Integrated Catchment-scale Mine Water Impact Assessment: A Case Study

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Abstract

This paper seeks to demonstrate the value of using GoldSim as the glue to combine and integrate various hydrological, hydrogeological and geochemical models such that they provide a holistic evaluation of potential catchment-scale water impacts. We share a template for water impact assessment modelling and also demonstrate how findings from this modelling and evaluated risk controls can be fed back into the project design to reduce water risk and take advantage of opportunities.

Keywords: Water stewardship, catchment-scale, GoldSim, water risk

Introduction

Water stewardship, namely equitable, environmentally sustainable and economically beneficial water use, demands that we look beyond hydrologically arbitrary site boundaries and consider interactions at a catchment level (AWS, 2019). This often requires a multidisciplinary approach to modelling potential impacts that is not limited to a single software package or model type.

The objective of this paper is to provide a real-world case study of integrating surface water, groundwater and water chemistry models into a catchment scale GoldSim model for prediction of water impacts from mining. The study focuses on a predevelopment, brownfield iron-copper-gold project in Finnish Lapland, approximately 100 km north of the Arctic Circle (Figure 1). Precipitation falls as snow from around October to around May when the spring snow melt begins. River flows are often lowest during the winter when hydrological processes are locked up in ice and snow. The project site is located around 15 km to the north-east, and draining to, the Muonio River. The Muonio drains to the Tornionjoki River which is a key transboundary river and subject to a Transboundary River Agreement between Sweden and Finland as part of the Water Framework Directive.

The project area is highly sensitive with very good baseline water quality. All rivers and lakes in the catchment are important aquatic habitats with protected Natura 2000 status and there are several “classified” groundwater zones in the area. The larger catchment watershed constitutes an international water management area and water resources in the area are highly valued by local communities with high stakeholder interest. The key water risks therefore relate to potential river flow and water quality impacts on water dependent ecosystems as well as stakeholder perception.

The purpose of this study was to produce a catchment scale water impact assessment of the proposed mining project both during operational conditions and post-closure. The study also aimed to validate some specific design proposals such as waste rock dump liner and cover configurations as well as proposed post-closure water management strategies. Water impact modelling requires collation of various discipline-specific models into a coherent and integrated catchment scale assessment. The study represented an update of a previous study which used a series of independent hydrological and geochemical models, with the results brought together in a spreadsheet. However, this approach was difficult to follow, not well-suited to representing a dynamic system and cannot handle uncertainty.

Figure 1 Aerial photo of the current site (image: Hannukainen Mining Oy).

The key risks to surrounding water features that were identified prior to the modelling exercise and which were to be investigated by the model included:

- Potential impacts on base flow to rivers, especially during pit late recovery.
- Release of poor-quality water from waste dumps and/or pick lakes to either groundwater or surface water systems.
- Potential changes in run-off from the site compared to baseline conditions affecting surface water flows downstream.

Methods

In the case of this study, the GoldSim software was selected to integrate various stand-alone models into a single consolidated water impact assessment tool, on a non-coupled basis but in other cases, such as with the pit lake geochemistry, on a fully coupled basis.

GoldSim is a Monte Carlo simulation software for modelling complex systems which can be used as the "glue" to link various models and calculations in a very logical and visual way. Models can accept a range of inputs and are able to quantitatively represent uncertainty to support decision-making and risk analysis. Results are easily communicated using graphs and schematics.

GoldSim can be directly coupled to a virtually unlimited variety of other modelling software using "DLL" files which allow GoldSim to interact with various other packages on an iterative basis. This allows a relatively unrestricted choice of modelling tool for any given process. DLL files have been created some well-known water and geochemical modelling packages, such as to allow the integration of GoldSim with PHREEQC as described in Eary (2007) as well as with FEFLOW as described by Martin and Gabora (2018).

Once constructed, GoldSim models can be quick to update and adapt, allowing efficient evaluation of potential mitigation options and/or other design opportunities. Furthermore, models can be run stochastically to produce a probabilistic result and evaluate uncertainty. Finally, the ability to produce "player" files with dashboards that allow non-GoldSim users to run and interrogate model scenarios and results without running the full GoldSim model or requiring paid software is extremely useful.

Figure 2 outlines the models and calculations which were integrated into the

GoldSim model, effectively using GoldSim as the "glue" to integrate results together as well as to couple models, where required.

Key processes that were represented using stand-alone modelling tools and then integrated into the GoldSim model included:

Waste rock and pit wall run-off source-term modelling.

Release rates were derived from laboratory tests on samples of key lithologies and scaled up to field conditions. PHREEQC 1D (Parkhurst and Appelo, 2013) geochemical modelling was used to represent mixing of the source terms with rainwater running off the pit walls and infiltrating into waste rock dumps as well as subsequent geochemical mixing processes, when combined with flow modelling, to provide an estimate of the chemical load entering the environment.

Cover infiltration modelling.

Unsaturated zone modelling was undertaken in HYDRUS-1D (Šimůnek , 2013) to represent infiltration of precipitation into the waste rock dumps through an engineered cover proposed to be emplaced at closure. This modelling was used to interrogate various proposed cover designs as well as to define waste rock dump seepage and infiltration.

Groundwater flow and contaminant transport modelling.

A MODFLOW USG (Panday *et al*, 2013) three-dimensional numerical groundwater flow model was constructed to evaluate impacts on baseflow to rivers and water levels. This model was then combined with MT3D three-dimensional contaminant transport modelling to evaluate potential for seepage and transport of potential contaminants.

Hydrological modelling.

Modelling of rainfall-runoff and river flow using HBV (Bergström, 1995) to evaluate surface water flows across the site and into site infrastructure, as well as flow in the receiving rivers.

Physical pit lake modelling.

CEQUAL-W2 (Cole and Wells, 2013) was used to define potential stratification of the post-closure pit lake that is expected to form. This could then be used to define into vertical zones that might be represented in the overall pit lake geochemistry model.

Pit lake water quality modelling.

A dynamic pit lake water quality model that reflects a range of geochemical processes that may occur in the post-closure pit lake was produced using PHREEQC. GoldSim and PHREEQC were coupled using the previously mentioned DLL to compute geochemical calculations for each timestep, producing a dynamic water model. After physical mixing in relative proportions, a PHREEQC model is run for each timestep to simulate the following geochemical processes in the pit lake:

- Equilibration with air (pH)
- Precipitation and dissolution of key minerals
- Kinetic biodegradation of N and P

Results from PHREEQC are then fed back into the next timestep. The results were calibrated to water sampling results from two existing pit lakes at the site.

Results

The GoldSim model was successfully able to integrate model outputs at varying scales and to represent physical mixing of flows and contaminants in site water ponds in the surrounding site surface watercourses in order to produce a predicted average water chemistry for key receptors.

Although exact concentrations cannot be shared due to confidentiality, some example post-closure results at four key surface water receptors are shown in Figure 3.

Model results were used both for early identification and management of water risks as well as opportunities to add value to the project design. For example, in terms of risk mitigation the results informed key focus areas for definition of trigger and threshold values based on bioavailability and toxicity. Furthermore, they were used to define the scope and duration of post-closure active water treatment that might be required and to validate proposed changes to the waste rock dump and process pond liner designs and post-closure water management strategies. In terms of value addition, opportunities for modifications to the post-closure waste rock

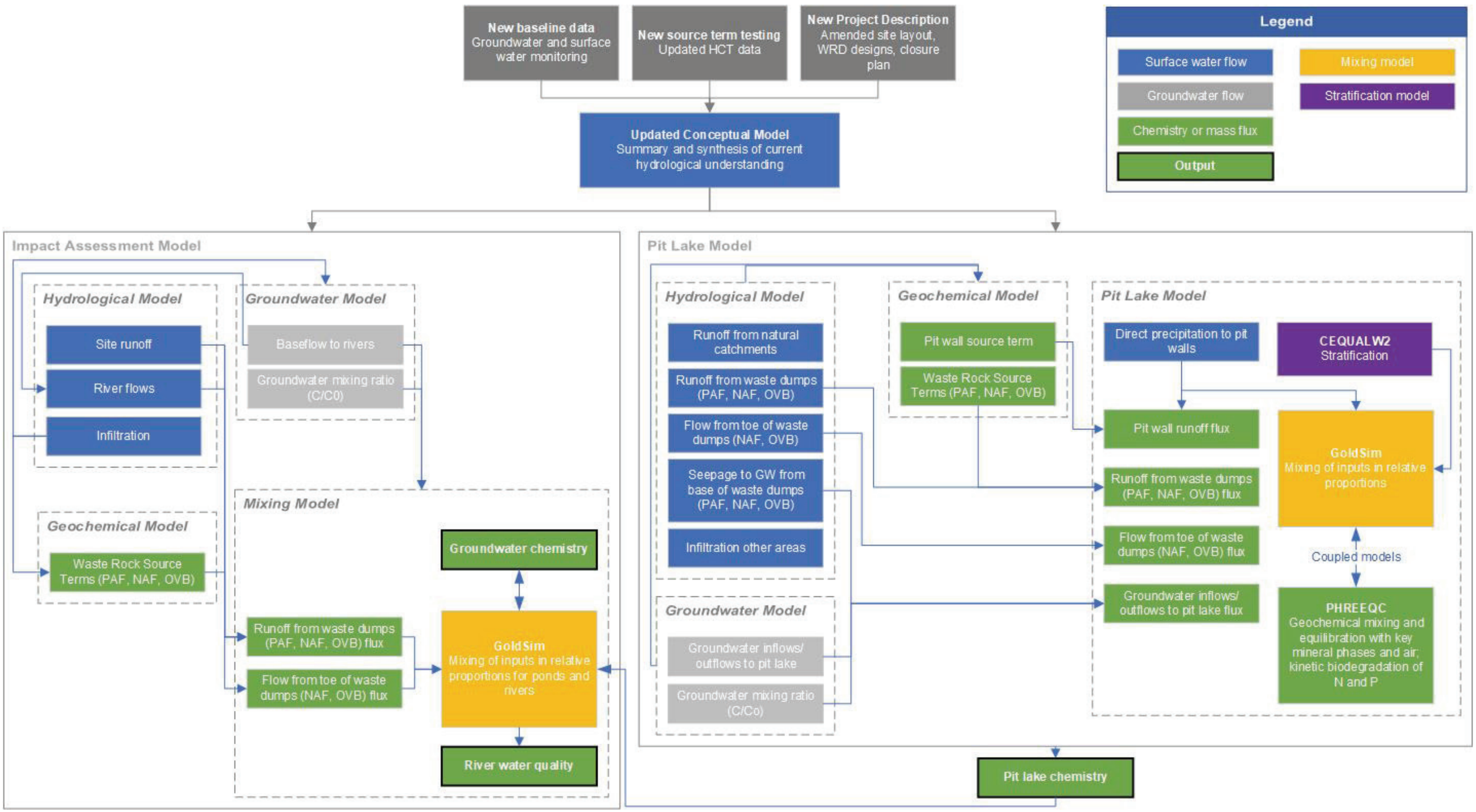

Figure 2 *Schematic summary of the GoldSim model make up showing interactions between models and calculations feeding into the GoldSim model as well as elements of the GoldSim model which were fully coupled with other models such as PHREEQC*

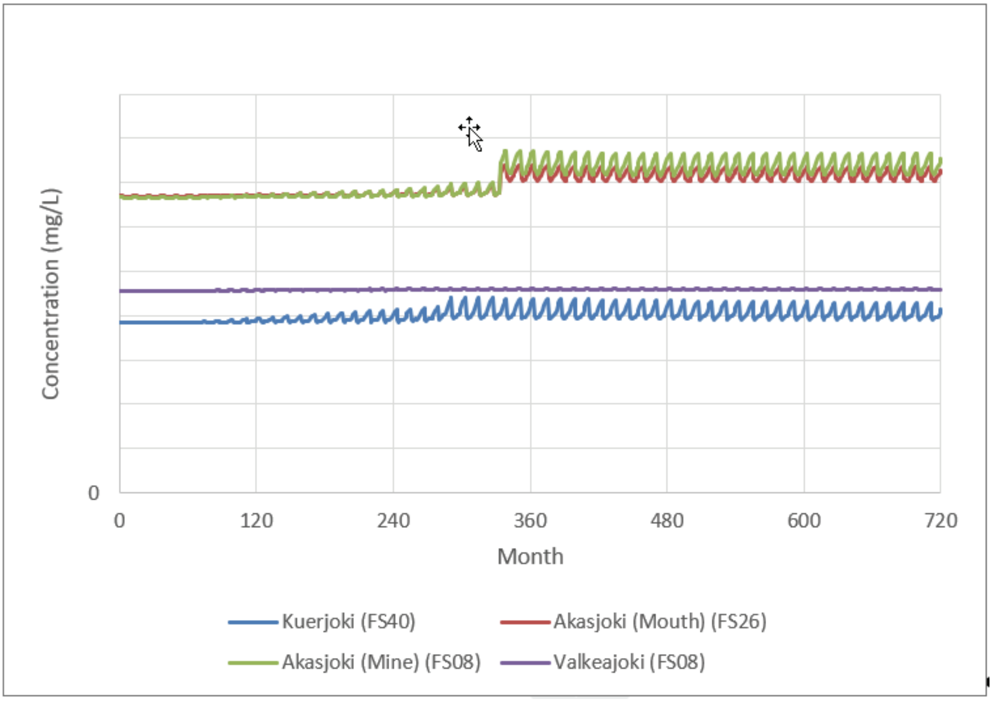

Figure 3 *Post-closure results for an example parameter at four key surface water receptors. The results show seasonal variation with flushing of source terms during the snowmelt season as well as the point at which the pit lake fills and overflows into surrounding surface watercourses.*

dump cover design were identified which had the potential to significantly reduce closure costs. Furthermore, it was demonstrated that active measures for post management of pit lake acidity were unlikely to be required.

Conclusions and Limitations

In this case study, GoldSim has been used to combine various independent models of catchment processes into a single holistic and integrated water impact assessment model. Such an approach provides a central point from which to link models and calculations, either directly or indirectly, in a logical and visual way as well as a tool to communicate results using graphs, schematics and "player" files. Bringing the models together in this way can also help to ensure that individual models do not adopt conflicting assumptions. Once constructed, the model has proven to be quick to update and adapt to assess design changes and new mitigation options. This type of integrated water impact modelling therefore has many advantages with regards to identifying and managing water risks at a catchment scale over other, more traditional approaches.

Although inputs can be represented stochastically in GoldSim enabling uncertainty analysis, few model outputs were available on a probabilistic basis including those which drove the largest changes in results. For example, water quality at the receptor as modelled by the GoldSim model is most sensitive to source term concentration which was difficult to quantify probabilistically in this case. Probabilistic modelling, and therefore quantification of uncertainty in the model results, would require further work to determine reliable stochastic outputs from all of the key model components in order to produce a useful quantification of uncertainty in this case.

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