Groundwater Water Quality Around an Existing Mine: From Current Conditions to Mine Closure

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Abstract

Groundwater quality around a mine constitutes a major part of a mine environmental permit. Understanding mine-water quality and its environmental impacts must be investigated not just during the mine operation but until stable state is reached that can be 100 years or more after closure. In this study, diffuse leakage water quality from a tailings management facility of an iron ore mine was modelled from the current condition, increased production and closure. Results show that while major elements will eventually decrease, trace elements will be attenuated via sorption to oxyhydroxides in the sediments which will improve the groundwater quality in time.

Keywords: Groundwater, PhreeqC, mine closure, reactive transport

Introduction

Modelling of groundwater quality is generally a complex task that involves several phases and expertise both from external consultants and the mine staff itself. A good hydrological model including a water balance model is generally a prerequisite to any water quality modelling work. This is to ensure that the flow rates and volumes are properly accounted for in calculating water mineral interactions, dilution effect, mass loading, and final concentrations to receiving environments such as a rivers and groundwater resources. Understanding and knowing factors contributing to water quality during operation and its closure is a pre-requisite to any mine-permit application.

An active tailings management facility (TMF) of an iron ore mine was used as the study area. The mine has been in production for over a century, producing iron concentrate from magnetite-hematite ore. Diffuse leakage coming from the TMF is observed based on the high concentration of Cl (82 mg/L) in some monitoring wells at the base relative to process water average concentration of 137 mg/L that enters the TMF during tailings deposition. The diffuse leakage quality is a result of the geochemical reactions within the tailings dam, in the support dike, the mineral processing, and mine water used in the ore processing.

Regional groundwater flows perpendicular to the tailing management facility and into the recipient river (Figure 1). According to current data, the groundwater is affected by the diffuse leakage coming from the TMF. The diffuse leakage contains elevated concentrations of major constituents such as Cl, SO4, and Ca as well as notable trace metals such as U and Ni. The mine plans to increase production which could directly affect the diffuse leakage and thereby the groundwater water quality through the increase in concentration of these constituents. This will also result in increased flow rates and water volume coming from the TMF into the river. In order to address these issues, the mine plans to implement protection measures to the groundwater and river by pumping contaminated water and cleaning that in the clarification pond prior to release in the receiving environment.

Groundwater quality was modelled downstream of the TMF towards the river with the goal of understanding the effect on water quality around the mine during its current operation, mine production expansion, and closure. The groundwater hydrology of the mine was first modelled using MIKE-SHE where particle tracking simulation of the diffuse leakage was also performed. A multi-component reactive transport modelling was performed using PHREEQC (Parkhurst, D. and Appelo, C., 2013) incorporating the transport parameters obtained from the results of the groundwater hydrogeology.

Methods

Prior to the modelling work, a conceptual model was first developed. The conceptual model was designed and agreed to by all stakeholders involved from the mining company side and the consultants working on the project. This ensures that the conceptual model is in line with the understanding of the current conditions as well as the past and future scenarios based on the identified mine plan and closure scenario. Input data and parameters were obtained from the site, either from field investigation or from literature and public sources.

Conceptual Model

The onset of water-mineral interactions begins within the tailings and support dike when mine process water enters these areas during tailings deposition via spigots. The resulting water quality from the water-mineral interactions between the tailings and support dike materials is what flows further down into the dam and then reacts with the underlying sediments. Based on geologic information as well sonic drilling data, moraine underlies the dam facility. It is within this moraine that major changes to the diffuse leakage water quality occur. Sorption and attenuation of most metals including Ni and U occur as the diffuse leakage intercepts the moraine. This is mainly due to the presence of iron oxyhydroxides and clay minerals within the moraine. Conservative elements such as SO4 and Ca generally retain their level of concentration within the moraine. As the diffuse leakage flows through the glaciofluvial sediments, sorption still occurs but at a lesser degree. The water quality that exits the glaciofluvial sediments is what reports to the recipient river.

Hydrological model

The MIKE-SHE integrated groundwater program simulated the diffuse leakage from the tailings dam to the recipient river using a particle tracking tool. This tool produced the total travel time and distance of the diffuse leakage from the source to the recipient, which was then subdivided into each zone of interest (tailings, support dike, moraine, glaciofluvial sediment). The average of these parameters provide basis for the residence time of the reacting water in each zone.

There is an increase in the travel time and distance during the applied scenario which is directly related to the increased height of the tailings dam from the current setting. This will also result in an increased height of the water table in the dam. During closure, the water table in the dam will eventually go down, increasing the thickness of the unsaturated zone. These changes in the TMF

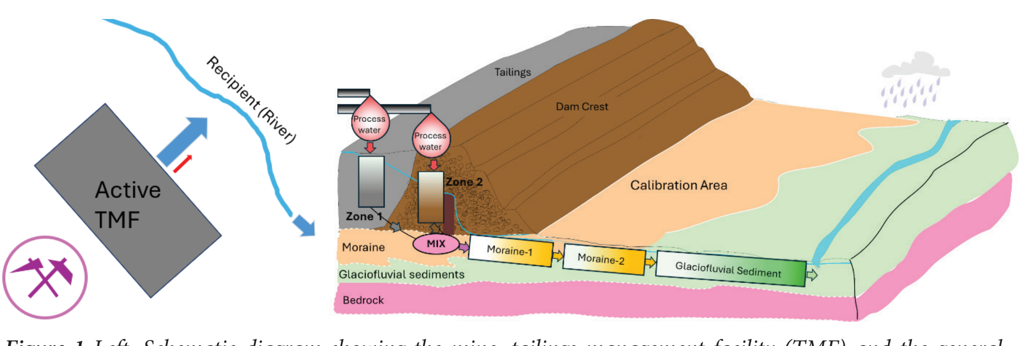

***Figure 1** Left: Schematic diagram showing the mine, tailings management facility (TMF) and the general direction of groundwater flow to the recipient river. The small red arrow denotes the contaminated diffuse leakage. Right: Flow path and modelling zones from the input of mine process water into the tailings pond until it reaches the recipient river.*

hydrogeology are included in the predictive modelling of the water quality.

PhreeqC reactive transport model

The design of the reactive transport model with PhreeqC tracks the source of the diffuse leakage as it flows through the different geologic materials until it reaches the river. These different geologic materials (tailings, support dike, moraine, and glaciofluvial sediments) correspond to zones or columns in the PhreeqC modelling.

Each zone was assigned as a column containing these materials of interest. For the current scenario, the mine process water input water quality is based on measured data. Similarly, calibration data was based on an average of wells downstream from the dam facility. During the applied setting, modelled mine process water was used as input water quality. The process water quality for the current and applied scenarios are used as the existing water quality within the tailings and support dike. During the closure scenario, only precipitation infiltrates the tailings dam, resulting to an improved water quality in time.

Geochemical characterization of the tailings, support dike (wall rocks from the mineral exploitation), moraine, and glaciofluvial sediments were obtained from sonic drilling data and literature. Mineralogical tests, XRD and full chemical analysis were performed for these materials. This information was used as input parameters for the mineralogy of the materials and their weight percentage in the columns.

Hydrological data such as travel time and distance of the diffuse leakage as it flows through the different zones were obtained from MIKE-SHE hydrogeological modelling. This information was used as input for the reactive transport modelling in PhreeqC.

Calibration and Validation

Calibration of the diffuse leakage water quality was carried out using the average concentration of selected wells downstream of the dam facility. These wells were selected based on the direct influence of the diffuse leakage which was based on the concentration of conservative elements such as Cl.

Groundwater quality during different time scenarios

The concentration of most constituents of the diffuse leakage during the current setting is seen to increase by as much as 50–100% for most constituents for the applied setting (maximum expansion of the mine). This is primarily attributed to the increased concentration of most constituents in the process water resulting from the change in the ore mix and increased volume of the ore that will be processed during the applied setting. The concentrations of these constituents are, however, seen to significantly decrease by as much 90% during closure, for example, 80 years after the mining operation has ceased (Figure 2). This decrease is primarily linked to the cessation of process water input into the tailings, with rainwater being the only incoming solution after that. An observed increase in some constituents, especially the trace elements during closure, is attributed to the continuous oxidation of sulfide minerals that will be exposed during the lowering of the phreatic water table in the TMF during the closure scenarios.

Generally, the variation in the relative percentage of increase or decrease of these constituents during the different time scenarios modelled is dependent on the heterogeneous nature of the materials modelled, including, but not limited to, mineral reaction rates, changes in physicochemical conditions and changes in hydrological conditions. A proposed cover system on top of the tailings facility is seen as an important measure to limit further oxidation and reactions brought about by increased oxygen and water infiltration.

Conclusion

Groundwater modelling from a tailings dam facility to a recipient river was performed for the current, applied and closure scenarios for an iron ore mine. A potential increase in mine production will also increase constituent elements in the modelled groundwater. Attenuation of metal transport was notable in the moraine and glaciofluvial sediments likely due to the strong presence of iron oxyhydroxides mineral. The closure and post-closure scenarios of the mine shows lowering

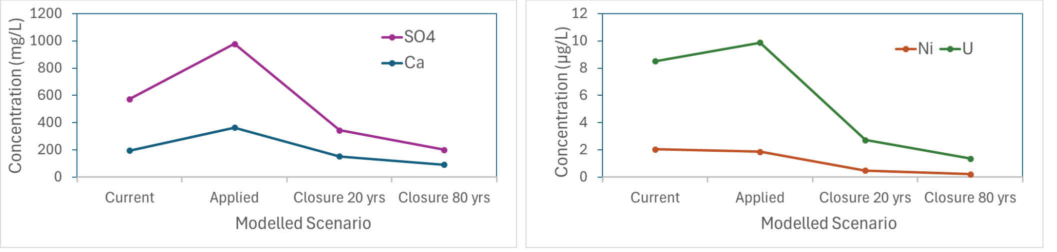

Figure 2 *Concentration of major constituents SO4 and Ca as well as trace elements U and Ni for the current condition, applied scenario and closure setting (20 and 80 years after closure).*

concentration of all constituents largely due to reduced diffuse leakage influence and continuous precipitation infiltration.

The results from these models provide a basis for a mine environmental permit application. These models also provide guidance on potential water quality risks that must be addressed and water management measures that must be implemented to make sure water quality around the mine remains within the set limits of regulatory agencies. In addition, these models provide a good picture of the hydrodynamics and water quality, their effect to mine operation, natural ecosystems surrounding the mine, communities and other stakeholders.

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References

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