Numerical Modelling of Transient Groundwater Flow and Contaminant Transport at the Myra Falls Mine Site

Mahmoud Hussein[1], Paul Ferguson[1], Christoph Wels[1]
Nicole Pesonen[2]

[1]*Robertson GeoConsultants Inc., Vancouver, Canada, mhussein@rgc.ca*
[2]*Myra Falls Mine Site, Campbell River, Canada*

Abstract
The Myra Falls mine is an underground lead-zinc mine on Vancouver Island, British Columbia, Canada. The mine site has been operated since the 1970s and is affected by Acid Rock Drainage (ARD) generated by sulphide-bearing waste rock in the historic waste rock dumps. A numerical groundwater flow and transport model was developed using the software MODFLOW/MT3D to simulate the movement of groundwater and the transport of zinc in the Myra Valley Aquifer (MVA) and to predict Zn loads to Myra Creek during an emergency shutdown of the site-wide SIS.

Keywords: ARD, MODFLOW/MT3D, Groundwater Model, MVA, Myra Creek

Modelling Objectives
The main objectives of the numerical modeling are to simulate "current conditions" for groundwater in the MVA from 2012 to 2019, including six years when the site-wide SIS consisted of the system of Old TDF underdrains in the Lower Old TDF Reach and two full years (since October 2017) when the Phase I Lynx SIS was also operating and to predict Zn loads to Myra Creek during an emergency shutdown of the site-wide SIS due to a power loss on site.

Model Overview
A transient groundwater flow model using the finite difference code MODFLOW and a solute transport model using the MT3D code were developed as part of updating the Site-Wide WLBM for the Myra Falls Mine Site. Together, these are often referred to as the "groundwater model" throughout this paper, unless the flow or transport model is specified.

The groundwater model is calibrated to eight years of monitoring data, including recent performance monitoring data collected during the operation of a fence of pumping wells that are intended to capture ARD-affected groundwater before it reaches Myra Creek. The model is a numerical representation of a conceptual hydrogeological model that has been developed iteratively since 2013. The model is incorporated into a site-wide Water and Load Balance Model (WLBM) that predicts loads and concentrations in Myra Creek due to contaminant loads from unimpacted areas and the water treatment system and groundwater affected by ARD.

The model domain and boundary conditions are shown in Figure 1. The groundwater model simulates groundwater flows and Zn concentrations in the MVA and Zn loading to Pumphouse No.4, the Lynx SIS and Myra Creek from January 1st, 2012, to December 31st, 2019. Simulated flows and loads are shown in Figure 2 and simulated Zn plumes are shown in Figure 3.

Sources of Seepage
Seepage (ARD) from the Lynx TDF berm and WRD#1 and WRD#6 are the major sources of Zn and other constituents to groundwater in the MVA. Secondary sources include PAG waste rock in the Mill and ETA/Cookhouse areas, sulphidic surface waste near the Superpond and in the HW office area and the former Myra Pit, and seepage from the Seismic Upgrade Berm.

Discussion – Current Conditions
The overall spatial extent of the simulated Zn plume is reasonably consistent with observed Zn concentrations in the MVA. For instance,

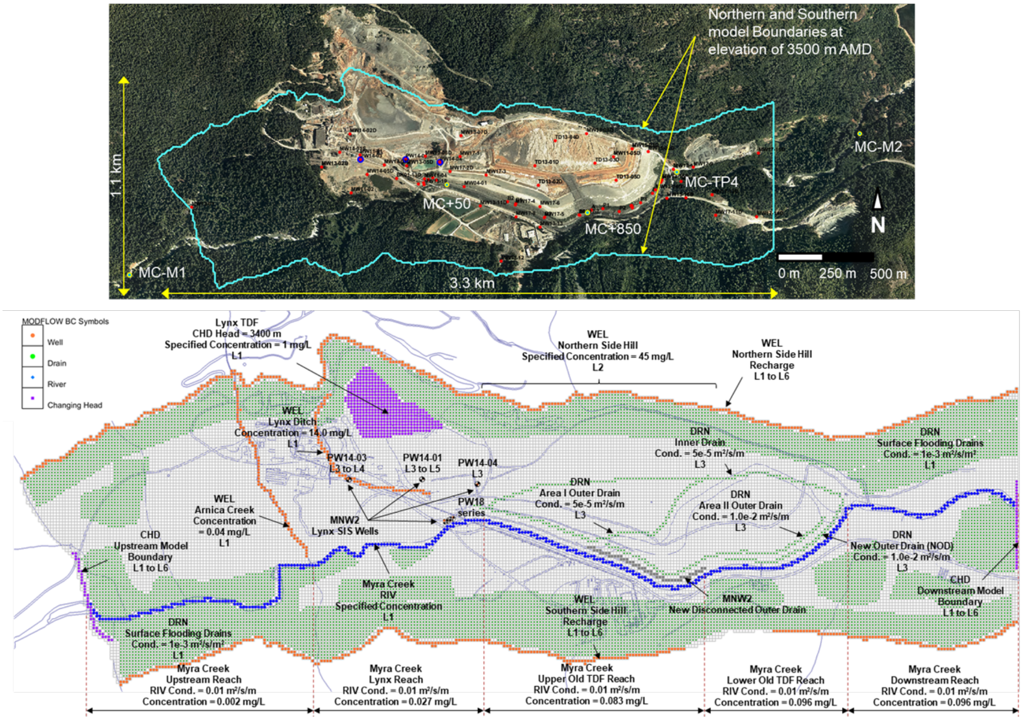

***Figure 1** Model Domain (top) Boundary Conditions and Internal Sources and Sinks (Bottom).*

the elevated Zn concentrations, observed in wells screened beneath the Old TDF (and within the main plume that migrates towards the Old TDF under-drains) are well reproduced by the model. Simulating these wells was a priority during model calibration to ensure Zn loads to the Old TDF under-drains could be represented.

Zn concentrations in key wells in the Mill area are also simulated reasonably, e.g. ≈15 to 20 mg/L Zn at MW13-05D (near PW14-01), and up to 50 mg/L Zn at MW13-06D (north of the Superpond near the toe of the Lynx berm).

The groundwater model simulates decreased Zn concentrations in groundwater in the Upper Old TDF Reach that are attributed to operating the Phase I Lynx SIS, where observed Zn concentrations have decreased from more than 20 mg/L in 2017 to less than 5 mg/L in late 2019 (and 2020). The model slightly overestimates the overall effectiveness of the Old TDF under-drain system as the system is simulated to capture nearly all of the Zn plume with no appreciable simulated bypass. Conceptually, approximately 10% of the Zn load in Myra Creek is related to groundwater bypass in the Lower Old TDF Reach. However, the fit between observed and simulated Zn loads to Pumphouse No. 4 in 2019 was very good, and the model reproduces the observed decrease in captured Zn loads in 2019 during operation of the Lynx SIS.

Discussion – Predictive Runs (SIS Shutdown)

The groundwater model was modified to predict Zn loads to Myra Creek during an emergency shutdown of the site-wide SIS due to a power loss on site for the following three scenarios: Scenario 1; Site-Wide SIS Shutdown, Scenario 2; Old TDF Under-Drain Shutdown and Scenario 3; Phase I Lynx SIS Shutdown. SIS shutdown was assumed during low flow conditions for groundwater in August 2018.

For Scenario 1, the groundwater model predicts increased Zn loads to Myra Creek at MC-TP4 from groundwater within days to a few weeks of the site-wide SIS shutdown

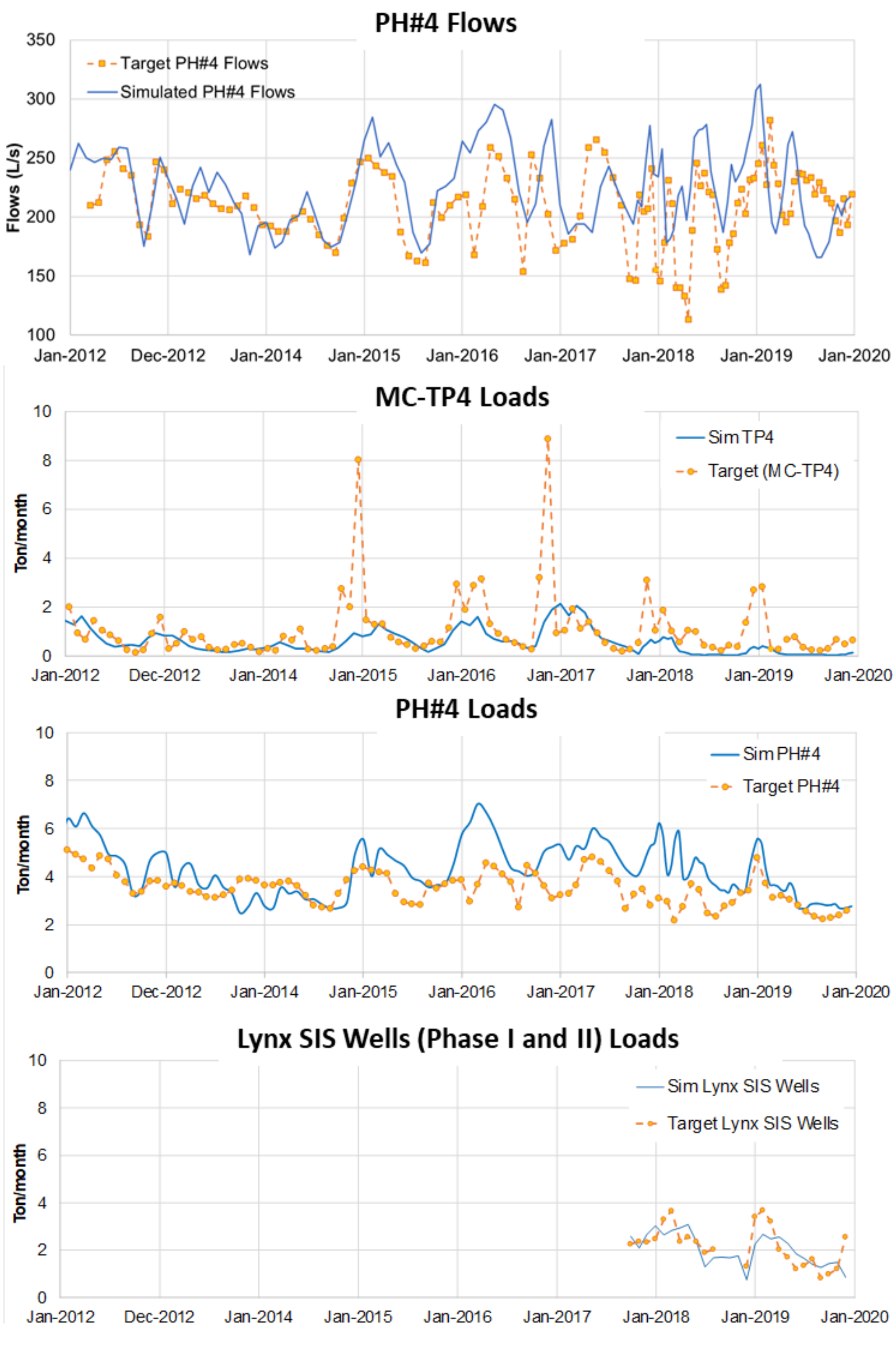

Figure 2 Simulated Monthly Flows to PH#4 and Zn Loads to Myra Creek, PH#4 and SIS wells 2012 to 2019.

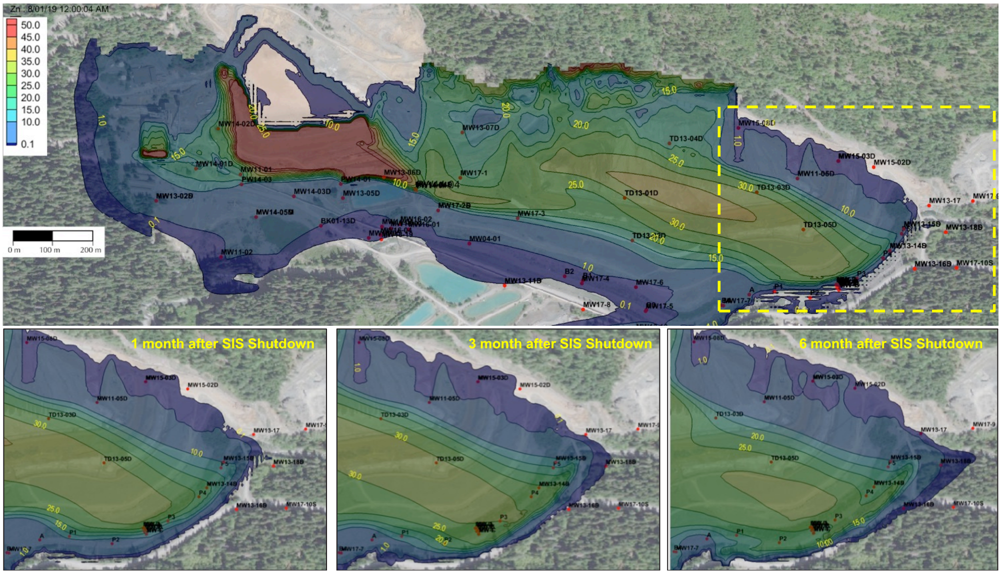

Figure 3 (Top) Simulated Zn Plume (Layer 3) – Lynx SIS Operating (August 2019). (Bottom) Simulated Zn plume in the Lower TDF reach 1, 3 and 6 months after SIS shutdown, Scenario 1.

(Figure 4). Zn loads are predicted to be about one order-of-magnitude higher than the simulated Zn loads to Myra Creek during summer low flow conditions prior to SIS shutdown within this period. The model predicts monthly Zn loads to Myra Creek will increase to approximately 5.8 t/month within six months.

The groundwater model predicts that the majority of the Zn load in groundwater in the shallow MVA will report to Myra Creek within close distance to the Old TDF. Nevertheless, the model also predicts some bypass of impacted groundwater in the shallow MVA. The model predicts that the leading edge of this developing "off-site" Zn plume will have advanced approximately 250 m east of the Old TDF at the end of the 16-month prediction period. This implies an average Zn transport velocity in groundwater of approximately 16 m/month towards the downstream model boundary. It should be noted that the model conservatively assumes that Zn transport in groundwater is not retarded due to the adsorption of Zn to MVA formation materials in the Downstream Reach. Experience at other sites with similar water quality and geology suggests that zinc shows some affinity for sorption resulting in retardation in the order of 30 – 50%. This implies the Zn plume in groundwater of the MVA could also be retarded, possibly migrating less than 200 m in one year. However, Zn retardation would only delay increased Zn loading to the creek in the Old TDF Reach by a few days, given the short distance (≈15 m) between the NOD and Myra Creek in the Lower Old TDF Reach (near MC-TP4).

For Scenario 2, the groundwater model predicts that effectively 100% of the increased Zn load to Myra Creek during the first two months following a shutdown of the site-wide SIS is related to the shutdown of the Old TDF under-drains. The high Zn load during this period is related to the migration of the main Zn plume that is captured by the Old TDF under-drains to Myra Creek. Following this period, the shutdown of the Old TDF under-drains accounts for 85 – 90% of the predicted Zn load to Myra Creek for Site-wide SIS shutdown (Scenario 1). For Scenario 3, the groundwater model predicts an increase in Zn loading about two months following the shutdown of the Phase I Lynx SIS. This Zn load is related to the Zn plume in the Lynx Reach and Upper Old TDF Reaches reaching Myra Creek near the car bridge and in the Upper Old TDF Reach.

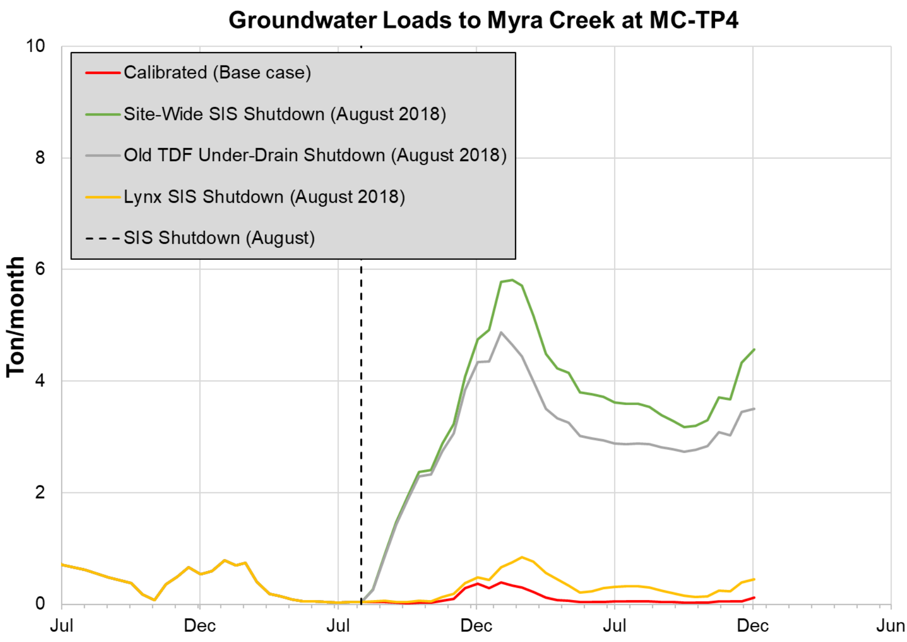

Figure 4 Predicted Zn Loads to Myra Creek at MC-TP4 from Groundwater, SIS Shutdown Scenarios, Shutdown in August.

Key Findings

Operating the Lynx SIS (since October 2017) has reduced loads of Zn and other constituents related to ARD in Myra Creek. This is particularly evident at stations MC+50 (in the Lynx Reach near the car bridge) and MC+800 in the Old TDF Reach. Operating the Lynx SIS also appears to have decreased Zn loads in groundwater captured by the Old TDF under-drains and delivered to the Superpond via Pumphouse No. 4.

The groundwater model provides a reasonable numerical representation of groundwater conditions in the MVA, as a good match between observed heads and the groundwater flow field and the flows captured by the Old TDF under-drains and the Lynx SIS is achieved. Moreover, the inferred Zn plume in groundwater and Zn loads captured by the Old TDF under-drains and the Phase I Lynx SIS are well reproduced. The development of a transient groundwater flow model has significantly improved RGC's understanding of the seasonal behaviour of the groundwater system and has identified aspects of the conceptual model that require improvement.

While the Phase I Lynx SIS has been operating, groundwater captured by the Old TDF under-drains via Pumphouse No. 4 has remained the largest contributor of flow and Zn loads to the Superpond. Groundwater captured by the Phase I Lynx SIS represents the primary contributor of acidity, Al, and Cu loads to the Superpond and are the second largest contributor of SO4 and Zn loads. Process water represents a substantial source of alkalinity to the Superpond that will increase if the milling rate increases.

Zn concentrations in Myra Creek at MC-TP4 and MC-M2 are predicted to increase within days to a few weeks of the site-wide SIS being shut down. Approximately 1 mg/L Zn is predicted initially which is approximately 30 times higher than the 0.033 mg/L Zn-t provincial WQG. Higher Zn concentrations are predicted (≈2 mg/L Zn) about six months after SIS shutdown (or about 60 times higher than WQG), as Zn loads to groundwater (and Myra Creek) increase due to increased recharge by rainfall during the wetter months of the year. Zn concentrations are predicted to remain in the range of 0.5 to 1.5 mg/L Zn until the end of the prediction period.

Approximately 90% of the predicted Zn load during shut down of the site-wide SIS is related to the shutdown of the Old TDF underdrains. The predicted Zn load to Myra Creek due to shut down of the Phase I Lynx SIS is relatively small and represents only a small proportion of the predicted Zn load to the creek during a shutdown of the site-wide SIS. Moreover, the groundwater model predicts it will take several months for Zn loads in Myra Creek to increase due to shut down of this system, due to the longer travel for the plume in the Lynx Reach to Myra Creek.