Probabilistic modelling for tailings remediation and restoration

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Abstract Tailings Management Facilities represent a hazard to the down gradient surface water and groundwater environment. The assessment of the risks such facilities pose to the water environment is an important issue for mine closure, particularly when the potential for an impact on the water environment has been identified. This paper will describe the application of probabilistic simulation in quantitative analytical models to assess the risks where confidence in modelled outcomes may otherwise be inhibited due to limited environmental data. The application of probabilistic modelling will be illustrated through case studies illustrating the use of probabilistic risk assessment to appraise differing closure and remediation strategies for a tailings management facility and the use of such tools to quantify the level of uncertainty in the assessment of risk.

Key Words Probabilistic, risk assessment, tailings, remediation, restoration

Introduction

Tailings are produced as a result of the processing of extractive ore, and can contain substances that are hazardous to the environment. The management of tailings slurry typically is by storage within a facility where the water in the slurry can evaporate, or to a lesser extent infiltrate into the ground, leaving behind a solid waste with a lower moisture content. Historically tailings have been deposited directly onto the natural ground and contained behind a dam or embankment, but with the advent of modern environmental legislation, particularly in Europe, to protect the natural environment following the Aznalcóllar (1998) and Baia Mare (2000) tailings dam failures (Amezaga and Younger 2006), tailings are currently typically managed in engineered facilities with low permeability liners.

The European Directive 2006/21/EC on the management of waste from extractive industries requires an operation to demonstrate that no significant risk of polluting soil, groundwater or surface water arises from the operation of the mine site. A risk assessment is undertaken to establish the potential impact on the environment of a tailings management facility. The risk assessment process often includes the use of numerical and analytical models of environmental processes such as groundwater flow and contaminant transport to assist in the evaluation and processing of available data. For assessing risks to groundwater such models may take the form of simple generic spreadsheet models through to complex numerical models.

The impact on groundwater in a bedrock aquifer from an existing tailings management facility in South America has been assessed using a probabilistic analytical model. The impact of the facility has been assessed under different management and remediation strategies using an analytical groundwater flow and contaminant transport model constructed in the GoldSim™ modelling environment (GoldSim Technology Group, 2007). The use of a probabilistic simulation methodology allows known and uncertain ranges in the environmental components to be applied within a model that is easily updated following the acquisition of additional data.

Risk assessment and probabilistic modelling

An environmental conceptual site model and risk assessment may be regarded as having, or considering, three components and if any of these three components are absent from a site setting then a negligible risk will be posed to the groundwater and surface water environment. The source is represented by the mine waste (i.e. the tailings) that has the potential to release pollutants through interaction with water. The pathways are any routes linking the source with any receptors, and in which attenuation process may occur, and the receptors consist of groundwater and surface water bodies such as rivers and streams.

The site setting of the tailings management facility was investigated and a hydrogeological conceptual site model, incorporating each of the three components outlined above (i.e. *source, pathways and receptors*), was developed based on the identified pollutant linkages. A probabilistic analytical model was then constructed as a basis for the risk assessment process.

Probabilistic modelling is used to address the uncertainty that is inherent in the majority of the input parameters required for any groundwater

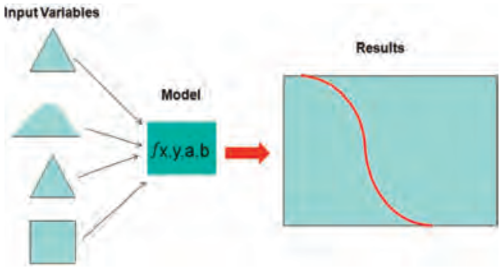

Figure 1 The components of a probabilistic model.

risk assessment. For example the hydraulic conductivity of an aquifer is never uniform, but varies spatially. GoldSim™ uses probabilistic methods to sample parameters for use in the model calculations by random selection from user-defined ranges of possible input values (Figure 1). This process of selection is repeated many times, in a method known as Monte Carlo Analysis, to produce a range of values that can be expressed statistically allowing the assessment of the likelihood of certain outcomes.

Development of a GoldSim model for the assessment of an existing facility

As part of a larger ongoing programme of mine development and restoration activities, at a site in South America, it is proposed to excavate tailings deposited in an existing unlined facility and place them in a new lined tailings management facility. The existing tailings management facility comprises the deposition of tailings in a valley area up stream of an engineered embankment dam with a grout curtain. Based on the results of a site investigation the tailings are currently saturated with a vertical groundwater head gradient driving the transport of contaminants such as zinc, lead and sulphate into the slate bedrock beneath. The upper part of the bedrock was weathered and altered and a component of shallow groundwater flow was identified within this zone, flowing through the grout curtain beneath the dam before discharging to a surface water creek flowing in the downstream valley. A second deeper component of groundwater flow was identified in the fractured slate bedrock that discharged to a river approximately 10 km downstream of the facility (Figure 2).

To provide a platform for the assessment of the current operational risk to groundwater and surface water from the facility and the future risk to groundwater and surface water following removal of the tailings a stochastic GoldSim™ simulation of the existing facility was constructed. The assessment of the future risk considered the risk from residual soil contamination following the removal of the tailings and included an assessment of whether to cap the area to control the migration of any residual contamination. The GoldSim™ simulation utilised analytical equations (e.g. advection/dispersion; mixing cell calculations; etc.),

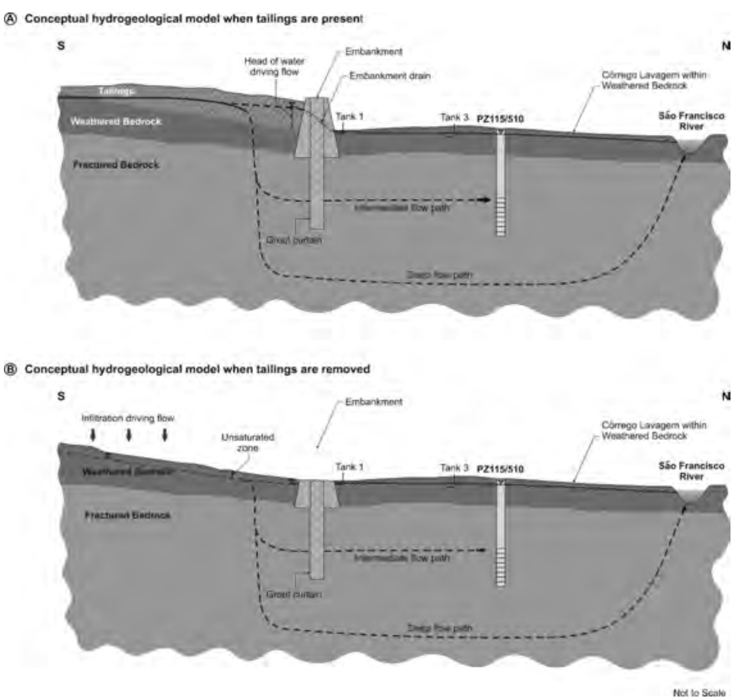

Figure 2 Tailings Management Facility GoldSim Simulation Conceptual Model

to model the movement of water and transport of metals and sulphate from the saturated tailings through the groundwater flow pathways identified to the identified groundwater and surface water receptors (the surface water creek and the downstream river). The risk from residual soil contamination following removal of the tailings was also considered. The stochastic nature of the simulation allowed the range of site investigation data that had been collected at the site to be included in the inputs to the model. For example, a range of contaminant concentrations within the tailings had been reported in laboratory analysis, a range of weathered bedrock thickness was identified through borehole logs and hydraulic testing carried out led to hydraulic conductivity estimates for the weathered bedrock ranging between 6.1×10^{-8} m/s and 3.1×10^{-5} m/s.

The GoldSim™ model constructed was calibrated against the groundwater quality data that had been collected from a series of groundwater monitoring boreholes installed down hydraulic gradient of the tailings management facility. It was shown through this process that there was little retardation of the metals in the bedrock (Figures 3 and 4), likely due to its fractured nature. For example the retardation factor for lead was calibrated to a range of between 0.4 mL/g and 1.2 mL/g, compared to published retardation factors for the partition between sediment and water of between 100 mL/g and 39,811 mL/g (Allison and Allison 2005).

Following calibration the model was used to calculate the predicted concentrations of the contaminants in groundwater following decommissioning of the facility and the excavation and removal of the tailings to a new lined facility. To mitigate the potential impact of the residual contamination in the underlying soils/weathered bedrock on groundwater and surface water it was proposed to cap the area of the tailings management facility with clay. The benefit of capping of the area following removal of the tailings was investigated using the probabilistic model. This was achieved in the GoldSim™ simulation by incorporating a time conditioned mixing cell that allowed an unsaturated zone to develop in the area previously occupied by the tailings and simulated the release of residual contamination following the removal of the tailings. The results of the two models were compared: one with the expected annual infiltration; and the other with reduced infiltration through a low permeability cap. By comparison, it was demonstrated that the construction of

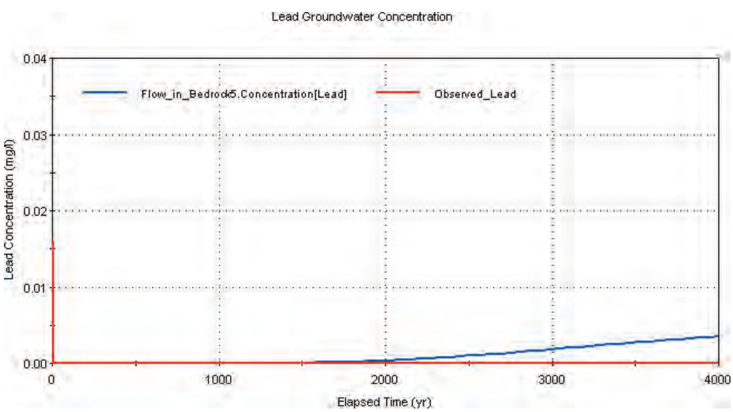

Figure 3 *Predicted lead concentrations - Partition co-efficient range 100 to 39811 mL/g*

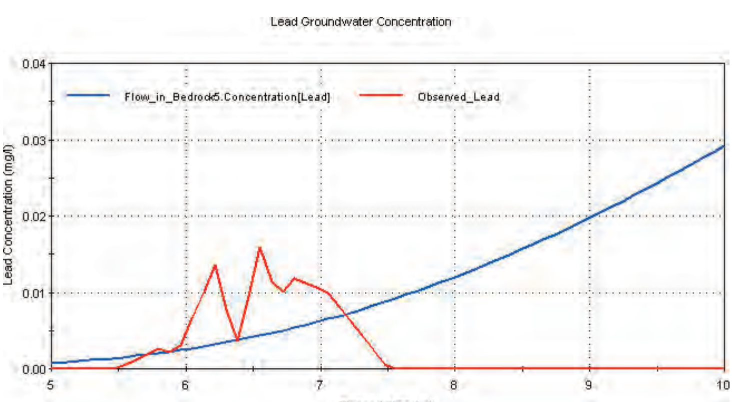

Figure 4 *Predicted lead concentrations - Partition co-efficient range 0.4 to 1.2 mL/g*

a low permeability cap would have little impact on predicted groundwater concentrations once the tailings were removed. This results as although the infiltration is reduced in the capped scenario, and there is a lower mass flux of contaminants, there is less dilution of the contaminants that are leached compared with the un-capped scenario.

Conclusions

The assessment of the risk that tailings management facilities pose to the water environment can be constructively assessed by applying probabilistic simulation to quantitative models. Probabilistic simulation allows the natural variability of the subsurface properties to be addressed and unknown parameters incorporated in the models. The likely range of results can be presented based on the probability of occurrence and an understanding of the sensitivity of the parameters incorporated in the model provides information in a quantitative format that can aid both regulatory and management decisions (Environment Agency, 2008).

The model constructed did not incorporate geochemical reaction pathways, however in this instance it was considered adequate to use simple retardation factors calibrated based on groundwater monitoring data from around the tailings management facility, as the model for the current situation was able to adequately replicate the contaminant concentrations and fluxes downstream of the dam.

The use of GoldSim™ provided a flexible platform for the probabilistic simulation of the risk from tailings management facilities as there is no in-built conceptual model in the software. The changes in the conceptual site model that would result from the proposed management scenarios (removal of the tailings and potential capping) were able to be incorporated in the probabilistic analytical model by applying time variant parameters. The probabilistic nature of the model allowed the variation and confidence in the measured properties to be incorporated.

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