3rd Canadian Conference on Nuclear Waste Management, Decommissioning and Environmental Restoration

Ottawa Marriott Hotel, Ottawa, ON, Canada, September 11-14, 2016

INTEGRATION OF FIELD INVESTIGATIONS AND AN INNOVATIVE MODELLING TOOL TOPRIORITIZE CLOSURE STRATEGIES FOR AN ABANDONED URANIUM MINE

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Abstract

The Gunnar Mine was a uranium mine located in northern Saskatchewan, Canada, on the north shore of Lake Athabasca. It operated as an open pit and underground mine from 1951-1963. The Saskatchewan Research Council began site decommissioning in 2010. Decommissioning options for the Gunnar Mine site were evaluated by considering the potential source loadings of trace metals and radionuclides from the site, and the potential effects of these loadings on downstream water quality. The evaluation of decommissioning options should be: 1. based on appropriate site data that accurately characterizes the mine source loadings; 2. holistic and account for all potential mine source loadings so as to prioritize sources based on net benefit to downstream water quality; and 3. clear and understandable to a broad group of stakeholders.

Field investigations were utilized in the development of a site specific loadings and water quality model (MineMod™). The model was developed with three objectives: 1. to assess the water quality that would result from preferred closure options; 2. to identify any issues that may require additional management; and 3. to assess the required efficiency of potential mitigation activities for closure.

Several conditions representing preferred closure options were built into the model. The model was developed and calibrated using operating data on flows and concentrations from known sources. Numerous sensitivity analyses were completed within the model to identify the key controls on the radium-226, uranium, arsenic, and lead concentrations in discharge from the site, as well as to understand how various mitigation strategies would influence water quality post-closure.

Model results showed that waste rock represents the greatest potential loading of radium-226, uranium, arsenic, and lead to downstream waterbodies. Overall, the loadings model results provide a path forward in assessing potential remediation strategies and subsequent trade off studies.

1. Introduction

Current closure planning practices address issues on a case-by-case basis and are often not well integrated on a site-wide basis. By not addressing risk management and risk characterization on a holistic basis, mining companies risk implementing remediation strategies that provide little value in reducing the risk profile. Additionally, opportunities for strategies with high relative value may be overlooked.

The evaluation of decommissioning options should be: 1. based on appropriate site data that accurately characterizes the mine source loadings; 2. holistic and account for all potential mine source loadings so as to prioritize sources based on net benefit to downstream water quality; and 3. clear and understandable to a broad group of stakeholders.

A GIS-based database management system and calculation tool called MineMod^{TM} was used in this evaluation. It represents a mass balance and mixing model that calculates loadings to, and concentrations in the receiving water bodies.It provides a real-time platform that can be used to easily evaluated differentdecommissioning options, to facilitate proactive closure planning and to ensure the most appropriate strategies are implemented.The model incorporates objects such as site hydrology, geographical site aspects, and site chemistry to predict loadings in the receiving environment, including Langley and Zeemel bays (general overview is shown in Figure 1.1.).

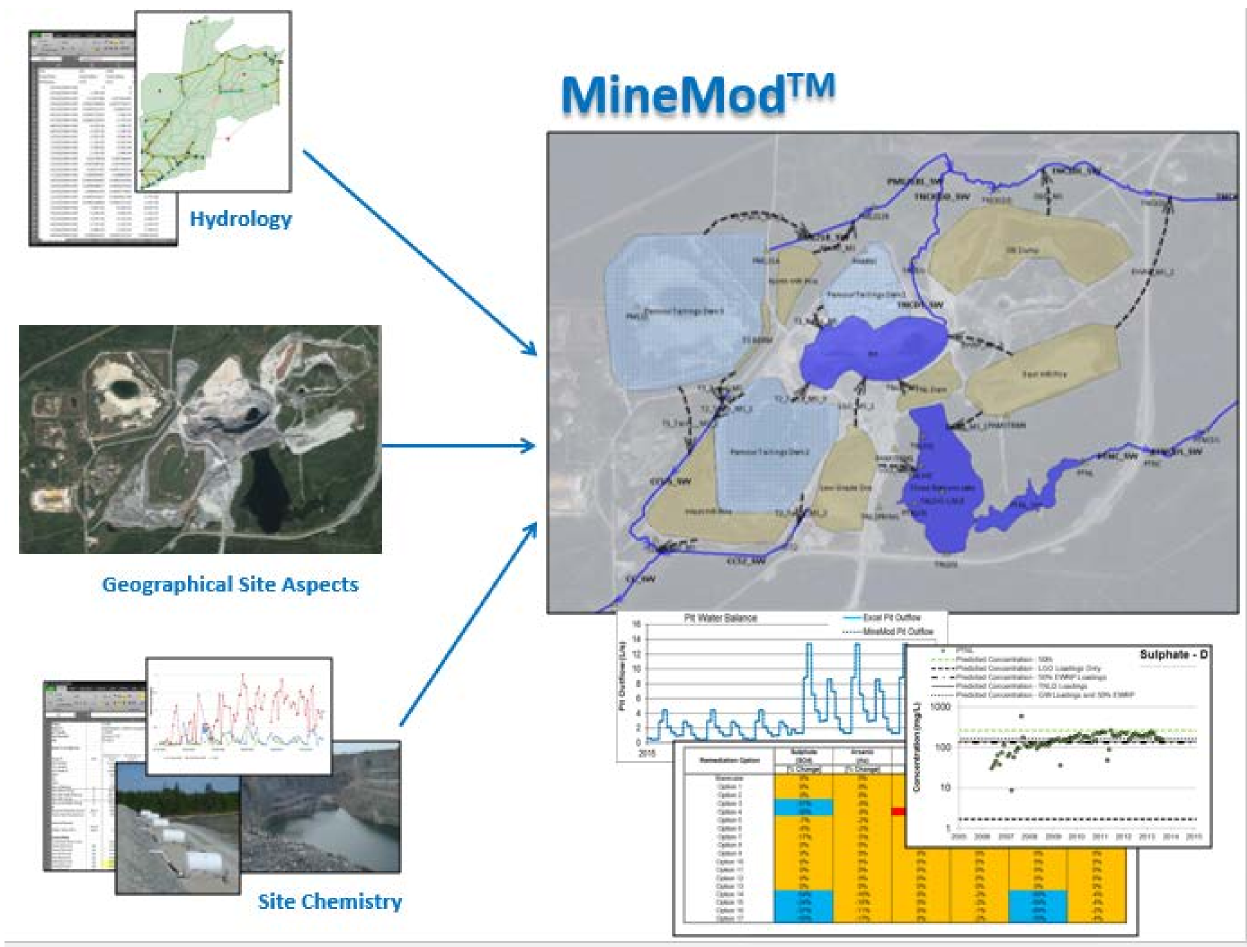

Figure 1.1 Graphical overview of MineMod^{TM}

2. Loadings Model Description

The loadings model developed for this project (MineMod™)includes conservation of mass and flow. The model is based on two types of water bodies; ponds or lakes that contain specified volumes and therefore have hydraulic retention or residence times that depend on flow rates; and creeks that, for modelling purposes have no retention time. The ponds are modelled numerically with a finite difference approach with specified time steps while creeks are modelled analytically with no need to specify calculation time step values. The concentrations of contaminants of potential concern (COPCs) in all waters can be specified for initial conditions, and can receive loadings of COPCs from baseline or background flows, upstream waters, and from mass loadings that are independent of flow.An example of the inputs and outputs for a pond is shown in Figure 2.1. Based on the inputs, the outflow rate and COPC concentrations are calculated.The volume of the ponds, flows and mass loadings can vary with time.

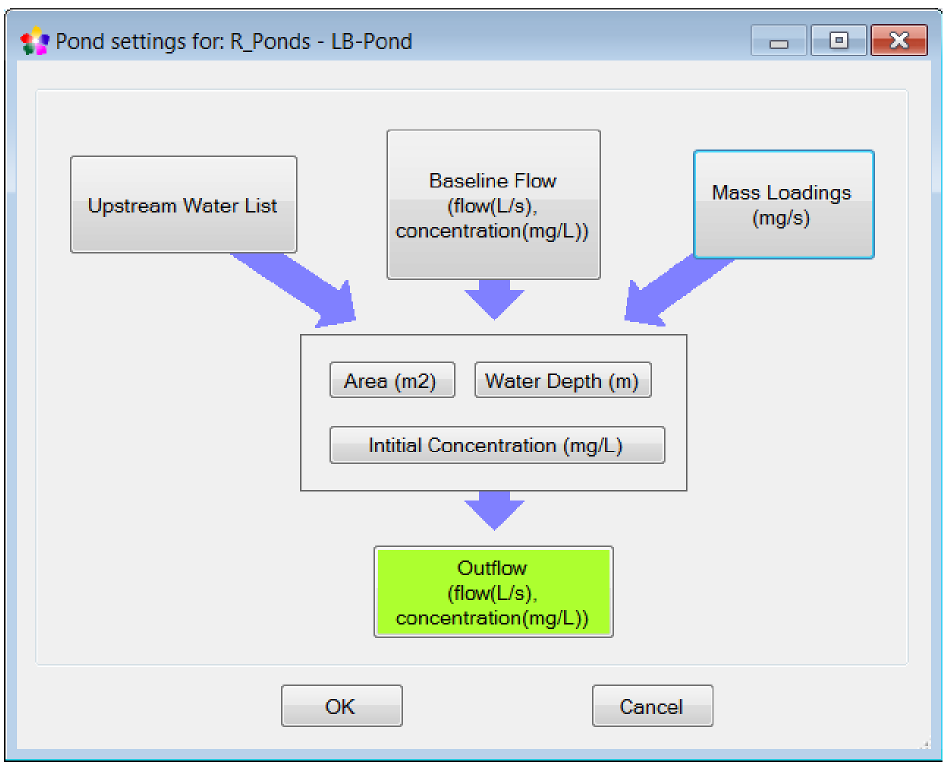

Figure 2.1 Structure of the pond model used in MineMod™

The input options for are baseline flow and concentrations, mass loadings, area and depth of the waterbody for ponds and initial concentrations. The pond outputs include outflow rates and concentrations and mass loadings.

Model source can be represented by mass loadings (mass/time) or as flow rates (volume/time) and concentrations (mass/volume). All inputs of flows, concentration and mass loadings can be specified for any time period of interest and can therefore be time-dependent in the model. Groundwater flow paths, flow rates, and concentrations of COPCs in groundwater can also be specified.

An example of a plot of outflow rates and concentrations of selected COPCs is shown in Figure 2.2.

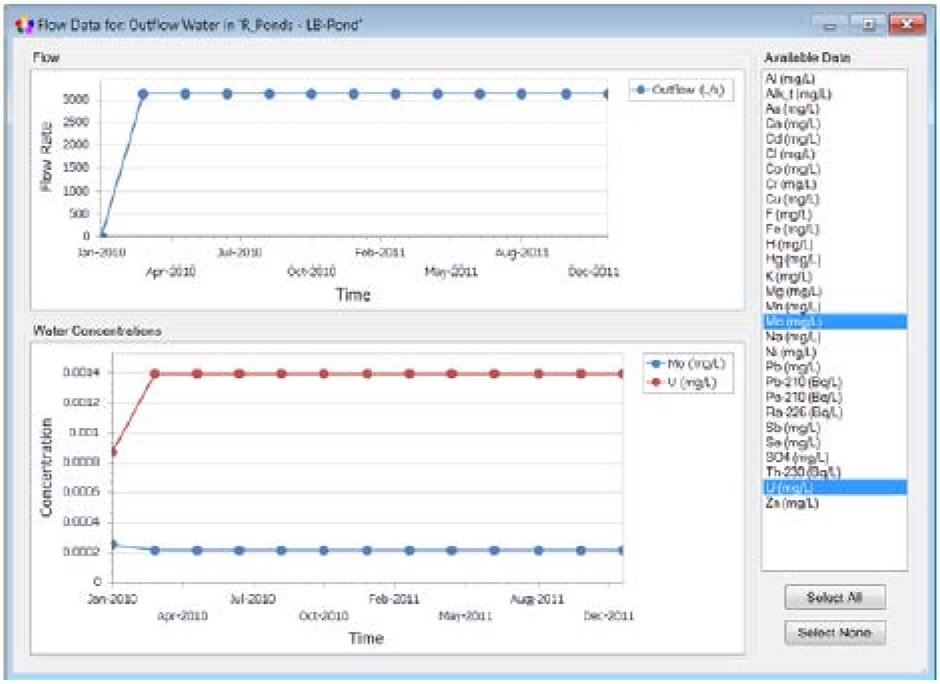

Figure 2.2 Example plot of outflow rates and concentration for selected COPCs.

3. The Gunnar Uranium Mine Case Study

The former Gunnar Uranium Mine (the “Site”) is located on the Crackingstone Peninsula on the northern shore of Lake Athabasca, approximately 25 km southwest of Uranium City, Saskatchewan. The mine operated with both underground and open pit mines for nine years until 1964, with a peak capacity of about 2000 tonnes per day. The mine was abandoned anddecommissioning is now the responsibility of the Government of Saskatchewan.The locations of Mine Site Aspects are provide in Figure 3.1.

A Detailed Quantitative Risk Assessment [1] was completed for the Site as part of Environmental Impact Study investigations [2]. The risk assessment for existing conditions concluded that uranium, radium-226, and cadmium represented a risk to aquatic and benthic organisms in the receiving environment. Risks to humans were also identified from arsenic and radium-226. Risks are somewhat proportional to the rates of transfer or COPC loadings rates from sources to receiving waters. Remedial measures have been considered for the various Gunnar Site Aspects (such as tailings, waste rock and other potential sources)as a means of improving site conditions and reducing risk to the environment.

EcoMetrix Incorporated (EcoMetrix) performed a loadings assessment for the Gunnar Site to provide a basis for comparing the relative benefits, represented by estimated decreases in loadings of important COPCs (e.g., radium-226, uranium, arsenic, and lead), for various remediation options.

The loading rates from Gunnar Site Aspects for current conditions werecompared to those for the proposed remedial options to assess the relative reduction ofloads and risks. A comprehensive Site-wide loadings model was developed for thispurpose.The Gunnar Site loadings model provides a framework to quantify the movement of COPCs through water pathways from source areas to the receiving water bodies. The loadings model is based on a conceptual model that includes the production of COPCs in Site Aspects, such as tailings, waste rock and other potential sources, the migration of COPCs through surface water and groundwater pathways and the estimation of concentrations of COPCs in receiving waters, including Langley and Zeemel bays [1].

The Gunnar Site loadings model represents a mass balance and mixing model that calculates loadings to, and concentrations in the receiving water bodies. Calculated concentrations can be compared to measured values derived from monitoring data at various locations across the Site to demonstrate the reasonableness of the selected source term loadings from the important Site Aspects. The loadings model can then be adjusted to account for changes associated with proposed remedial activities and the resulting effects on the receiving water bodies can be assessed and compared to existing conditions and to the effects of other remedial options.

Figure 3.1 Gunnar Mine Site Aspects

3.1 Study objectives

The overall goal in developing the loadings model in MineMod™for the Site was to compare relative benefits, represented by decreases in loadings of COPCs and to decrease risk. The overall goal can be broken down into the following study objectives:

1. to assess the water quality that would result from preferred closure options;
2. to identify any issues that may require additional management; and
3. to assess the required efficiency of potential mitigation activities for closure.

To achieve these study objectives, a site wide quantitative loadings models was developed and applied to assess existing conditions and potential remediation alternatives related to sources, pathways and key receptor water bodies.

3.2 Gunnar Site loadings model

3.2.1 Sources of Contaminants of Potential Concern

There are several potential sources of COPCs on the Gunnar Site that contribute varying quantities or loadings of COPCs to local surface drainages or subsurface water. The source terms considered by the model included tailings, waste rock, and the open pit. A key component to understanding the potential source terms associated with the waste rock and tailings is the physical and chemical characterization of the water present within these materials. Characterization of these materials included the physical and chemical quantification of soluble loads in the moisture or pore waters that have resulted from weathering reactions and the flow of infiltrating waters originating as rainfall and snowmelt [3]. Source terms were developed by considering the dynamics of flow in combination with leaching that resulted in the observed soluble loads

The physico-chemical processes producing COPCs from uncovered tailings that are exposed at surface include rinsing or flushing of shallow tailings porewater during rainfall events or snow melt that is transported in surface runoff. As well, deeper tailings porewaters, represented by water from the monitoring wells, can migrate out of the tailings with groundwater. The physico-chemical processes producing COPCs from the underwater tailings in Langley Bay include the upward mass flux from the tailings surface into the overlying water column as well as the porewaters that can migrate with groundwater from the tailings into the bay.

Field investigations were carried outto characterize waste rock and tailings [3]. The program involved collecting 124 samples from 24 test pits and analyzing for metals, radionuclides, and leachable mass, pore water concentrations, grain size analysis, and validation against field seep data. The results of the field investigations indicated that there are soluble solid masses releasingCOPCs in the pore waters associated with the waste rock piles. These soluble constituents are released from the waste rock as a result of leaching by rainfall and snow melt. The main pathway for the release of COPCs from the waste rock is infiltrating water that transports the soluble constituents to the base of the piles, where the water either flows across the natural ground or may enter the shallow groundwater before entering Zeemel Bay and St. Mary's Channel.

Water within the Gunnar Open Pit currently exhibits elevated concentrations of several COPCs, including uranium and radium-226 from runoff and local groundwater inputs on the Site. The various loadings sources reporting to the Pit include; groundwater from the Main Tailings, the Acid Plant area and the East Waste Rock Pile, as well as surface runoff and groundwater from the Mill Complex Area (see Figure 3.1). The Pit was therefore considered as a potential source of COPCs to Lake Athabasca.

3.2.2 Overview of pathways

The two types of pathways considered in the loadings model include surface water flow in streams and creeks and groundwater flow through the subsurface. The pathways connect the sources to the receiving water bodies as they do in natural systems. Extensive surface water and groundwater investigations have been completed to define the flow pathways at the Gunnar Site [4, 5, 6]. Surface water and groundwater flow pathways to receiving water bodies are shown in Figure 3.2.

There are natural surface water flows that connect sources to receiving water bodies, such as the stream that carries the flow from the Main Tailings, north toward Langley Bay. Other streams and creeks that may not be linked to sources are included in the model to maintain the appropriate water balance for the receiving water bodies.

All streams and creeks were assigned flow rates equal to the average annual values that are based on average precipitation values, runoff coefficients and drainage areas [2].

Groundwater flow directions were estimated from previous groundwater modeling studies [2, 4] as well as the results of field investigations of groundwater [2, 5, 7].The groundwater flow rates from the tailings were taken from previous estimates [2, 4], or were estimated from recent hydrogeological measurements [5].

3.2.3 Overview of receiving waters

The ultimate receiving water body for loadings of COPCs from the Gunnar Site is Lake Athabasca, including St. Mary's Channel. The results of the human health and ecological risk assessments [1], show that the lake itself is not at risk, and does not represent a pathway for important risks to other receptors. The site-specific risks that were identified for human and ecological receptors were limited to those associated with Langley and Zeemel bays. Therefore, the focus of this loadings assessment was on those bays.

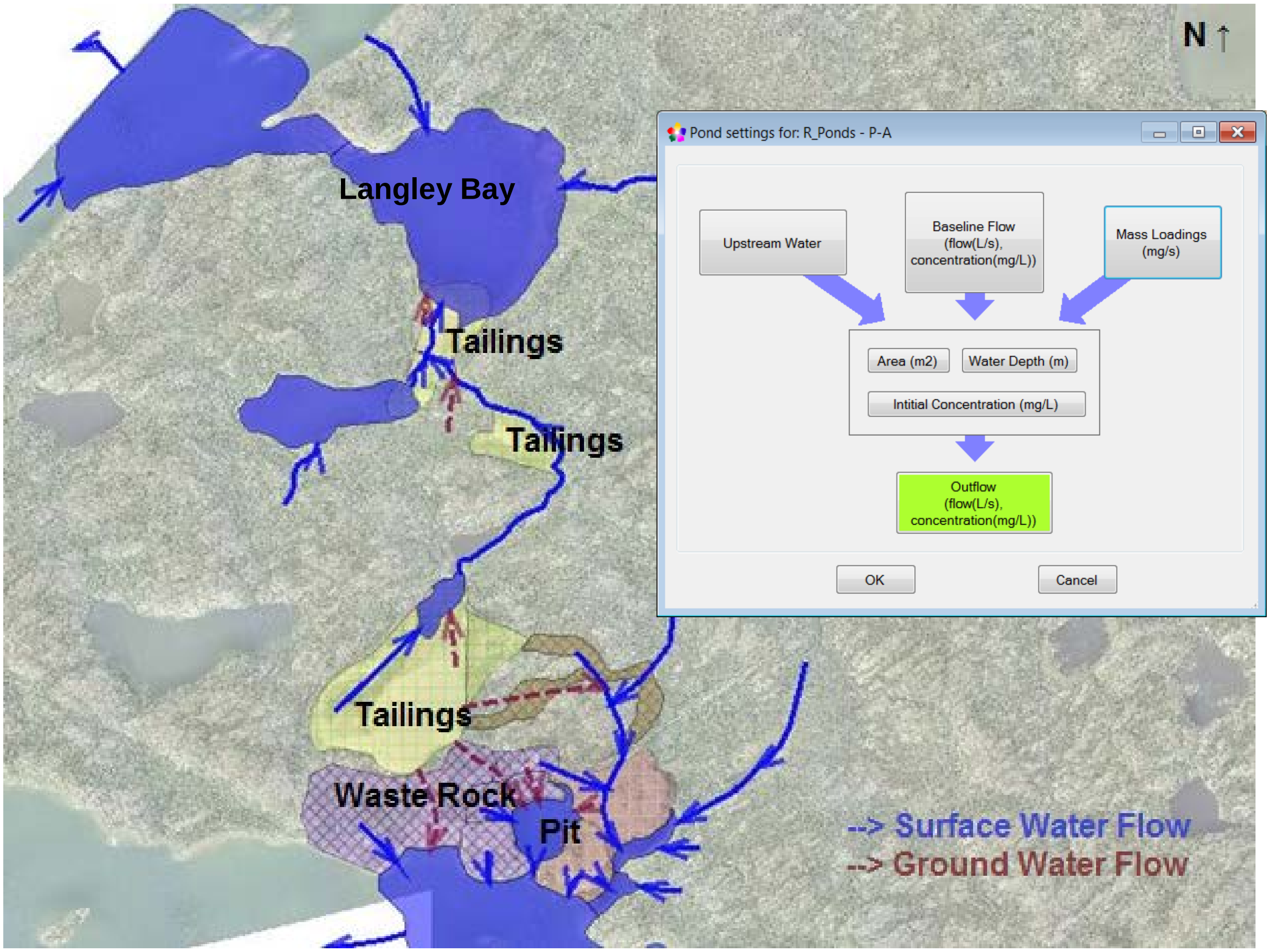

Figure 3.2 Model surface and groundwater flow pathways and pond input-output windows

3.2.4 Conceptual loadings model

The loadings model combines the quantified releases from individual sources at the Site with flows on surface and in the subsurface directed to downstream receiving water bodies. The flows follow natural creeks and groundwater pathways to downstream receiving waters. The flow rates in the model represent average annual values. The loading rates from each source were estimated over a yearly time-frame for consistency. A mass balance is maintained for all selected COPCs from sources, through pathways and in receiving waters. The results can be considered either as flow rates and concentrations, or as annual loading rates into any water body.

3.3 Results

3.3.1 Basecase

A base case scenario was run using the Gunnar site loadings model (MineMod™) with the primary objective of evaluating loading rates to key receiving waterbodies and to determine the effectiveness of potential remediation measures on those loadings. The basecase scenario is based on status quo conditions of loadings to Langley Bay and theupper portion of Zeemel Bay.The estimated loading rates for waste rock were adjusted to account for grain size,assuming that 30% of the waste rock stockpile is comprised of fine-grained (less than 5 cmor 2 inch diameter) material and the associated ratios of leachable contents for eachCOPC, as determined by grain size investigations.

The model predictions for loadings in the receiving environment showed good agreement with actual measurements as shown in the representative sample results shown in Figure 3.3.

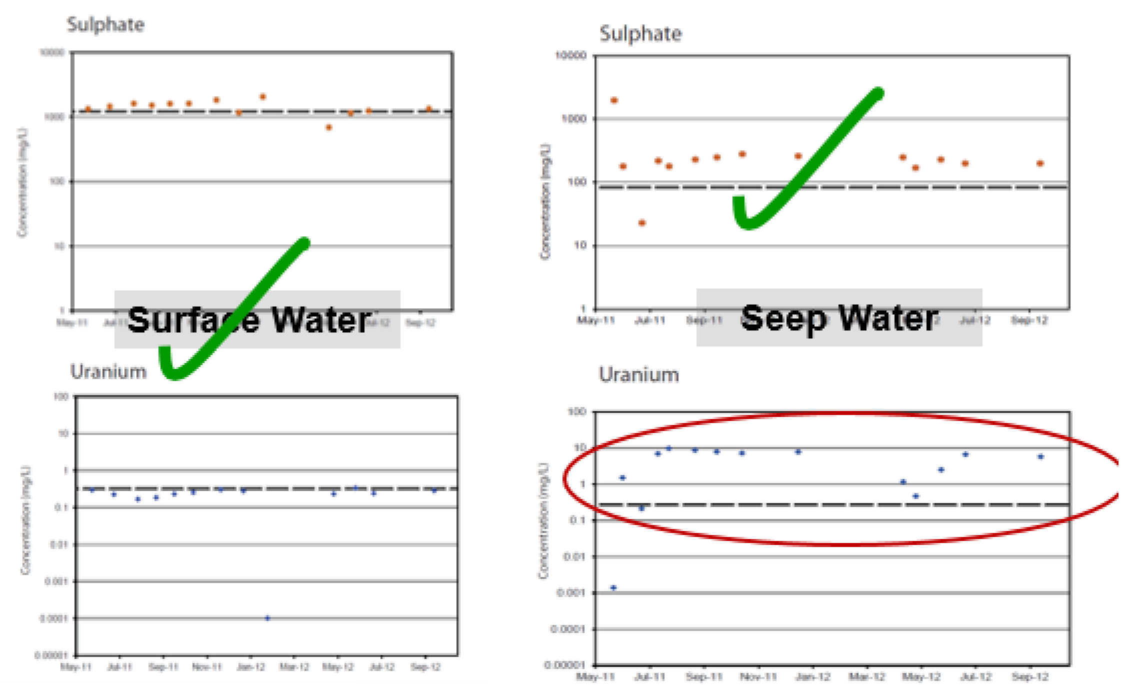

Figure 3.3 Representative sample of model predictions compared to measured concentrations in the receiving environment (dots = measured data, dashed line = predictions)

The only COPC where model predictions did not show good agreement with measured concentrations was for uranium, where the model under-estimated concentrations.

3.3.2 Sensitivity analysis

Several scenarios were developed and a sensitivity analysis performed to investigate the under-estimation ofuranium in surface water down-gradient from the waste rock piles.The sensitivity analysis was conducted by adjusting loading rates from the waste rock piles with and without grain size correction by using:

- 10th percentile porewater concentrations
- 90th percentile porewater concentrations
- Arithmetic average porewater concentrations
- 50th percentile porewater concentrations, no grain size correction
- 10th percentile porewater concentrations, no grain size correction
- 90th percentile porewater concentrations, no grain size correction

As shown, in Figure 3.4a and b, results indicated that upper bound loading rates (90th percentile) are required to resolve measured surface water values, with grain size correction. The dots represent measured data and the lines represent the model predictions. The red circle indicates the best fit.

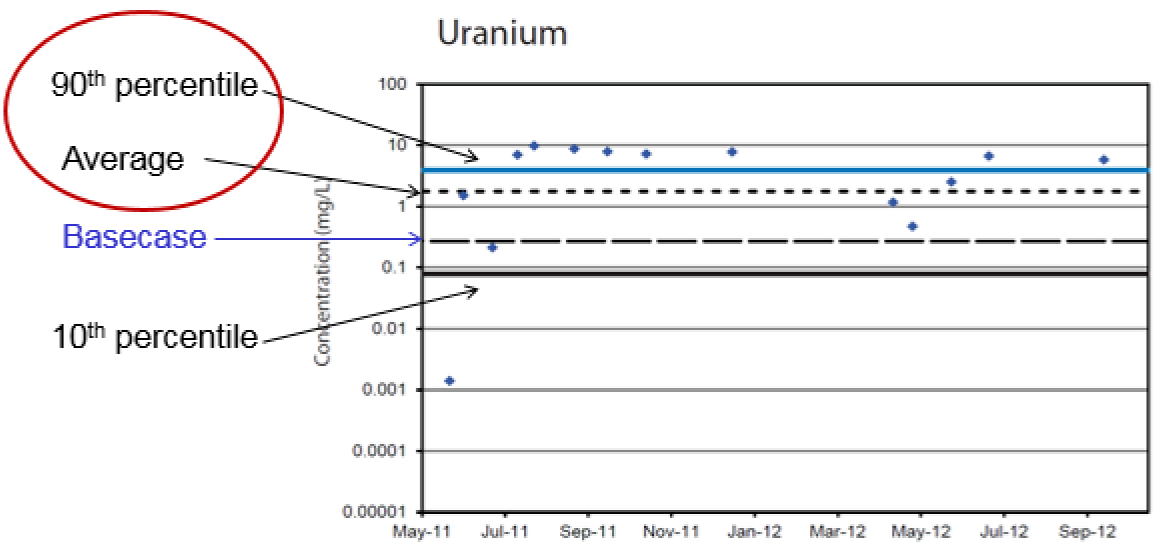

Figure 3.4a Sensitivity analysis uranium concentrations – no grain size correction

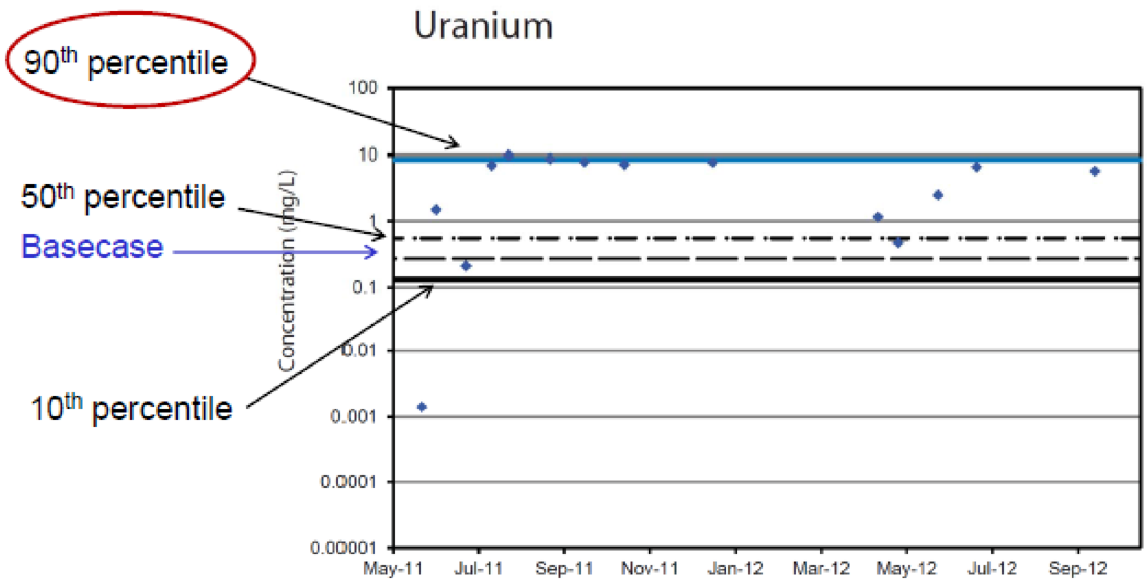

Figure 3.4b Sensitivity analysis uranium concentrations – with grain size correction

The sensitivity analysis results suggest that uranium may be controlled by an equilibrium reaction within the waste rock piles and that its solubility is not expected to be a function of particle size. Several additional scenarios were developed to investigate sources of uranium in surface water down-gradient from the waste rock piles, but a number of uncertainties still remain.

3.3.3 Summary of Results

In summary, the Gunnar site loadings model (MineMod™) was able to reasonably predict the observedconcentrations of COPCs in receiving waterbodies whenindependently derived sources for each of the Site aspects, were incorporated. Predicted loadings and concentrations were performed for various remediation options. The model indicates that a 70% reduction in uranium loadings to Langley Bay can beachieved by covering the Gunnar Main, Central and Langley Bay Tailings areas. However,covering the Gunnar Main Tailings alone, with an engineered cover, accounted for most ofthe uranium load reduction, as predicted by the model.

The most beneficial reduction of uranium loadings to Zeemel Bay were found for relocationof the Waste Rock Piles to the Pit, associated with a 98% reduction, and the redirection offlows to Zeemel Creek, associated with a 92% reduction because of the removal of theseep that is considered to represent the largest single source of uranium loadings onthe Gunnar site.

Overall, the predicted loadings and concentrations for the various remediation options incorporated into the model indicate preferred options based on reduced loadings to the environment.The loadings model can be used to evaluate any number of permutations of remediation options.

4. Conclusions

Overall, the Gunnar site loadings model demonstrated the relative benefits of remedial actionsandcan also be applied to refine the benefits assessment when more detailed engineeringdesigns are proposed for the selected remedial options. By providing a holistic approach to site wide loadings, the model allows forfocus on priority sources and decommissioning strategies. The visual nature of MineModTM,its transparency, and ability to easily modify and re-run scenarios, makes it a useful communication tool whenevaluating site aspects with regulators/industry.

5. References

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