Validation of Springer Pit Lake Water Balance and Water Quality Model, Mount Polley Mine, British Columbia, Canada

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Abstract

The Mount Polley Mine is a copper-gold mine consisting of three open pits and an underground operation, located in British Columbia, Canada. Following the failure of the glacial lacustrine layer beneath the perimeter embankment and the resulting breach of the embankment at theTailings Storage Facility on August 4, 2014, the Springer Pit has been used to store water draining from existing site facilities and submerged tailings. The Springer Pit continues to be used as a water storage facility under short-term restricted operations and discharge approvals, which also require the pit lake to be drawn down by treating and discharging the water to the receiving environment.

Water needs to be drawn down in the pit lake for two reasons:

- The mine has a positive water balance, so it has a finite capacity and consequently a finite amount of time before water begins to exfiltrate to groundwater and discharge to surface after the pit ultimately reaches its spillway elevation; and,
- The pit lake will need to be dewatered (and the tailings removed) to continue mining viable reserves, pending regulatory approval.

A stochastic water and mass balance model was developed for the Springer Pit to evaluate discharge water quantity and quality in the pit and at downstream receptors. Springer Pit water levels and water quality were simulated on a monthly time step from April 2015 to December 2016 to encompass the period of pit filling and restricted operations. The results of the model were also used to develop mine water management strategies, to provide a basis for selecting a water treatment technology, and to support permitting.

At present (May 2016), the pit lake has been filled to approximately 75% of its total capacity. Monitoring of the pit lake elevations and water chemistry have been ongoing and the empirical data provided an opportunity to validate model predictions. As noted in [2, 3], "two of the biggest problems with modern geochemical pit lake predictions are the challenge for model reviewers to independently repeat and check calculations, and the lack of understanding of the uncertainty associated with predictions." This study addressed both of these problems and can be used to refine model inputs before extending the model for the next stages of mining. This is consistent with the recommendation provided in [4], that is "if the lake is in the filling stage, compare model predictions with observed data…validate and refine inputs to the model whenever information becomes available." Moreover, it provides a counterpoint to critiques of pit lake modelling [5].

Predicted water elevation and concentrations were compared to observed data collected in the Springer Pit lake. In general, observed concentrations were within or below the range of predictions during filling, indicating that the model is performing well, particularly in light of challenges generally associated with pit lake models [3]. Three key factors that have led to a failure to predict mine waters elsewhere [6], particularly at copper mines, were favourable at Mount Polley: the predominance of non-acid generating material on site; the high quantity and quality of operational mine water data; and, the mine's adherence to the water management plan.

Key words: pit lakes, modeling, validation

Introduction

The Mount Polley Mine (the mine) is a copper-gold mine operated by Mount Polley Mining Corporation (MPMC), a subsidiary of Imperial Metals Corporation. The mine is located approximately 56 km northeast of Williams Lake, British Columbia, Canada (Figure 1) and includes open pit and underground operations. Following the failure of the glacial lacustrine layer beneath the perimeter embankment and the resulting breach of the embankment at the at the Tailings Storage Facility (TSF) on August 4, 2014, the Springer Pit has been used to store water draining from existing mine facilities and tailings (both of which would previously have been stored in the TSF). A short-term water management plan was developed to manage a positive site water balance while drawing down water that has accumulated in Springer Pit since the breach.

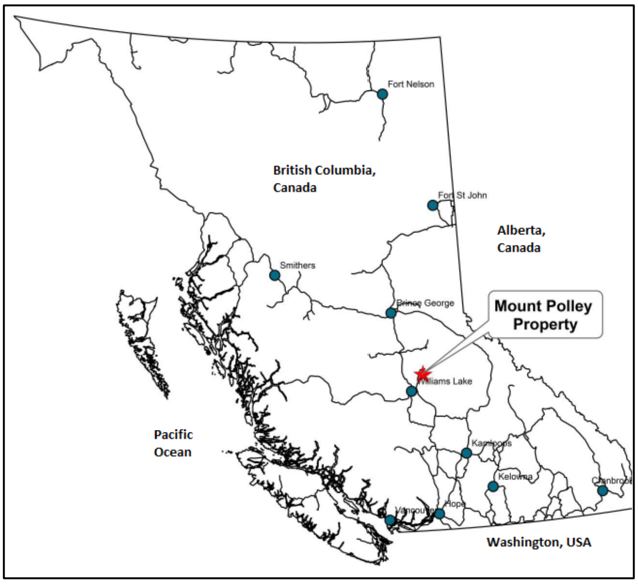


Figure 1. *Location of Mount Polley Mine, B.C., Canada*

As part of the water management planning, two models were developed to assess water quantity and quality in the Springer Pit lake:

1. **Site-Wide Water Balance Model (WBM):** the objective of this model was to simulate site water quantities, including Springer Pit volumes, under the current and proposed site water management plan.

2. **Mass-Balance Water Quality Model (WQM):** this model was developed to predict Springer Pit lake water quality for the purpose of estimating effluent quality and identifying constituents of potential concern in this facility and in discharge to the receiving environment.

The above models were developed using GoldSim™ Version 11.1 [1] and were internally linked. The WBM accounted for all flows within the mine as well as flows in local watercourses. The WQM accounted for mass transfers from each of the flows that could influence the water quality in Springer Pit.

To address uncertainty, the model was developed stochastically using a Monte Carlo approach. In the model, each input was defined as a probability distribution function that was randomly sampled over 1000 realizations. This approach provided a range of water elevations and qualities in Springer Pit at each timestep, which were subsequently used to calculate percentiles for each parameter at each model timestep. The predicted maximum of the 95th percentile constituent concentrations, projected over the duration of the model, were used to inform the water treatment plant design and to propose effluent limits for the short-term discharge permit. For additional detail on the WBM and WQM development, the reader is referred to the project Technical Assessment Report [7].

Water Balance Model

The pit lake is presently (as of May 2016) filled to approximately 75% of its capacity of approximately 15 Mm^3. Ongoing monitoring of pit lake water levels provided an opportunity to validate model predictions. The term "validation" as applied here refers to measurement of water levels and concentrations while the pit lake is filling, and comparing those measured values to model predictions that were generated before filling.

The water balance model has been updated regularly with measured climate and water level data since April 1, 2015 (Figure 2). The simulated lake elevations began to diverge in mid-June 2015, with the predicted lake elevation at the end of June 2015 being approximately 3.9 m higher than the observed value. Since July 2015, the simulated change in lake elevation has continued to diverge from the observed elevations at a slower rate. By the end of November 2015, the simulated Springer Pit lake elevation was 9.9 m higher than the observed level. This is equal to a total over-prediction between April 1 and November 30, 2015, of 2.8 Mm^3.

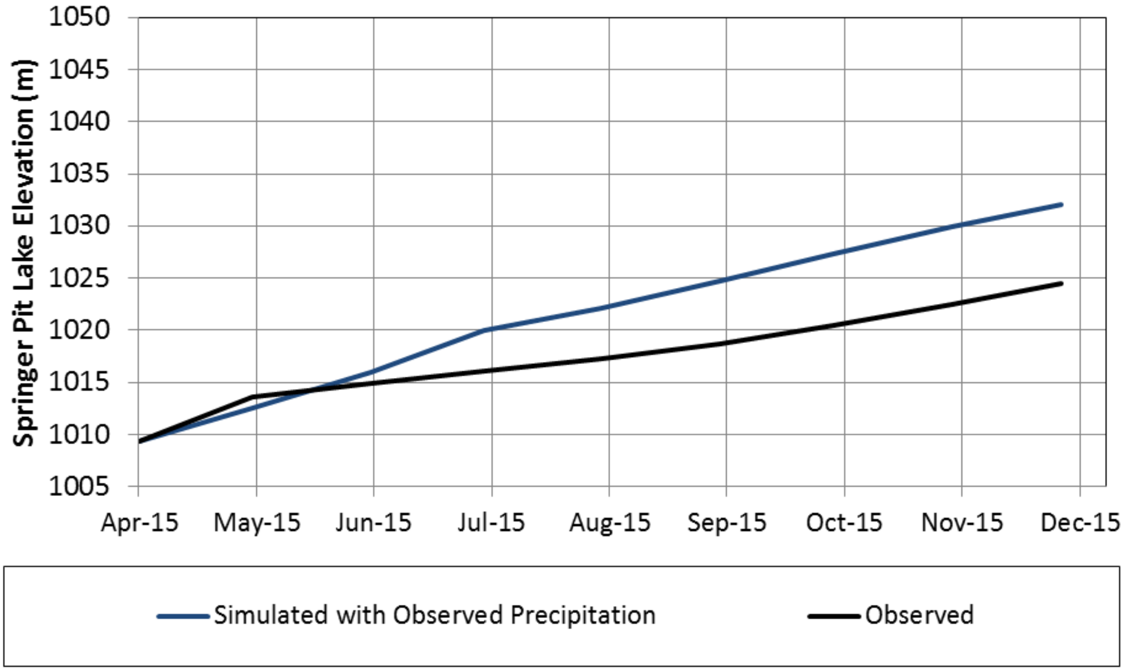


Figure 2: *Comparison between Observed and Simulated Springer Pit Lake Elevations (m)*

A review of the assumptions built into the WBM and the implementation of water management strategies during restricted operations revealed that the mill restart and the commencement of Springer Pit dewatering occurred at a later date than assumed in the WBM. The WBM was updated to reflect the actual timing of the mill restart and pit dewatering date. Predicted Springer Pit water levels, accounting for these updates, are presented in Figure 3. Water elevations are simulated in the WBM using stochastic climate values, and results are shown for the Average, and the 1 in 200-y Wet (99.5th percentile), and the 1 in 100-y Dry (0.5th percentile). Comparing the updated simulation that is based on measured climate inputs against the original, stochastic predictions, updated Springer Pit lake elevations have consistently tracked between the Average and 1:200-y Dry projections, and have climbed towards the Average projection over time (Figure 3).

Comparing measured water levels against both sets of model simulations, the observed Springer Pit lake elevations track consistently below the 1:200-y dry projection (Figure 3) from June 1 onwards. This is explained by the early snowpack depletion and extreme dry conditions experienced in early 2015. As of April 1, 2015, the snowpack at Mount Polley had essentially been depleted. Between the typical freshet months of April through June, a total of 105 mm of rainfall plus snowmelt was recorded. For comparison, the historic average rainfall plus snowmelt is 338 mm, and 176 mm for 1 in 200-y dry conditions. Therefore, runoff at the mine for the freshet period in 2015 (April through June) was compounded by a lack of April snowpack, plus the extreme dry conditions that remained close to 1:200-y dry conditions during May and June. For the remainder of 2015, the Mine has generally experienced more normal precipitation.

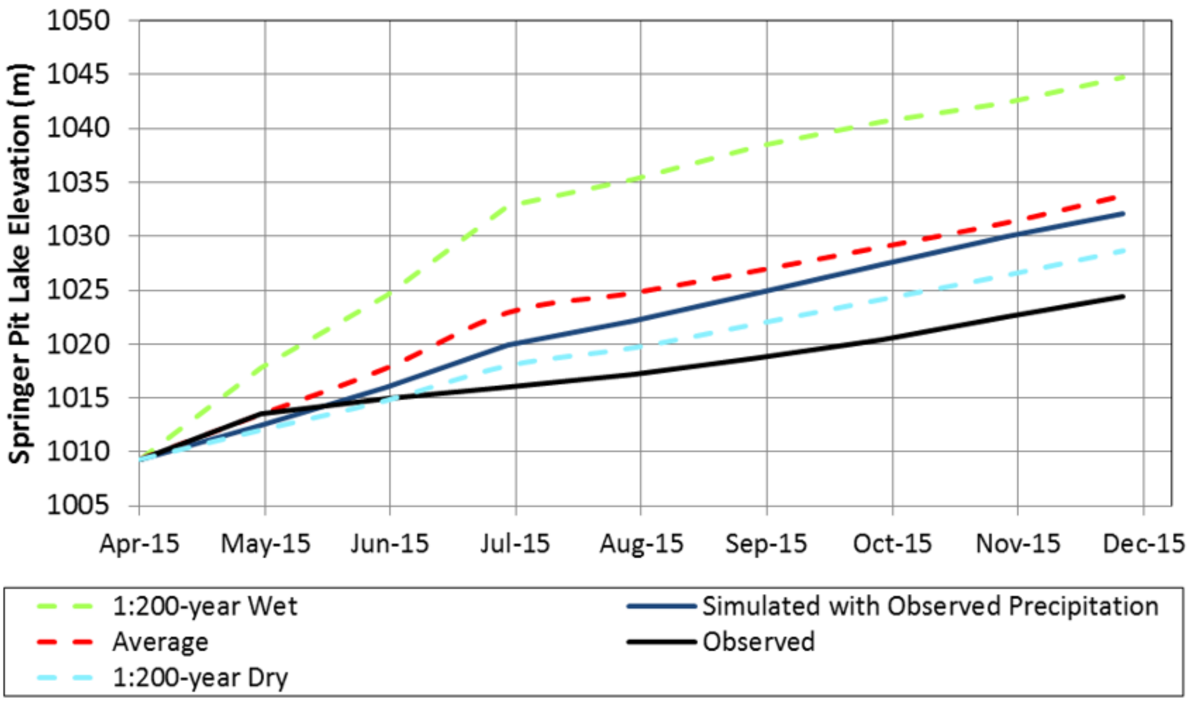


Figure 3: *Comparison between Observed and Simulated Springer Pit Elevations with the TAR Predictions.*

Water Quality Model

Water concentrations of forty modelled constituents were measured in Springer Pit lake during the period of July to December 2015, which included restricted restart of operations and pit filling. A comparison of the WQM predictions against measured concentrations shows that most constituent concentrations were either within or below the predicted range. Based on the comparison, predictions were grouped into three categories:

- **Over-predicted**: concentrations that were observed to be generally below the 5th percentile model predictions, including:
  - **Ions and nutrients:** chloride, ammonia, and total phosphorus;
  - **Dissolved metals:** aluminum, arsenic, cadmium, cobalt, manganese, and zinc; and
  - **Total metals:** aluminum, cadmium, chromium, cobalt, copper, manganese, silver, vanadium, and zinc.
- **Accurate**: concentrations that were observed to be between the projected 5th and 95th percentile model predictions including:
  - **Ions and nutrients:** total dissolved solids, calcium, sulphate, and nitrate;
  - **Dissolved metals:** antimony, boron, chromium, iron, molybdenum and silver; and
  - **Total metals:** antimony, boron and molybdenum.

- **Under-predicted**: concentrations that were observed to be greater than the 95th percentile model predictions, including:
  - **Ions and nutrients:** magnesium, and nitrate;
  - **Dissolved metals:** copper and selenium; and
  - **Total metals:** arsenic and selenium.

Figure 4 provides examples of select constituents that were representative of the above categories. Observed data on these plots are represented by samples from the Springer Pit dewatering sump, as well as samples collected within the pit lake near the surface and bottom.

Sulphate and molybdenum were two constituents that were observed to be within the WQM projected concentration ranges (Figure 4). The good agreement indicates that model inputs were well characterized and that these constituents were not sensitive to the differences in water management described above.

Observed concentrations of total phosphorus and copper in Springer Pit were below the WQM projected ranges (Figure 4). There are several reasons why the model may be over-predicting concentrations, including:

- The model was developed to predict water quality conservatively; where uncertainty existed in model inputs, the inputs were selected to minimize the risk of under-prediction.
- Metal concentrations that are far below detection limits may be skewed upward by model inputs where half-detection limits were applied.
- Processes such as uptake of nutrients, precipitation of dissolved species, and adsorption and settling of particulate materials were not accounted for in the model.

Although these factors may lead to over-prediction of concentrations, the model is considered valid for the purpose of developing permit effluent limits because the limits are also derived such that acute guidelines and Metal Mining Effluent Regulations limits are met at end-of-pipe and chronic guidelines are met within an Initial Dilution Zone in the receiving environment. By excluding the process of setting of TSS and particulate metals in the pit lake, the limits applied to the discharge cover a range of conditions, including worst-case conditions with respect to settling. Therefore, deviations in model predictions from observed conditions in this category tend to promote the ultimate objective of the model, which is protection of end uses in the receiving environment.

Nitrate and total selenium were observed to be above the projected ranges in the WQM (Figure 5). (*Note that other under-predicted constituents such as magnesium and dissolved copper were only marginally above predicted ranges*). A review of the WQM input assumptions and actual mine conditions (e.g., water management implementation, ongoing water quality monitoring), identified the following reasons that could result in an under-prediction of these constituents:

- the actual mill restart time (August 4, 2015) occurred later than was assumed in the WQM (June 1, 2015);
- increases in selenium concentrations were observed in one of the mine site facilities (the Northwest Sump) draining to the Springer Pit, at consistently higher concentrations than measured during the period when the water quality model input for this facility was derived (Figure 5);
- some oxidation of stockpiled ores may have occurred during the year that the mine did not operate following the TSF breach (August 2014 to August 2015), which could have increased the mass load of constituents upon restart of milling;

- some water transfers among site facilities differed from those projected at the time of model development (due in part to the unusual climate conditions in 2015 as described above); and
- a later than anticipated discharge approval date resulted in dewatering of Springer Pit commencing on December 1, 2015 rather than on July 1, 2015.

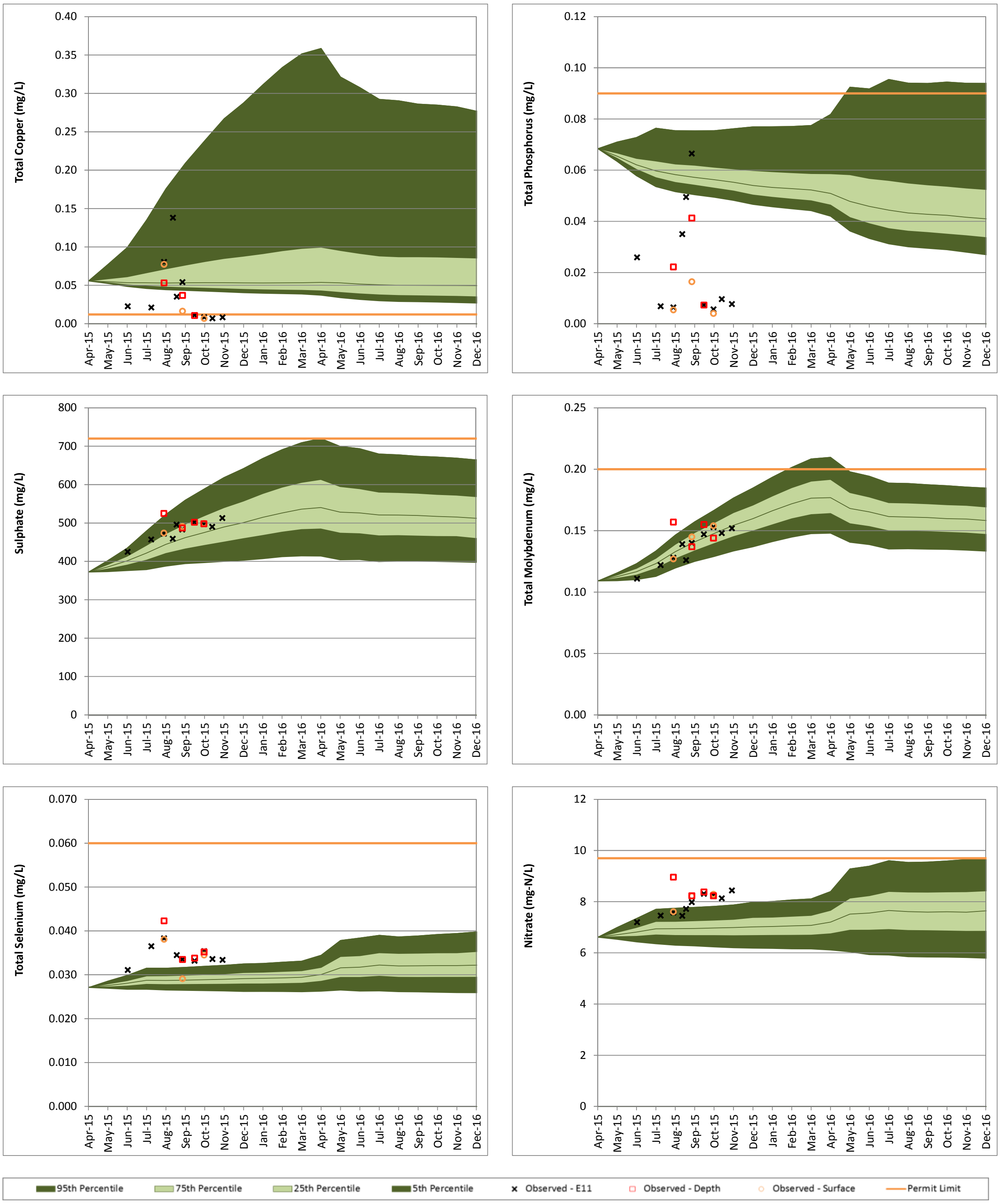
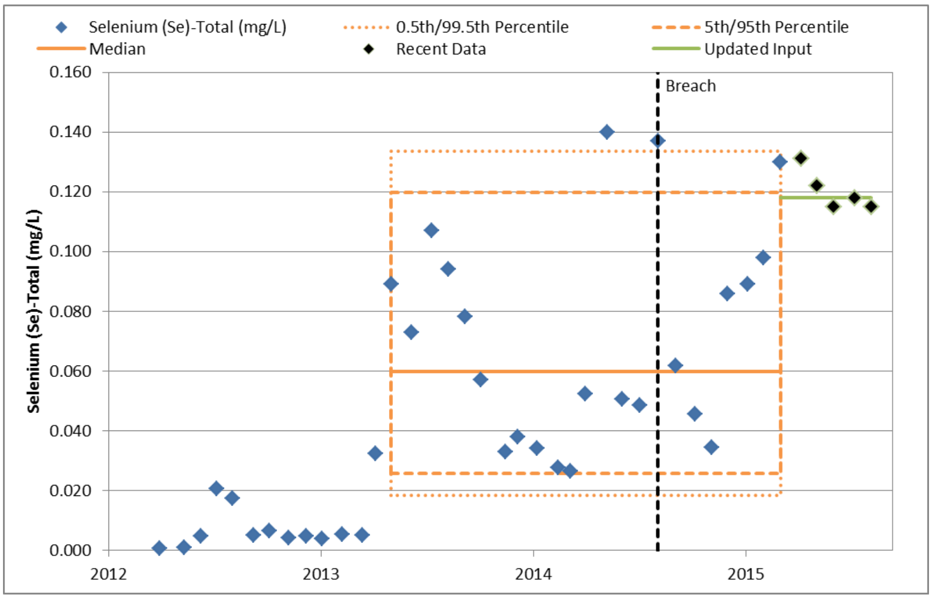


***Figure 4:** Comparison of Observed Concentrations and Model Predictions for Select Constituents*



Note: Orange box indicates range of inputs used to derive inputs for model; green line shows mean of measurements after model predictions were generated.

Figure 5: *Monitored Total Selenium in the NW Sump and Water Quality Inputs Used*.

Model Refinements

After comparing observations to predictions and reviewing model inputs to identify the cause of any differences, the WBM and WQM were updated to improve future predictive ability. The main update was to align the water balance with measured flows on site, and the second was to update the water quality input for the Norwest Sump that collects drainage from the Temporary Potentially Acid Generating (PAG) Stockpile (in particular for selenium). Runoff for the period after model predictions were generated was observed to have higher concentrations (mean shown as the green line in Figure 5) than the previous period (shown in the orange box in Figure 5), which was originally used to derive inputs. Model predictions generated by re-simulating the same time period with these updates are shown in Figure 6. The update improved the comparison of measured values against model predictions (which are now hindcasts) for constituents that were under-predicted, but did not appreciably change those that were over-predicted. In the updated predictions, the uncertainty bounds were narrowed for most constituents.

Total selenium concentrations measured in the pit lake peaked in mid-August (Figures 4) and subsequently declined. Although the peak measured concentration of total selenium remained above the maximum of the updated model predictions, measured concentrations have decreased to be within the 5^{th} and 95^{th} percentile predictions, following this peak (Figure 6).

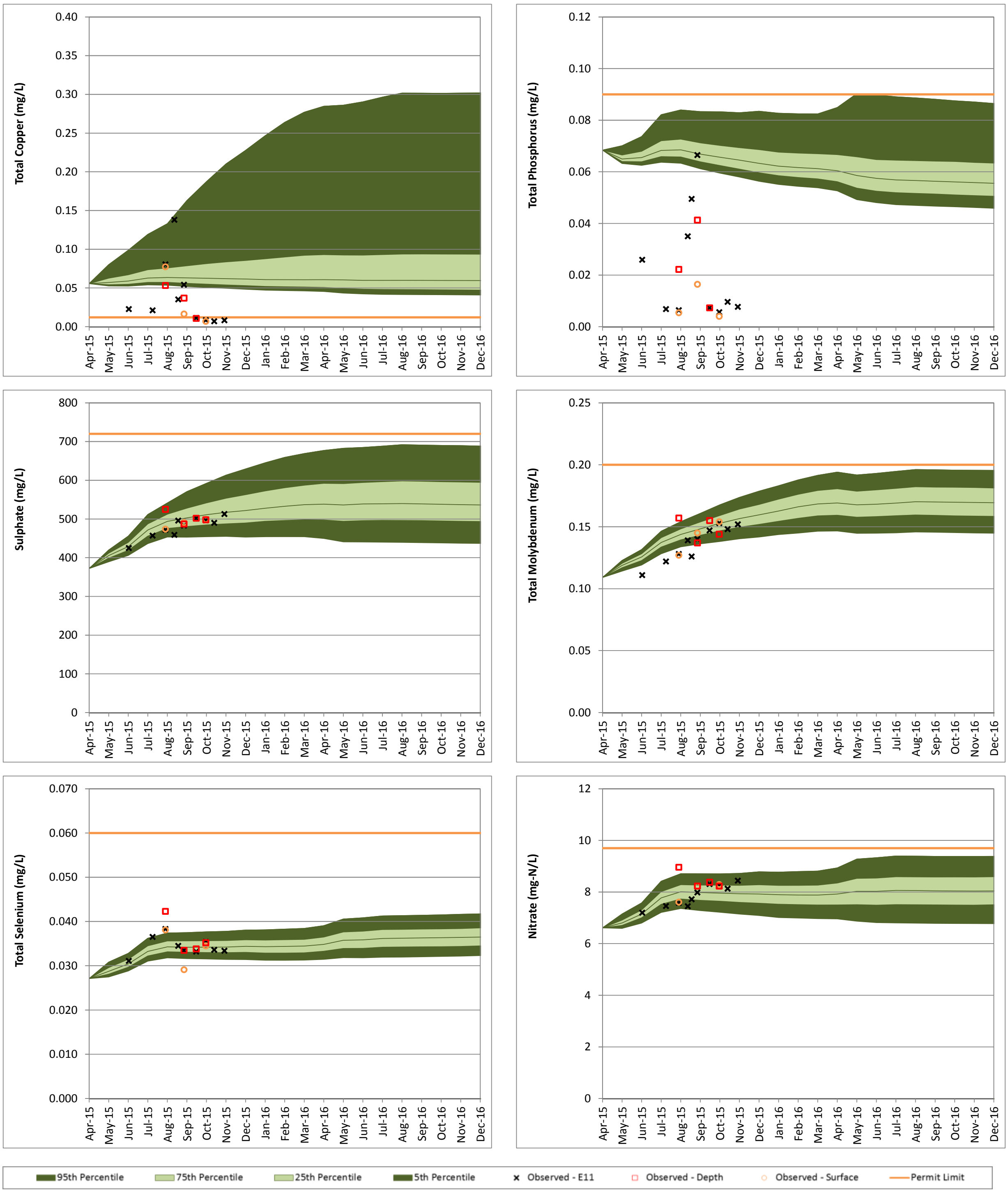


Figure 6: *Comparison of Observed Concentrations and Updated Model Predictions for Select Constituents*

Conclusions

A probabilistic WBM and WQM model were developed to predict water quantity and quality in the Springer Pit lake during restricted operations at the mine (contact water and tailings stored in the pit) [7]. At present (May 2016), the pit lake has been filled to approximately 75% of its total capacity. Monitoring of the pit lake elevations and chemistry have been ongoing and the empirical data provided an opportunity to validate model predictions.

Based on observed accumulations in Springer Pit, the WBM appears to be over-predicting water volumes. Although predictions have remained below average, the simulated water volumes inflows to Springer Pit since May 2015 have consistently exceeded the observed volumes. In light of these results, the model calibration parameters (runoff coefficients and base flows) will be reviewed and consideration given to atypical weather occurring during the validation period to improve model predictions. The model will be updated regularly to observed water levels for ongoing water management.

Based on a comparison of modelled to monitored concentrations in Springer Pit, most constituent concentrations were within or below predicted ranges. The model is presently being updated with geochemical source terms and a longer time frame of operations, and the differences identified during the model validation will be considered in the long-term update.

As noted in [2, 3], "two of the biggest problems with modern geochemical pit lake predictions are the challenge for model reviewers to independently repeat and check calculations, and the lack of understanding of the uncertainty associated with predictions." This study addressed both of these problems and can be used to refine model inputs before extending the model for the next stages of mining. This is consistent with the recommendation provided in [4], that is "if the lake is in the filling stage, compare model predictions with observed data…validate and refine inputs to the model whenever information becomes available." Moreover, it provides a counterpoint to critiques of pit lake modelling [5].

In general, the model is deemed to have performed well and achieved its objectives, particularly in light of challenges generally associated with pit lake models [3]. Three key factors that have led to a failure to predict mine waters elsewhere [6], particularly at copper mines, were favourable at Mount Polley: the predominance of non-acid generating material on site; the high quantity and quality of operational mine water data; and, the mine's adherence to the water management plan.

Water quantity and water quality models are a valuable tool that are commonly used to evaluate site effluent water quality and volumes for several purposes, including deriving mine effluent criteria and informing water treatment plant design. The validation of the Mount Polley WBM and WQM as part of the current study highlights the need to monitor, review and refine models after predictions are made to improve predictive ability when the model is applied to future iterations.

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