THE APPLICATION OF PROBABILISTIC RISK ASSESSMENT TO TAILINGS MANAGEMENT FACILITIES

***H. Culshaw*[1] *and G. Digges La Touche*[2]**

[1]*Golder Associates (UK) Limited, 1st Floor, Carnmoney House, Edgewater Business Park, Edgewater Road, Belfast, BT3 9JQ*

[2]*Golder Associates (UK) Limited, Attenborough House, Browns Lane Business Park, Stanton-on-the-Wolds, Nottinghamshire, NG12 5BL.*

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 aspect of both the planning process for new sites and the ongoing management of existing sites. This paper will describe the application of probabilistic simulation in quantitative numerical 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 two case studies, one using GoldSim and the other using ConSim to assess risks from tailing management facilities in Brazil and Finland respectively. The case studies will illustrate that probabilistic modelling of environmental risk can provide mine operators and regulators with a tool not only to assess the risk that tailings management facilities may present to the water environment, but also as a means of quantifying the level of uncertainty in the assessment of risk.

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e-mail: hculshaw@golder.com

Introduction

Tailings resulting from extractive ore processing can contain substances that are hazardous to the environment. Tailings slurry is usually managed by storage within a facility where the water content of the slurry can evaporate, or to a lesser extent infiltrate to ground, leaving behind a solid waste. Historically disposal of these tailings has been directly onto natural ground contained behind a dam, but with the advent of legislation, particularly in Europe, to protect the environment following the Aznalcóllar (1998) and Baia Mare (2000) tailings dam failures (Amezaga and Younger 2006), tailings are now mainly managed within lined engineered facilities.

The European Directive 2006/21/EC on the management of waste from extractive industries requires a facility to establish that it poses no significant risk of polluting soil, groundwater or surface water through the management of the facility. The assessment of environmental risks, or risk assessment, is used to establish the potential for impact on the environment from a 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. Models ranging from simple generic spreadsheet models to more complex numerical models are commonly used in risk assessment for impacts to groundwater.

Probabilistic analytical models have been used as tools for assessing the impact to groundwater from two tailings management facilities. The impact on groundwater in a bedrock aquifer from an existing facility in Brazil under different management and remediation strategies was assessed using the package GoldSim™ (GoldSim Technology Group, 2007), while the impact from a proposed engineered facility in Finland was assessed using the package ConSim (Golder Associates, 2003). The use of these probabilistic simulation methodologies allowed known and uncertain ranges in the environmental components to be applied within models that were easily updated following the acquisition of additional data.

Risk Assessment and Probabilistic Modelling

There are three components to any environmental risk assessment. 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. If any of these components are absent from a site setting then negligible risk will be posed to the groundwater and surface water environment.

The site setting of each of the facilities was investigated and hydrogeological conceptual site models, incorporating each of the three components outlined above (i.e. source, pathways and receptors), were 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 risk assessment. For example the hydraulic conductivity of an aquifer is never uniform, but varies spatially. Both ConSim and GoldSim use probabilistic methods to sample parameters for use in the model calculations by random selection from user-defined ranges of possible input values, shown diagrammatically in 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.

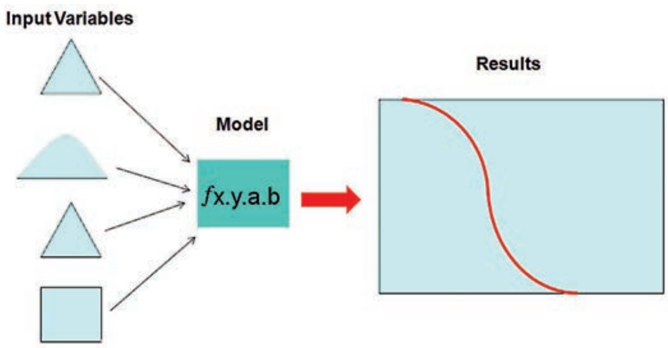


Figure 1. *The components of a probabilistic simulation.*

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

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

In order to assess the ongoing risk from the facility and the risk following removal of the tailings, including an assessment of whether to cap the area to control the migration of any residual contamination, a stochastic GoldSim simulation of the existing facility was constructed, utilising analytical equations (e.g. advection/dispersion; mixing cell calculations; etc.), to model the movement of water and transport of metals and sulphate from the saturated tailings through the groundwater flow pathways identified to the specified surface water receptors (the surface water creek and the downstream river). 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 x10^{-8} m/s and 3.1 x10^{-5} m/s.

The GoldSim model constructed (with a minimum time increment of one year) was calibrated against the groundwater quality data that had been collected from the 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, likely due to its fractured nature. Figures 3a and 3b show the predicted lead concentrations and the observed groundwater concentrations that were collected in the modelled time period between 5.5 and 7.5 years elapsed only. Using the limited groundwater quality data collected 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).

The calibrated model was used to predict the concentrations of the contaminants in groundwater following decommissioning of the facility and the excavation and removal of the tailings to a new lined facility. The benefit of capping of the area following removal of the tailings, to mitigate the potential impact of residual contamination in the underlying soils/weathered bedrock on groundwater and surface water, was also investigated. 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. It was demonstrated by the comparison of the results of two models, one with the expected annual infiltration and another with reduced infiltration that would occur if a cap were installed, that the construction of a low permeability cap would have little impact on predicted groundwater concentrations once the tailings were removed.

Development of a ConSim Model for the assessment of a proposed facility

As part of the development of a copper-cobalt mine in Finland it was proposed to construct an engineered tailings management facility. The proposed facility was designed to be constructed from engineered till excavated at the site. Once operational there would be a component of leakage of contaminated water through the engineered base into the underlying glacial moraine aquifer.

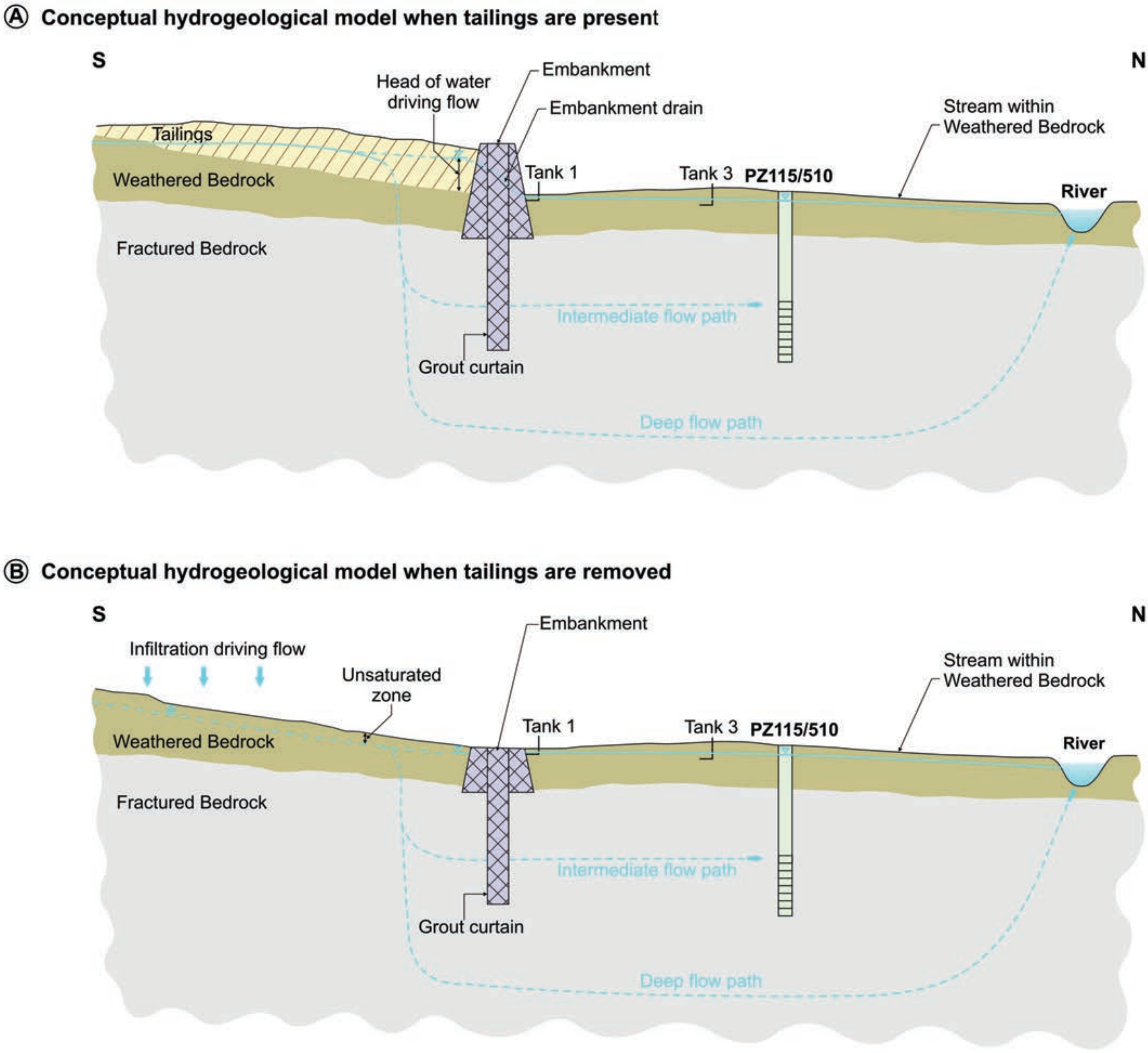


Figure 2. *Brazil TMF GoldSim Simulation Conceptual Model*

Site investigation data collected at the proposed site indicated that an unsaturated zone could exist beneath the facility during summer with a maximum thickness of 2.5 m, which would provide some retardation of the contaminants from the potential tailings leakage. The shallow nature of the groundwater in the moraine indicated that flow would be away from the area of the proposed facility to local surface water streams that discharged to a lake.

Since the conceptual site model identified for the proposed facility was aligned with the conceptual model built within the groundwater risk assessment tool ConSim (schematic workings of the tool are shown in Figure 4), this was used to undertake an assessment of the risk to the groundwater from the proposed tailings management facility. As the facility was only proposed it was necessary to generate an estimate of the concentrations of contaminants that would be present within the tailings. Chemical analysis was carried out on a sample of tailings supernatant from a site processing ore of a similar nature and using a similar process to that at the proposed site. Based on the analytical results ten contaminants, whose concentrations were elevated, were identified as the principal contaminants of concern (PCOC), and used as the source term for the ConSim model as single leached values. Of the ten PCOC manganese, potassium, and nickel were predicted to pose a significant risk to groundwater at the point of discharging to the lake at the 50th (most likely) percentile within 1,000 years based on the proposed design criteria. Figure 5 shows the predicted nickel groundwater concentrations, which exceeded the water quality standard, applied as the European Drinking Water Standard of 0.02mg/l (shown as a horizontal red line) within 1,000 years.

The ConSim software contains an in-built analysis tool that gives an indication of the level of impact each input range is having on the model results. However since the source concentration applied in the model was based

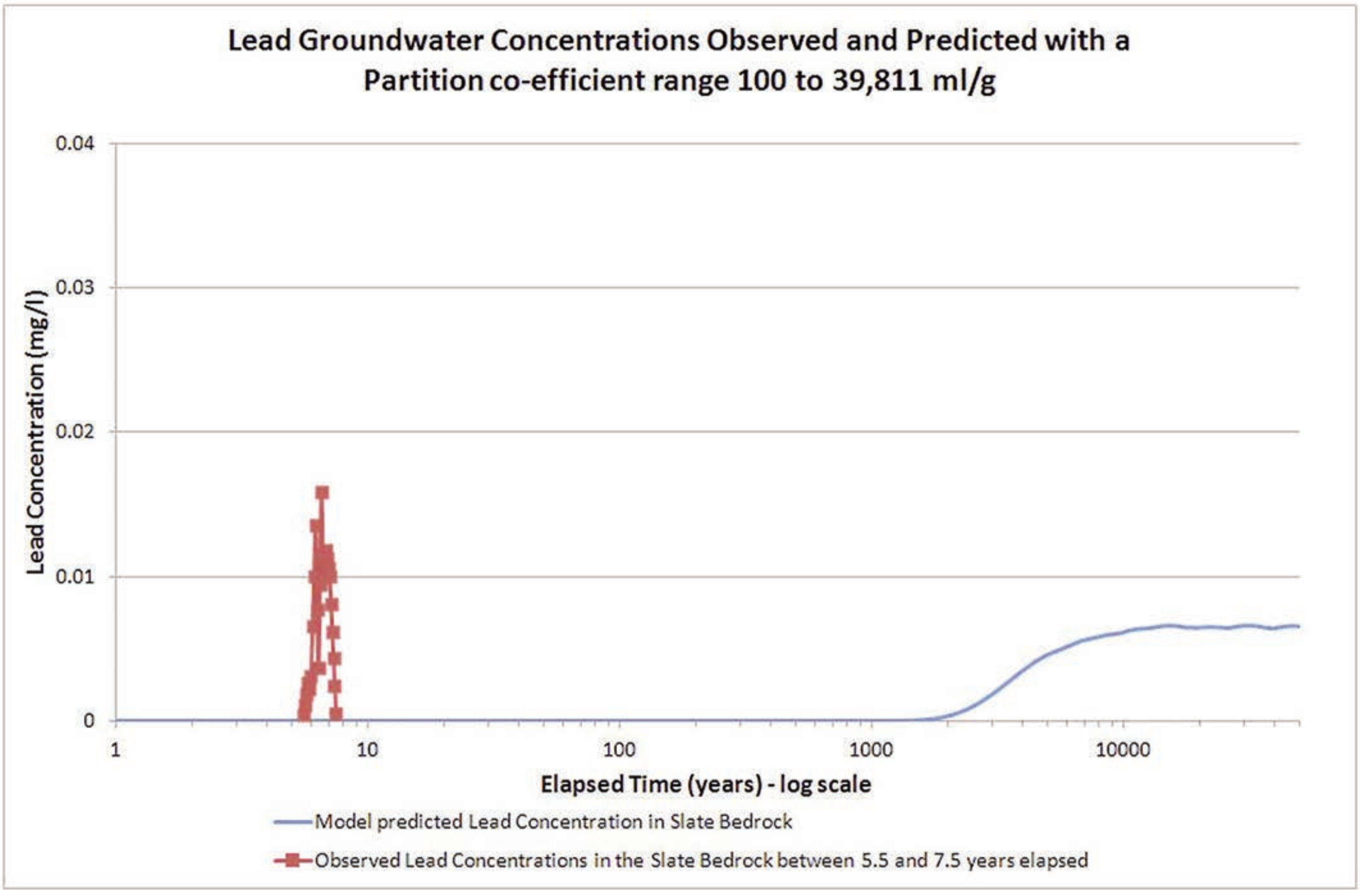
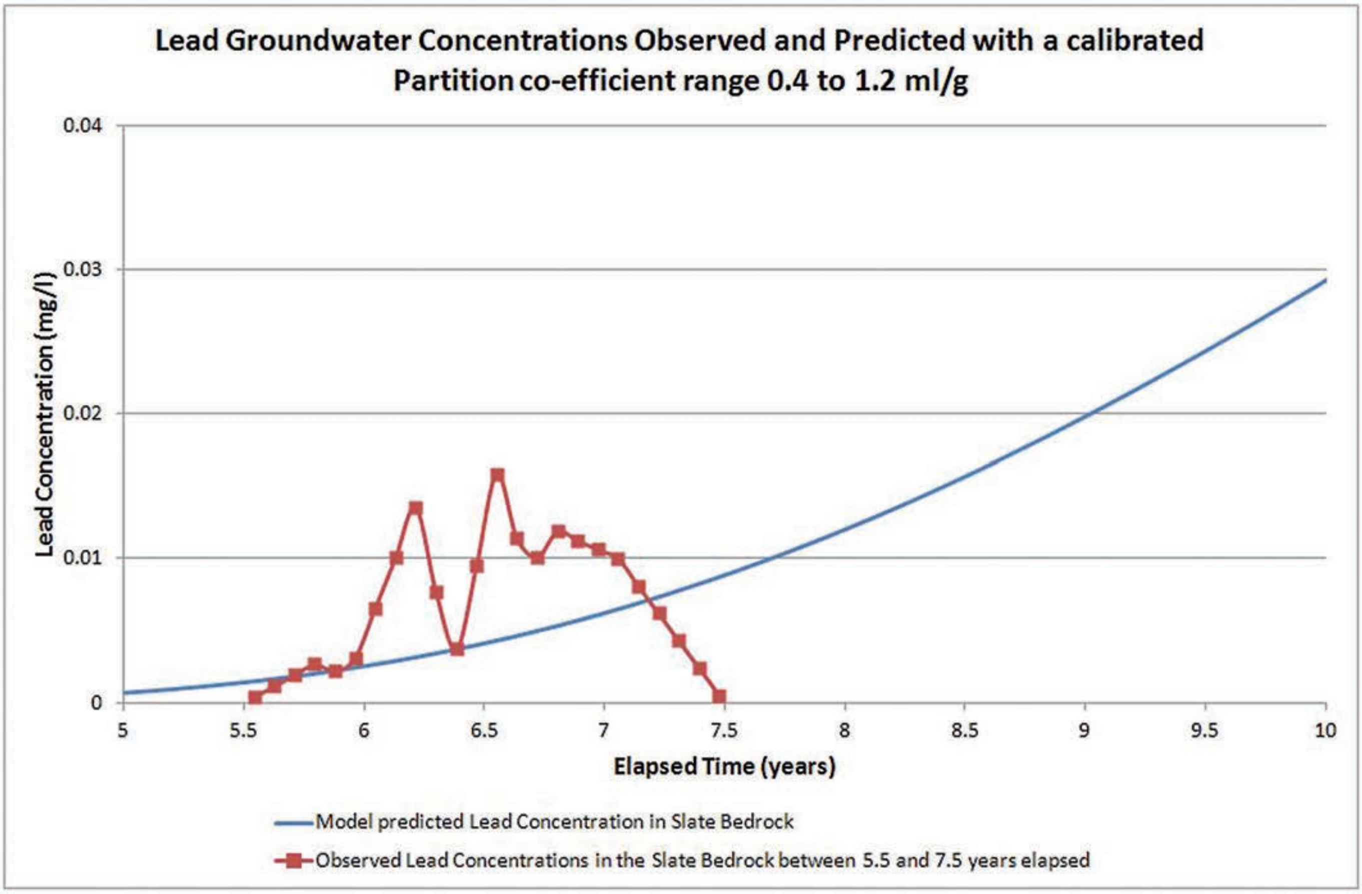


Figure 3. *Lead and groundwater concentrations, observed and predicted*
Above a*) Partition co-efficient range 100 to 39811 ml/g*
Below b*) Partition co-efficient range 0.4 to 1.2 ml/g*



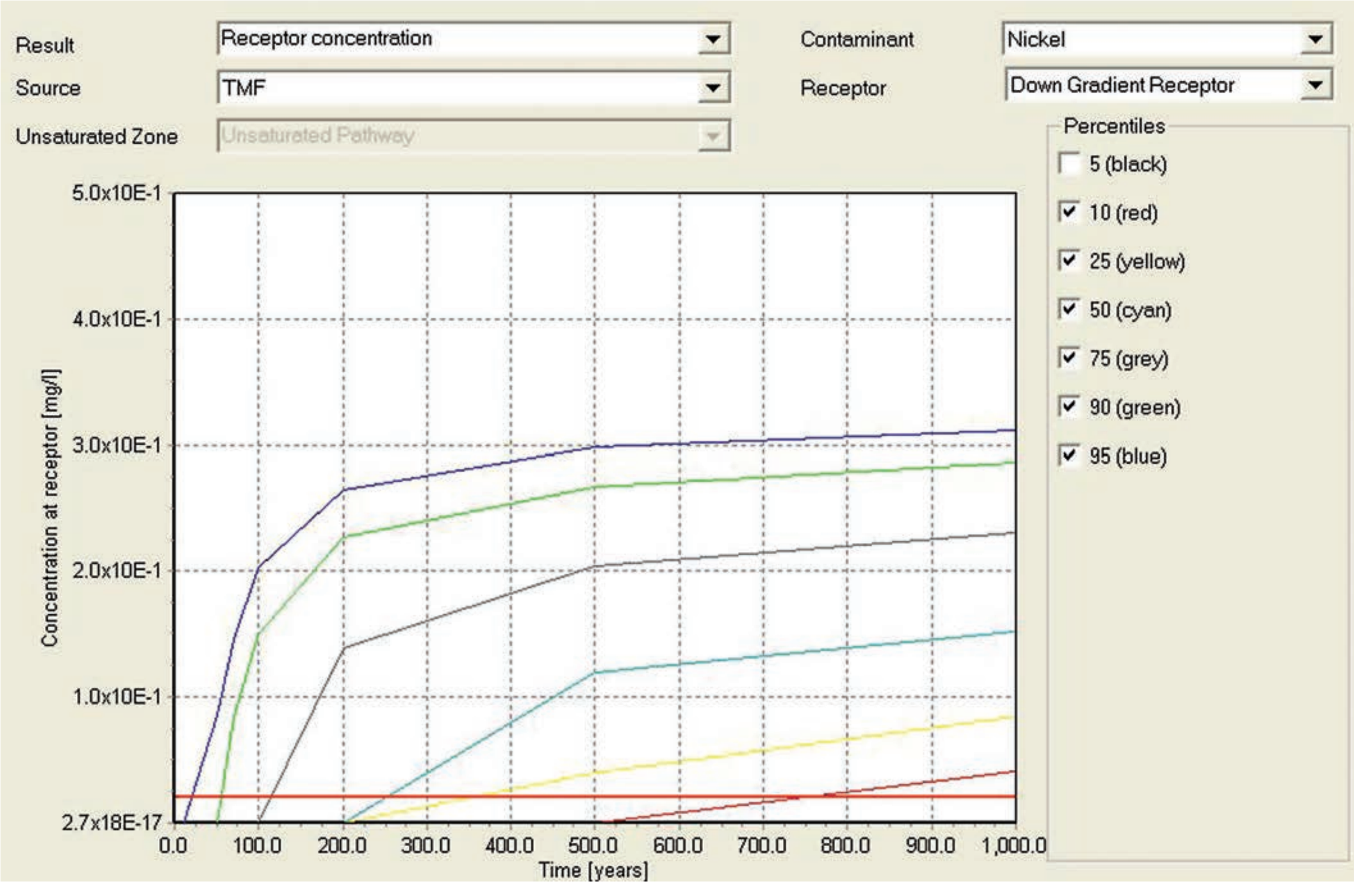


Figure 4. *Nickel Concentrations predicted in Groundwater, over 1,000 years within ConSim, in relation to the water quality standard.*

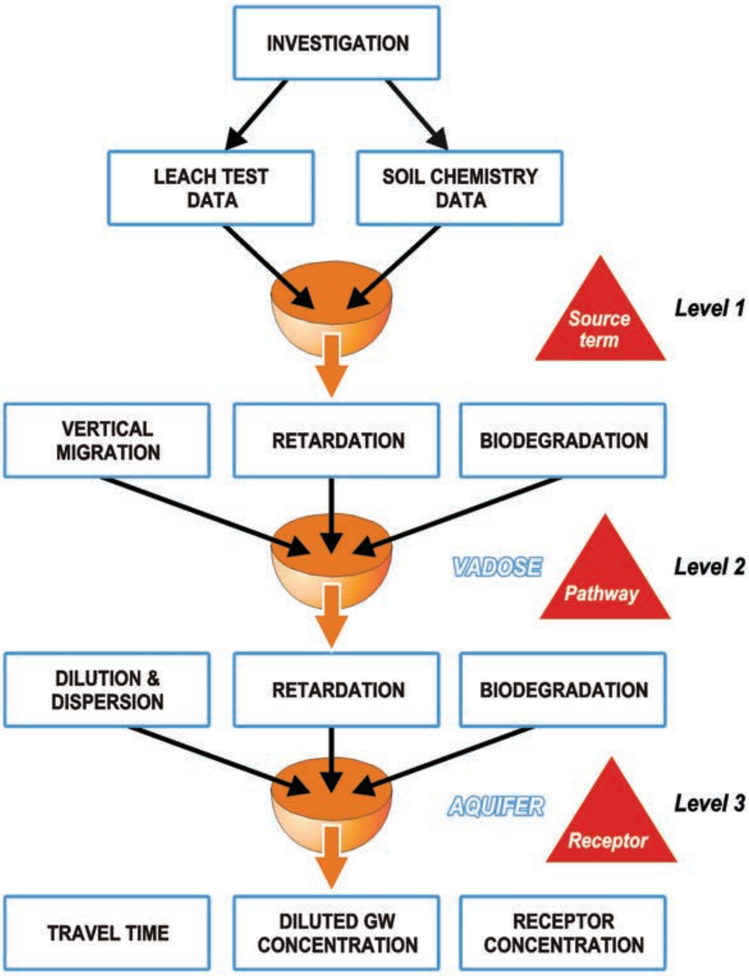


Figure 5. *ConSim Conceptual Model.*

upon only one single assumed value from a different site the assessment could not provide any indication of the sensitivity of the model to the actual future source term. As a consequence additional supernatant samples were collected for analysis to allow the associated uncertainty in the source term to be assessed. A further three samples were analysed in the laboratory and from this probability density functions were developed to better describe the anticipated source term composition.

The results of the revised model revealed that manganese, potassium and nickel still represented a risk to groundwater at the most likely 50th percentile, with the addition that sulphate was also predicted to pose a risk. The sensitivity analysis of this revised model indicated that for these contaminants the source concentration input had the greatest effect on the predicted groundwater concentration.

It was recommended that the assessment would benefit from the collection of further site specific information relating to the groundwater to better constrain physical inputs that had been applied as conservative ranges. The revision of the source term illustrated that the model produced could be easily updated to include additional data.

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 probability of occurrence and an understanding of the sensitivity of the parameters incorporated in the model and provides information in a quantitative format that can aid both regulatory and management decisions (Environment Agency, 2008).

The use of ConSim for the assessment of a proposed tailings management facility allowed the sensitivity of the unconstrained source concentrations to be assessed in terms of the risk it posed to the groundwater environment. By applying probabilistic simulation following the collection of additional supernatant analysis results the model allowed the sensitivity of the model to the source term to be assessed rapidly and effectively.

The use of GoldSim provided a more flexible platform for the probabilistic simulation of the existing management facility than ConSim, which has its own in-built conceptual model. 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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