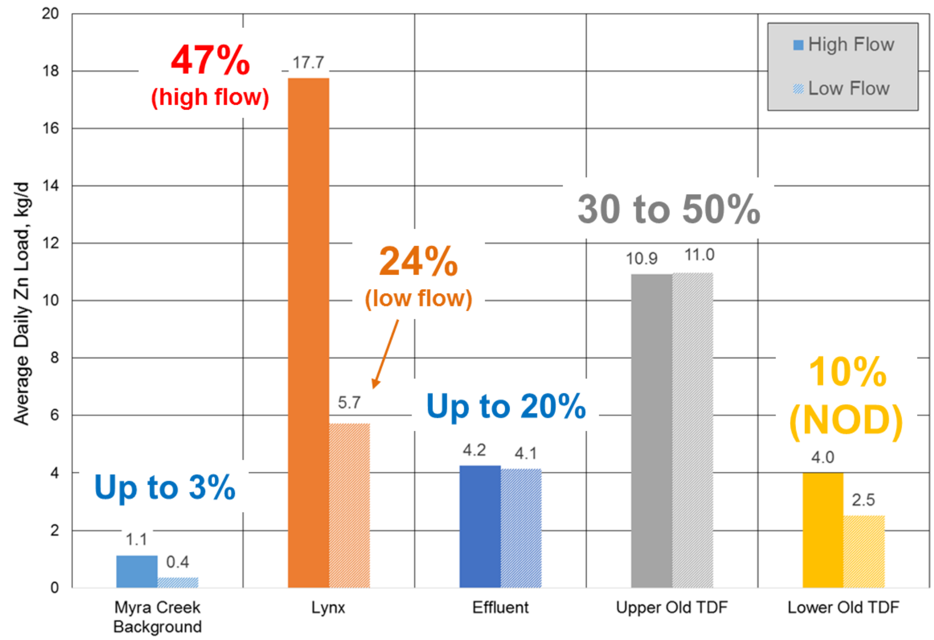

Figure 2: Average daily zinc loads in Myra Creek

Zn Load Captured by the Old TDF Under-Drains

From 2012 to 2016, the Old TDF under-drains recovered an estimated 43.7 t/year Zn from the local groundwater system. The average Zn load in Myra Creek at MC-TP4 from 2012 to 2016 is estimated to be 14.0 t/year Zn. The estimated Zn load to Myra Creek from the Lynx Reach, the Upper Old TDF Reach, and the Lower Old TDF Reach is estimated to be 11.8 t/year Zn after the 2.2 t/year Zn from treated effluent is accounted for. These Zn loads imply that the Old TDF under-drains capture about 80% of the Zn load that enters the groundwater system from various surface sources. NOD bypass is estimated to be ~10% of the load in Myra Creek, implying a substantial load to Myra Creek from the Lynx Reach and the Upper Old TDF Reach.

Zn Loads in Groundwater

Zn loads in groundwater within the Lynx Reach, Upper Old TDF Reach, and Lower Old TDF Reach were estimated to determine the contribution of source areas within these three study reaches. Zn loads in groundwater within each zone were estimated by multiplying groundwater flow in the aquifer by a representative Zn concentration in groundwater. Representative Zn concentrations for groundwater were selected by reviewing routine groundwater quality data collected since 2012.

Groundwater flows were estimated using the Darcy flow equation. Estimated Zn loads to Myra Creek were calibrated to observed Zn loads in Myra Creek during thirty-three sampling campaigns undertaken from 2012 to mid-2016.

Seven zones were delineated within the major site reaches:

- **Lynx Reach:** Zone I Mill and ETA/Cookhouse area and Zone II Lynx TDF and Super Pond area.
- **Upper Old TDF Reach:** Zone III Polishing Pond & HW area and Zone IV Upper Seismic Upgrade Berm.
- **Lower Old TDF Reach**: Zone V Upper Old TDF (upgradient of Inner Drain), Zone VI Lower Old TDF (downgradient of Inner Drain), and Zone VII downstream of NOD.

Loads in groundwater within the model zones are summarized in Figure 4. WRDs #1 and #6 (in Zone V and VI) and the Lynx TDF embankment berm (in Zone II) are the largest sources of Zn to groundwater. NOD bypass is estimated to be 1.4 t/year Zn. This is 12% of the annual Zn load in Myra Creek. The other 10.2 t/year Zn reports to the creek from areas upstream of the NOD (namely the Lynx Reach, mill area, and ETA/Cookhouse area).

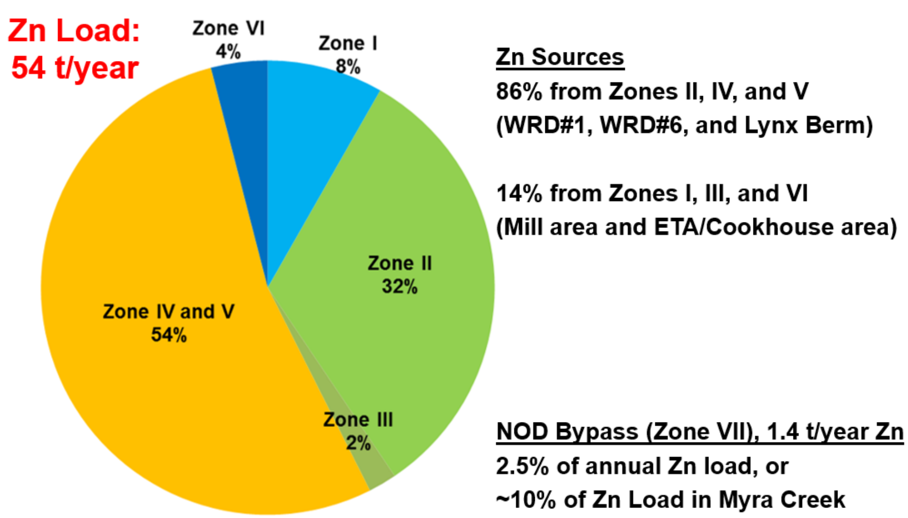

Figure 3: Estimated Zn loads in groundwater (by zone)

Numerical Contaminant Load Balance Model

RGC developed a numerical contaminant load balance model for NMF using the GoldSim platform. The model is a numerical representation of the conceptual site-wide contaminant load balance model that is summarized above. The model was developed to predict the performance of the Lynx SIS and assess proposed closure measures. Specific modeling objectives included simulating daily Zn loads within the groundwater system and to Myra Creek for current conditions (2012 to mid-2016). Further, Zn loads to and from the MVA and Zn concentrations in Myra Creek were predicted for the following (future) conditions:

- Lynx SIS operational.
- Old TDF closed.
- Lynx TDF berm raised to its final height.
- Lynx TDF berm covered.
- Additional SIS options implemented.

Model Domain

The GoldSim model covers the entire catchment area of Myra Creek except for the small area that drains to Myra Creek downstream of MC-M2 between Myra Falls and Buttle Lake. The Myra Creek catchment was sub-divided into twenty-seven sub-catchments to estimate runoff components of the water balance. Sub-catchment boundaries were delineated based on footprint areas of Zn sources, boundaries of conceptual aquifer zones, outlines of diversion ditches, and locations of flow and/or water quality monitoring stations.

Model Structure

The numerical load balance model is a tool to track the movement and storage of water and associated Zn loads within the Myra Creek catchment. A flowline is established for each major source of water and/or Zn load to or from the MVA or Myra Creek. The load balance performs its computations for the MVA and Myra Creek from upstream to downstream. At any given point in Myra Creek, the model aggregates all flowlines and associated Zn loads that enter the stream at upstream locations, including discharges from the MVA.

The yield generated within the catchment of Arnica Creek has three potential destinations: the underground workings beneath the MVA, the MVA itself (i.e. recharge), or Myra Creek. The yield estimated by the hydrological model is partitioned based on user-defined fractions. The hydrological model represents the runoff process as comprising two components: one that responds quickly (overland flow and interflow) and one that responds slowly (groundwater), i.e. a “fast” and a “slow”’ reservoir. The hydrological model was set up to simulate the delay and dispersion in the MVA by passing recharge flowlines through a linear reservoir.

Model Inputs (Zn Loads)

The following Zn loads report directly to Myra Creek within the boundaries of NMF:

- Zn loads from treated effluent.

- Zn loads from Arnica Creek and Webster Creek
- Zn loads from upstream areas of Myra Valley.

Zn loads in treated effluent were estimated from daily flow measurements from the Parshall flume and daily measurements of the total Zn concentration in effluent from the auto-sampler at station "Runoff 11A". The average daily effluent flow from 2012 to mid-2016 is 378 L/s (n = 1645). Daily flows ranged from 164 L/s to 1,529 L/s during this period. The average Zn load to Myra Creek via treated effluent from 2012 to 2016 is 2.4 t/year Zn.

Zn loads from Arnica Creek and Webster Creek (both un-gauged) were estimated from simulated daily flows from the hydrological model and average Zn concentrations in grab samples collected in 2011 and 2012. Estimated Zn loads to Myra Creek from Arnica Creek and Webster Creek are 0.6 t/year Zn and 0.1 t/year Zn, respectively. Zn loads in Myra Creek at MC-M1 (upstream of the mine site) were estimated as the product of the simulated daily flow and 0.004 mg/L Zn. This is the average Zn concentration in grab samples collected in 2011 and 2012. The Zn loads at MC-M1 represent natural loads from upstream sources. The annual Zn load in Myra Creek at MC-M1 was 0.7 t/year Zn from 2012 to 2016.

Daily Zn loads to groundwater from other sources to groundwater (i.e. WRDs, etc.) were estimated as the product of (i) daily recharge rates and (ii) a constant Zn concentration that is considered representative of seepage and/or tailings porewater. Initially, Zn concentrations from RGC (2014) were assigned to each source. Zn concentrations were then varied to reproduce Zn loads in groundwater within the model zones. For recharge, net percolation rates for waste rock from O-Kane Consultants Inc. (2014) were applied to WRD#1, WRD#6, the Lynx TDF embankment berm, and the Seismic Upgrade Berm. Monthly rates were re-distributed to match the daily time step in the GoldSim model. For other sources, daily recharge rates from the hydrological model were applied. Infiltration rates from the hydrological model were not assigned to the WRDs because these rates were not considered representative of waste rock.

Annually, the recharge rates for WRD#1, WRD#6, and the Lynx TDF embankment berm correspond to 74% of MAP. For tailings, a recharge rate of 300 mm/year from OKC (2014) was assigned. For the Seismic Upgrade Berm, the net percolation rate for waste rock covered with 1 m of vegetated till from OKC (2014) was applied. This rate corresponds to about 50% of MAP and is the same rate that was eventually assigned to the Lynx TDF embankment berm after it has been covered with till, rock, and soil. Lateral groundwater inflows to WRD#1 from the northern hillslope were assumed to represent an additional source of recharge to the model. Lateral groundwater inflows were varied to calibrate the numerical load balance model using the 50 mg/L Zn source term that was derived in RGC (2014). Lateral inflows of groundwater to WRD#1 were estimated to be 5.5 L/s during model calibration.

Model Calibration (Current Conditions)

The primary calibration targets for the load balance model were the observed daily Zn concentrations and inferred Zn loads in Myra Creek at MC-TP4 (n = 1644) and the observed zinc concentrations and inferred zinc loads from the thirty-three synoptic stream surveys at MC+50, MC+800 and MC-TP4 (i.e. at the end of each major site reach). The simulated concentrations at these MC stations were plotted against the observed zinc concentrations and these scatter plots evaluated visually and statistically. In addition, the incremental zinc loads simulated by the model for each model reach to Myra Creek and the total zinc load captured were compared to the inferred average zinc loads.

Initial model calibration involved varying flows to improve the fit of the scatter plots that compare simulated and observed daily Zn loads in Myra Creek. The model was also calibrated to groundwater flows and Zn loads to Pumphouse #4 during the initial stages of model calibration. Final calibration involved adjusting source terms to explain annual average Zn loads from 2012 to 2016 between model zones and to Myra Creek. Combined, these Zn loads represent 54.6 t/year Zn in groundwater each year.

Calibrated Results

Zn loads captured by the Old TDF under-drains range from 44.3 to 65.3 t/year Zn. The 4-year average for the calibration period is 55.3 t/year Zn. This represents about 86% of the average Zn load to groundwater after the Zn load from treated effluent is accounted for. Average annual flows from Pumphouse #4 range from 175 L/s (in 2014) to 241 L/s (in 2015). The 4-year average flow was 211 L/s. Calibrated Zn concentrations in Myra Creek are shown in Figure 2.

Some key observations regarding Zn concentration in Myra Creek are summarized here:

- The calibrated model suggests higher Zn concentrations in the creek often persist during lower flow periods (i.e. in the summer) when the dilution of Zn loads in the creek are lowest. Zn concentrations typically decrease in the fall and during the spring freshet due to the large flows of unimpacted water from upstream of the mine site. This variation is consistent with the observed pattern of Zn concentrations in Myra Creek. 85% of the simulated daily Zn concentrations in Myra Creek at MC-TP4 were higher than the provincial WQG.
- During high flow periods in 2012, 2013, and early 2014, simulated Zn concentrations in Myra Creek compare reasonably well to the Zn concentrations observed during sampling campaigns and with the auto-sampler at MC-TP4. During low flow periods, the model tends to over-estimate Zn concentrations by about 10 to 15%. This suggests that Zn loads to Myra Creek in 2012, 2013, and early 2014 are likely well-represented by the sources that were incorporated into the GoldSim model.

- From August 2014 to August 2015, the model tends to under-estimate Zn concentrations in Myra Creek during low flow and high flow periods. This could be related to more flushing of impacted groundwater from the MVA during the prolonged wet periods that characterized these years than during the drier years of 2012 and 2013. Alternatively, the number of sources represented in the GoldSim model could be insufficient to explain Zn loads to Myra Creek.

Model Predictions

To assess future conditions, RGC simulated loads and concentrations from 2012 to mid-2016 with the GoldSim model in "'post-closure mode". When this mode is specified, the model is run with the same climatological conditions that were applied during model calibration. This allowed future Zn loads and concentrations to be assessed as though the change to the model had been implemented during the calibration period. The effects of each closure measure are additive so there is a progressive decrease in simulated Zn concentrations over time as each measure is implemented. Predicted Zn loads and Zn concentrations are summarized in Table 1.

Table 1: Predicted flows and Zn loads for future conditions

Scenario	Input to Groundwater		Captured by Old TDF under-drains (Pumphouse #4)		Captured by Lynx SIS		Captured by Additional SIS	
	Load, t/year	Recharge L/s	Load, t/year	Flow, L/s	Load, t/year	Flow, L/s	Load, t/year	Flow, L/s
Current Conditions	62.1	48	55.3	211	-	-	-	-
Lynx SIS	60.0	46	39.8	167	16.6	57	-	-
Old TDF closure	48.4	42	28.9	163	16.6	57	-	-
Final Lynx TDF at closure	48.7	42	29.0	163	16.8	57	-	-
Covered Lynx TDF Berm								
Final Lynx TDF (rock and till cover)	43.7	41	27.5	162	13.3	57	-	-
Final Lynx TDF (geomembrane)	33.8	38	24.7	159	6.5	57	-	-
Additional SIS (assuming rock and till cover)								
Additional SIS (Zone IV only)	43.7	41	27.5	162	13.3	57	0.5	8
Additional SIS (Zone I only)	43.7	41	27.5	162	13.3	57	0.3	18
Additional SIS (Zones I and IV)	43.7	41	27.5	162	13.3	57	0.9	26

Lynx SIS Performance

Predicted Zn concentrations in Myra Creek are shown in Figure 4 with calibrated Zn concentrations (2012 to mid-2016). Key observations for this scenario are summarized here:

- The Lynx SIS is predicted to capture 16.6 t/year Zn or about 70% of the Zn load to groundwater from sources in Zones I and II.

- The Zn load to the Old TDF under-drains is predicted to be reduced by about 30% to 39.8 t/year Zn by seepage recovery upgradient. Flows to the Old TDF under-drains are reduced to 167 L/s. This represents a 20% reduction compared to the calibrated flows for current conditions.
- The average Zn concentration in Myra Creek at the carbridge (MC+50 m) is predicted to be 0.012 mg/L Zn once the Lynx SIS is operational. This represents a 60% reduction compared to the average annual Zn concentration that was simulated for current conditions.

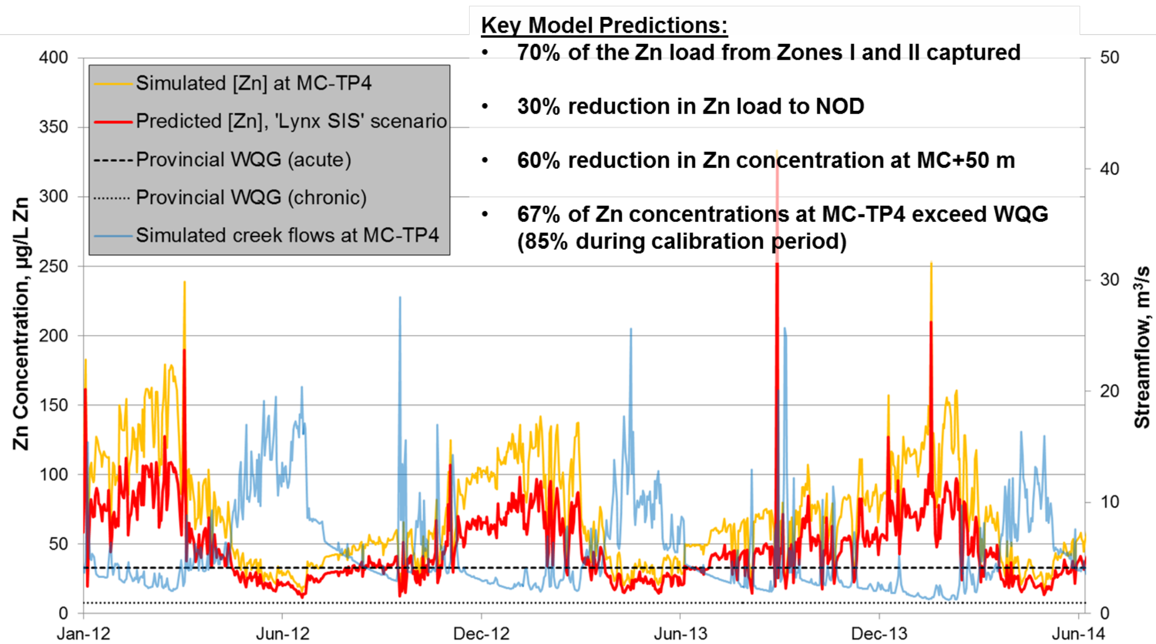

Figure 4: Predicted Zn concentrations in Myra Creek, Lynx SIS operational scenario

Old TDF Closure Performance

Predicted Zn concentrations in Myra Creek are shown in Figure 5 with predicted Zn concentrations from the "Lynx SIS Operational" scenario. Key observations for this scenario are summarized here:

- Reducing infiltration to WRD#6 to 2% of MAP (due to liner placement) is predicted to reduce Zn loads to groundwater by 11.6 t/year Zn. The model suggests that Zn concentrations in Myra Creek will not be substantially reduced by covering WRD#6 because the Zn load from WRD#6 (albeit smaller after Old TDF closure) will continue to be directed to the Lower Old TDF Reach where it will be mostly captured by the NOD.
- The annual Zn load to the Old TDF under-drains will be reduced to 28.9 t/year Zn by Old TDF closure and ongoing operation of the Lynx SIS. This is about 50% of the Zn load that reports to the Old TDF under-drains under current conditions. Old TDF closure is predicted to reduce Zn concentrations in Myra Creek by about 10%.

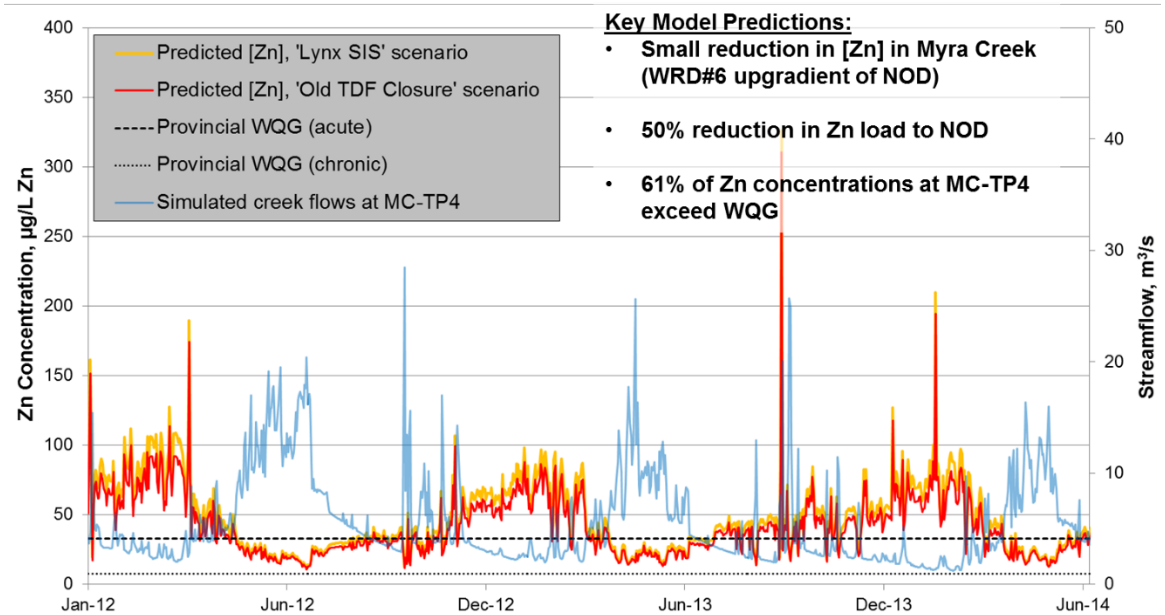

Figure 5: Predicted Zn concentrations in Myra Creek, Old TDF closure scenario

Final Lynx TDF Berm (No Cover)

Key observations for this scenario are summarized here (see Table 1):

- Zn loads to groundwater in Zone II are predicted to increase to 48.7 t/year Zn after the Lynx TDF berm is raised to its final height (or about 1% higher than the load after the Old TDF has been closed). This small increase is attributed to substantial Zn loads to groundwater that were simulated from surface waste within the future footprint of the berm under current conditions.
- The load to the Old TDF under-drains is predicted to be reduced to 29.0 t/year Zn. This is about the same Zn load as is predicted to be recovered from groundwater after the Old TDF is closed.
- Zn concentrations in Myra Creek will not be affected by raising the Lynx TDF embankment berm to its final height. This is because the Lynx SIS will continue to intercept most of the Zn load that is directed towards the creek in Zone II.

Performance of Lynx TDF Berm Cover

Key observations for this scenario are summarized here (see Table 3):

- For final closure, NMF plans to cover the Lynx TDF embankment berm with a mixture of rock, till, and soil that will be re-vegetated with trees (see Amec Foster Wheeler, 2016). Reducing recharge to the Lynx TDF embankment berm to 50% of MAP is predicted to reduce the Zn load to the groundwater system to 43.7 t/year Zn. This is 10% lower than the predicted Zn load to groundwater once the Lynx TDF berm has been raised to its final height.

- For comparison purposes, RGC simulated the effect of placing a geomembrane liner on the Lynx TDF embankment berm. Reducing recharge to 2% of MAP (representing a liner) is predicted to reduce the Zn load to groundwater by 30% but it is not predicted to affect simulated Zn concentrations in Myra Creek. This reflects the effectiveness of the Lynx SIS, which is assumed to operate in perpetuity to reduce Zn loads to Myra Creek.

Additional SIS Options

Zn concentrations in Myra Creek could be further reduced by additional seepage recovery in the Upper Old TDF Reach and in the ETA/Cookhouse area, by re-connecting the NOD in the Upper Old TDF Reach, or by the installation of additional pumping wells.

Should these measures be implemented, ~40% of the predicted Zn load to Myra Creek at MC-TP4 is related to treated effluent. 23% of the Zn load at MC-TP4 is related to Zn loads from upstream sources and Arnica Creek. Zn concentrations in Myra Creek could therefore only be further reduced by:

- Additional seepage recovery from the Lynx Reach.
- Improved performance of the NOD in the Upper and Lower Old TDF Reaches.
- Reducing Zn concentrations in treated effluent.

Of these options, reducing Zn concentrations in treated effluent by upgrading the water treatment system is likely the most feasible. Portions of Myra Creek could also be lined and/or raised to prevent groundwater discharge to the creek.

Conclusions

This paper has shown that future Zn loads and Zn concentrations in Myra Creek will be reduced most effectively by operating the Lynx SIS. NMF implemented the first phase of the Lynx SIS in 2017, and its hydraulic performance and effect on Myra Creek is currently being monitored. Performance monitoring will allow the interference between the Lynx SIS and NOD to be characterized, and will allow the operation of the Lynx SIS pumping wells (and the shallow drain component) to be optimized.

Neither the operation of the Lynx SIS, nor the subsequent closure of the Old TDF and Lynx TDF, are predicted to reduce Zn concentrations below provincial WQGs. To do so, one or more of the following measures could be implemented:

- Additional SIS pumping well(s) in the ETA/Cookhouse area.
- Western (upgradient) extension of the shallow component of the Lynx SIS.
- Shallow cut-off wall along northern side of Myra Creek stream channel in lower Lynx Reach.
- Lining and/or re-alignment of Myra Creek in the lower Lynx Reach.

NMF is also developing Science Based Environmental Benchmarks (SBEBs) in support of future closure planning. SBEBs for Cd, Cu, and Se are being developed. The SBEBs, when available, will determine whether any of the measures above will be implemented, or if alternative closure strategies should be further evaluated.

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References

Amec Foster Wheeler. 2016a. NX14001K Nyrstar Myra Falls Mine Old TDF closure cover permit level design, Draft.

Amec Foster Wheeler. 2016b. NX14001K.2 Nyrstar Myra Falls Mine Lynx TDF dam face closure cover permit level design, Draft.

Nautilus Environmental Consulting Inc. 2016. Development of site-specific objectives for waterbodies associated with Nyrstar Myra Falls Mining Operations.

O'Kane Consultants Inc. 2014. Myra Falls closure planning – net percolation estimates for various TDF and WRD cover system alternatives.

Robertson GeoConsultants Inc. 2014. Site-wide contaminant load balance model for Nyrstar Myra Falls.

Robertson GeoConsultants Inc. 2016a. Contaminant load balance model for current and future conditions.

Robertson GeoConsultants Inc. 2016b. Old TDF (APA) hydrogeological investigation, Nyrstar Myra Falls.

Robertson GeoConsultants Inc. 2016c. Performance review of new outer drain, Nyrstar Myra Falls.

Wels, C., Thomas, A. and Pesonen, N. 2018. Groundwater discharge into tailings facility during intense precipitation events, Nyrstar Myra Falls, in *Proceedings of the Third Annual International Conference on Mine Water Solutions,* Vancouver, Canada.