IMPACT PREDICTION OF THE REACTIVATION OF AN UNUSED TAILINGS DAM

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ABSTRACT

A frequent occurrence in areas with a long history of mining is the reactivation of mine residue deposits. This paper presents an impact prediction study conducted for the reactivation of a gold tailings dam. Two phases of new tailings deposition are proposed. The objective of the study was to assess the potential impact on downstream groundwater quality.

The tailings dam footprint overlies dolomite and quartzite aquifers. The footprint is also located over the watersheds of three separate catchments. For the purposes of predictive modelling the footprint was subdivided into three sections and separately modelled.

Samples of tailings were collected by boring auger holes into various locations. Samples indicating the composition of the two new depositional phases were obtained from bench simulations of the tailings process. The samples were characterised by laboratory analysis and the results were used to assess likely seepage quality.

Physical characteristics of the tailings were used to assess the likely volumes of leachate generation during the pre-deposition phase and Phase 1 and Phase 2 of new deposition. During deposition leachate quality was assumed to be dominated by the quality of the process water used to deposit the new tailings.

A model was developed which included the tailings source, unsaturated zone and aquifer pathway. The characteristics of the unsaturated zone and aquifer pathway were established from available information supported by limited on-site field assessment. The potential groundwater quality impact of the proposed deposition was assessed using Monte Carlo simulation.

1. INTRODUCTION

The area around Johannesburg has been mined since the 1870s. This has resulted in the development of significant quantities of gold tailings, scattered throughout the area as tailings facilities or “dumps”. In recent times, the residual gold and uranium content of these dumps has attracted the interest of gold mining companies. Given newer technologies and rising prices, the residual uranium and gold content can now be economically recovered from the tailings. However, areas must be found to deposit the reprocessed tailings. One option under consideration is the deposition of reprocessed tailings on decommissioned facilities which will not themselves be reprocessed.

Gold tailings are derived from milling of pyritic, gold-bearing quartzites. As such, the tailings comprise mostly quartz with a small fraction of pyrite, chlorite and other minerals. The grain size tends to be finer than 0.1 mm. This grain mineralogy and large surface area gives the tailings significant potential to generate acid drainage, should sufficient oxygen and moisture be available. Even if not acidic, tailings drainage quality is likely to be saline and can affect local groundwater quality. Neutralized ARD can have elevated concentrations of zinc, arsenic and other metals that are mobile at neutral pH.

This paper presents the results of modelling to assess the potential impact of drainage from deposition of reprocessed tailings on the Millsite tailings facility (MTSF) near Randfontein, South Africa.

2. BACKGROUND

The Millsite tailings facility has been in use since the 1930s. It lies on the watershed between two minor catchments of the Tweelopiesspruit. The geology underlying the site varies from Black Reef quartzites in the west to dolomite in the east. Groundwater to the north of the site is used to supply domestic and small-scale agricultural needs and has already been impacted by mining activities (Table 1).

Table 1. Groundwater quality downgradient of the MTSF, as determined from a 2007 hydrocensus. Red values indicate exceedance of the Water Quality Guideline (WQG).

Sample ID	Units	WQG[1]	Plot 45	Plot 47	Plot 63	Plot 69	Plot 175A	Plot 175 B
pH	@ 25°C	6 - 9	6.6	6.8	7.1	6.8	6.2	6.1
Conductivity	mS/m @ 25°C	70	73	49	11	5.8	131	151
Calcium	mg/l	32	59	44	15	5.1	118	144
Magnesium	mg/l	30	45	21	5.3	2.5	56	64
Sodium	mg/l	100	12	7.6	<0.1	<0.1	48	56
Potassium	mg/l	50	1.8	1.2	0.6	0.5	5.1	6.4
Manganese	mg/l	0.05	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
Iron	mg/l	0.1	0.3	0.1	0.3	0.2	0.6	0.7
Ammonium	mg/l	1	2.5	2.3	2.0	2.7	4.4	2.4
Alkalinity	mg/l $CaCO_3$	-	42	45	39	10	26	25
HCO_3	mg/l $CaCO_3$	-	51	55	48	12	32	31
Chloride	mg/l	100	11	11	<5.0	8.2	67	81
Sulphate	mg/l	200	217	120	<50	<50	399	494
Nitrate	mg/l	6	5.0	2.7	<0.5	0.5	6.0	5.0
Fluoride	mg/l	0.7	0.2	0.3	<0.1	0.1	0.3	0.3
Uranium	ug/l	0.07[2]	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0

WQG: Water Quality Guidelines for domestic water use (DWAF, 1996)

Based on hydrocensus results, groundwater generally follows the topography. The groundwater flow direction in the Tweelopies West catchment is northwest from the MTSF towards the watercourse. In the Tweelopies East catchment, groundwater flow is from the MTSF to the northeast.

3. METHODS

A source-pathway-receptor system was simulated using the ConSim software package (UKEA, 2003). This has been verified and validated using data from sites in the UK. ConSim allows Monte Carlo simulation of a soil or tailings source, unsaturated pathway and aquifer pathway to obtain a probabilistic output of receptor groundwater quality. Uncertainty in the input parameters can be taken into account by expressing the expected range of parameter values as a probability distribution function. ConSim randomly selects values from the designated distributions for each realisation of the source-pathway-receptor system. The range of results over all realisations provides an indication of likely groundwater quality concentrations at designated receptors.

ConSim includes several means of representing the source. However, the tailings source term, as seepage volume and seepage quality, was determined separately and included in ConSim.

Tailings samples were collected from the MTSF to characterise the current seepage quality and the material characteristics that influence seepage flow. Samples were collected using an enclosed mechanical auger. Samples were withdrawn from the auger tube at 1.5 m depth intervals. Each sample, therefore represents a composite of material over the 1.5 m depth interval.

A sample of reprocessed tailings was obtained from a laboratory-scale simulation of the extraction process. This yielded both an indicative sample of reprocessed tailings and an indicative sample of the process water.

The tailings samples and process water sample were tested for the following:

- Acid-base accounting;
- XRD mineralogy;
- Acid digestion and whole element determination; and
- Paste extracts, comprising 1:1 solid:liquid ratio mixtures of tailings and demineralised water to obtain an indication of the composition of interstitial water in the tailings.

Seepage was modelled by simulating one-dimensional profiles through the tailings source using the finite element model, SVFlux, developed by SoilVision Systems Ltd. (Thode et. al., 2006). SVFlux was developed specifically for the analysis of seepage in saturated/unsaturated flow systems. SVFlux allows for automated mesh generation and refinement, as well as automated time step refinement which improves model stability in a seepage analysis. Unsaturated flow was simulated on a daily time step.

Seepage quality was assessed by equilibrating paste extract composition with geochemically credible mineral phases in Phreeqc (Parkhurst and Appelo, 1999) at the ambient moisture contents indicated from the SVFlux modelling.

4. RESULTS

The ABA analyses indicated that the potential of the tailings to produce acid drainage is uncertain, based on the methodlogy of Price (1997), modified after Usher et al (2003) (Figure 1). As expected, the tailings mineralogy consists mainly of quartz with lesser amounts (<10%) of pyrophyllite, muscovite and chlorite. Pyrite was present in amounts less than 3%. The whole element analysis was generally consistent with the mineralogy.

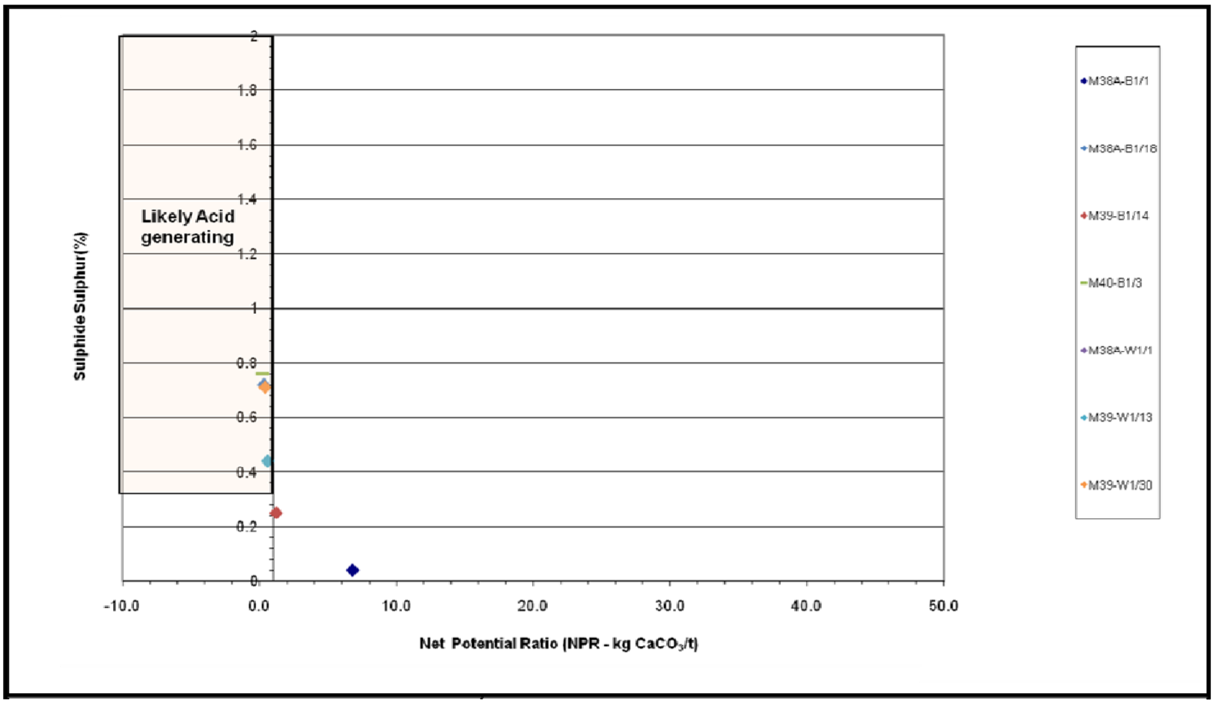

Figure 1. Tailings Net Potential Ratio plotted against Sulphide Sulphur content.

Paste extract results indicate a broad range of interstitial water composition (Table 2).

Table 2. Ranges of 1:1 (solid:liquid) paste extract results for tailings beach and wall samples from the MTSF.

Parameter	Beach			Wall		
	Average	Minimum	Maximum	Average	Minimum	Maximum
pH	4.6	2.6	5.9	5.1	2.6	6.2
Chloride	9.6	<5	49	8.4	<5	39
Sulphate	4200	1300	25000	3300	1200	10079
Calcium	412	140	640	320	37	520
Iron	52	<0.02	600	44	0.040	440
Magnesium	53	1.1	330	34	4.5	130
Manganese	11	0.015	91	13	0.0050	84
Sodium	14	0.025	54	11	<0.05	36
Zinc	5.4	0.085	36	5.4	0.085	31

Seepage volumes and qualities were obtained from the SVFlux and Phreeqc modelling to describe the source term for the base case, operational and post-closure phases of the proposed tailings deposition.

- Base Case consisted of the current post-closure conditions. The phreatic surface (the interface between saturated tailings below and unsaturated tailings above) has receded to the base of the MTSF and seepage flow is driven by climate at the top surface of the facility.
- Operational phase. The operational phase is driven by saturated flows associated with the deposition of the tailings on top of the existing tailings.
- Post-closure phase. For this phase it was assumed that the phreatic surface had receded to the base of the facility again and steady state conditions had been reached. This is a return to the base case conditions.

Each phase was characterised as a separate source in the ConSim software. Each source was superimposed within the model space and activated/deactivated, as dictated by the proposed schedule of the tailings deposition. The schedule was modified to account for the saturated conditions that prevail after the operational phase as the phreatic surface recedes.

Receptors, which may be conceptualised as boreholes within the ConSim model space, were defined at distances downgradient of the source which approximated the distance downgradient of the MTSF of watercourses at which groundwater quality impacts were required.

5. DISCUSSION

The ConSim modelling makes certain assumptions and simplifications about the system being modelled, these are summarised as follows:

1) Chemical equilibrium exists between the tailings material and interstitial water, and dilution effects from infiltrated rain will be small. Therefore the Phreeqc equilibrated leachate concentrations represent the tailings material interstitial water quality for the operational and post-closure phases respectively.
3) The leachate concentration remains fixed through time during the operational and post-closure phases. The infiltration rate therefore controls the contaminant load from the MTSF.
4) Unretarded contaminant transport within the unsaturated zone and aquifer was assumed which implies that contaminants move at the same speed as flow. No sorption of contaminants on clay minerals in the unsaturated zone and aquifer was simulated.
5) The effect of a shallow perched aquifer or low permeability layer in the unsaturated zone beneath the facility was not considered in ConSim since the presence of such layers is accounted for in the SVFlux seepage estimates.
6) ConSim assumes one dimensional laminar vertical flow through the unsaturated zone and one dimensional horizontal flow in the aquifer with flow lines approximately parallel to the facilities.
7) The contaminant, geosphere and aquifer properties were assumed to be constant in ConSim.

The groundwater quality at the receptors was found to have the general form of the graph in Figure 2. This indicates a rise in downgradient groundwater concentration associated with past activities at the MTSF. At some receptors, the peak of this “slug” of contaminated groundwater is seen to pass the receptor over time, leaving an elevated background due to the long-term post-closure contaminant load that continues to affect the groundwater. The proposed new deposition of tailings results in a fresh “slug” of contaminated groundwater that is superimposed on the base case results. Since several locations on the MTSF are operational at different times, the passage of more than one “slug” can be seen in the groundwater quality response at the receptors.

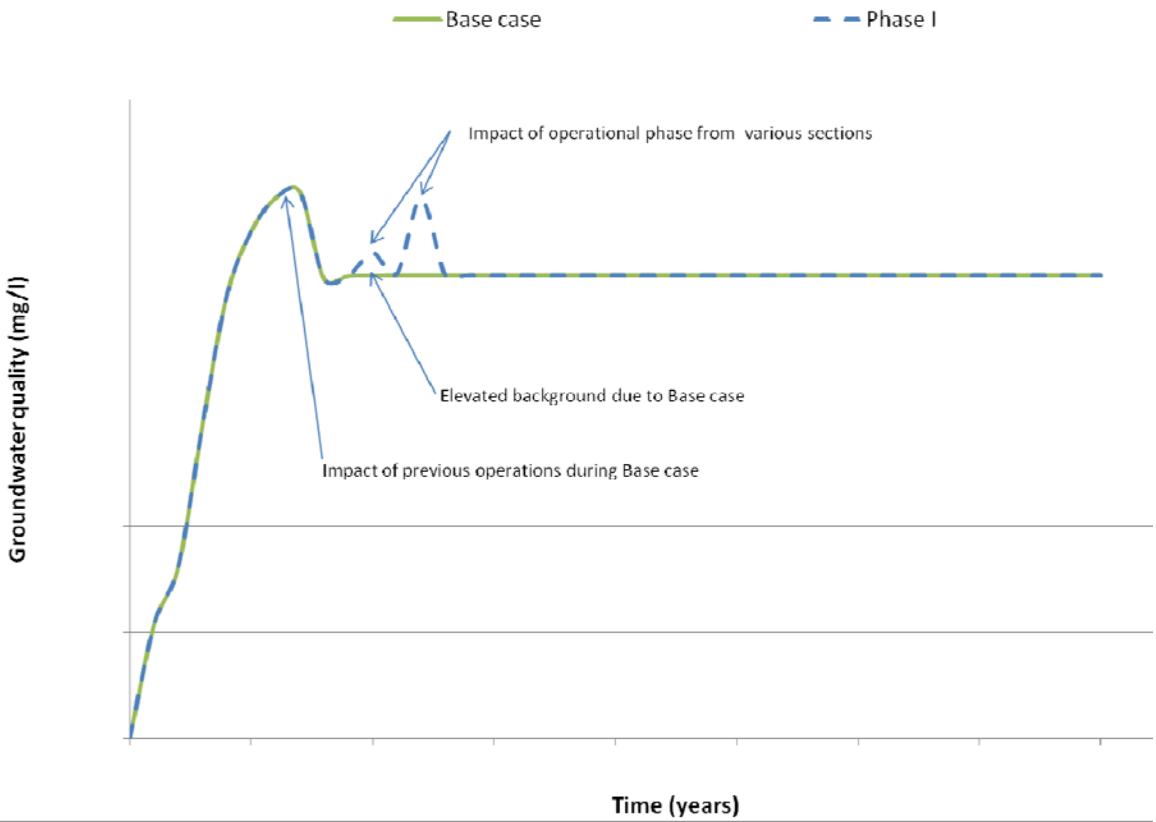

Figure 2. Typical modelled concentration-time curve at receptors downgradient of the MTSF.

It should be noted that the greatest impact to the receptors occurs within the first 70 years of the modelling period which corresponds to the historical activities at the MTSF. In comparison to the impacts already present at the site due to these previous activities, the proposed activities exhibit little or no impact on the system. This can be attributed to the fact that the time period over which the historical activities occurred at the MTSF is far greater than that proposed for the new deposition. The percentage change indicated from the modelling is summarised in Table 3. At some receptors, there is a reduction in concentration for some parameters.

Table 3. Percentage change in groundwater concentrations downgradient of the MTSF based on ConSim model results.

Parameter	**East**	**West**
Chloride	2.6	7.0
Sulphate	-3.1	11.6
Calcium	-60.8	-3.6
Iron	3.9	15.3
Magnesium	-15.2	11.2
Manganese	10.5	8.5
Sodium	-30.7	11.5
Zinc	4.3	14.3

The results obtained in this study are preliminary and have not been fully validated against monitoring data. There is some agreement between monitoring data and model results. However, for parameters, such as sulphate, which is a key indicator of tailings impact on water quality, the model significantly overestimates the downgradient groundwater concentrations. The reason for this probably lies in the high concentrations of the source-term for the post-closure phase. Those portions of the MTSF in the post-closure phase therefore have a disproportionate contribution to downgradient groundwater quality.

A validation process is underway to refine the model predictions.

6. CONCLUSION

A groundwater quality impact assessment has been conducted which uses a source-pathway-receptor approach simulated using the software ConSim. ConSim employs a probabilistic methodology which allows incorporation of data uncertainty.

The ConSim modelling graphical results suggest that, while there is a possible increase in the modelled groundwater concentrations from the proposed reprocessed tailings deposition at Millsite, this is small in terms of the impacts that have already occurred at this site due to historical deposition activities. However, these results have not been fully validated against monitoring data.

7. REFERENCES

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