HEATHGATE

BEVERLEY MINE REPORT

Groundwater flow modelling of migration of mining fluids from the proposed Four Mile East mining zone

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Final Report

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1 INTRODUCTION

This report documents numerical flow modelling, undertaken as part of the Four Mile Uranium Mine Lease Application. The aim of this work is to develop a model that can predict the expected down-gradient flow paths and flow velocity of groundwater and mining fluids which flow through the Four Mile East Orebody.

The modelling approach is to develop a simple, two dimensional model, using known aquifer properties and boundary conditions. The intention is that the model be fit for purpose, and reflect the currently available information with minimal uncertainty, or non-uniqueness. To this end, the model set-up comprises very simple boundary conditions which reflect measured data, and a simple, two dimensional, transmissivity based, approach to aquifer property setup and calibration.

Model setup, calibration and reporting have been undertaken in accordance with the current industry standard guidelines for numerical groundwater modelling (MDBC, 2000).

The modelling serves two purposes:

- Firstly, to confirm that the conceptual model is hydraulically feasible. I.e. that the model can be calibrated to measured water levels using realistic aquifer properties and boundary conditions that are supported by real data.
- Secondly, to predict flow paths and flow velocities which can be used as inputs into geochemical modelling of natural attenuation. The geochemical modelling will consider water – rock reactions in two dimensions along these flow paths.

2 CONCEPTUAL HYDROGEOLOGICAL MODEL

The regional conceptual hydrogeological model is reported in detail in SKM, (2008). A brief summary as applied to this modelling work is presented here. The conceptual model is presented in Figure 1.

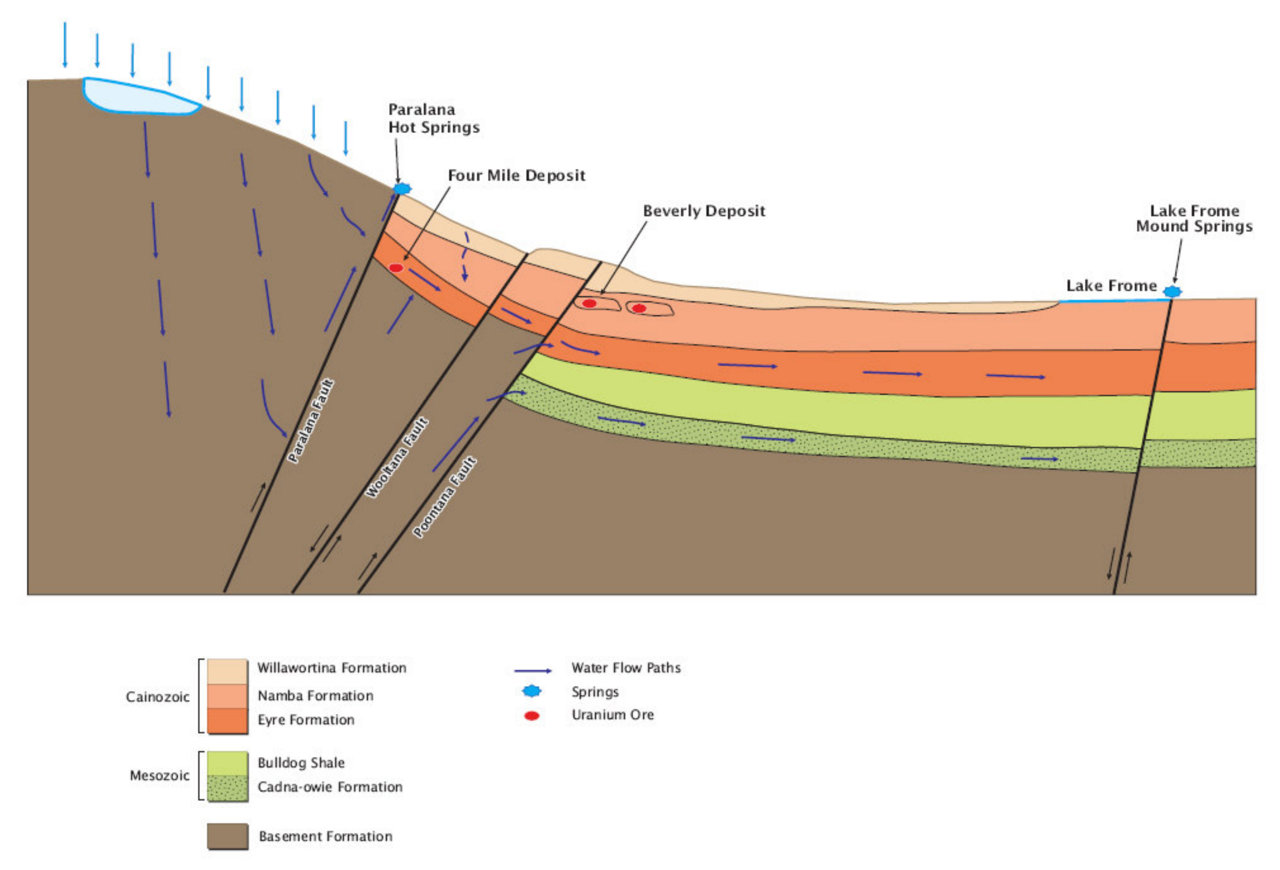

Figure 1: Conceptual Hydrogeological Model

The Four Mile East Orebody is hosted in the Lower Eyre Formation aquifer. Aquifer thickness ranges from 70m at the First Stage Mining Area (FSMA) to 50 to 60m further down-gradient.

Aquifer testing demonstrates that this aquifer is bounded above and below by low permeability units. The predominately Silt and Clay, Namba Formation forms the overlying bounding unit, whilst a cemented diamictite forms the lower bounding unit at the first stage mining area (FSMA). Further down-gradient, to the north-east, the Namba Formation remains present as the overlying boundary, whilst the Bulldog Shale mudstones on-lap fractured rock basement to comprise the underlying boundary. Aquifer testing at the FSMA indicated that the lower Eyre Formation exhibits a transmissivity of approximately 350m^2/day. Anisotropy, calculated from aquifer testing data, was 30:1, where horizontal permeability is 30 times greater than vertical permeability.

The measured aquifer pressure gradient across the Four Mile East orebody is 0.0025 along a south-west to north-east orientation. The flow patterns in the Eyre Formation at the Four Mile ore bodies are thought to be constrained by basement structure which forms an embayment (The Four Mile Embayment) which is formed between the Northern Flinders Ranges and elevated bedrock forming the “Poontana Inlier” further to the east between the Wooltana and Poontana Faults zones. This “inlier” becomes less pronounced to the north which allows groundwater flow out of the embayment, through the fault zone and into the greater Lake Frome Embayment. A distinct drop in aquifer pressure across this fault zone indicates that this zone exhibits reduced transmissivity.

Recharge to the Eyre Formation within he Four Mile Embayment is via infiltration from stream flood outs in the south west of the Embayment where the Eyre Formation outcrops at surface, and via lateral and vertical upward leakage from fractured rock aquifers which recharge in the Northern Flinders Ranges. Discharge is via lateral flow followed by eventual upward leakage, and evaporation at Lake Frome, the regional groundwater sink some 50km to the east.

3 MODEL SETUP AND CALIBRATION

3.1 Modelling Software

The numerical groundwater modelling was undertaken using the MODFLOW package (Mcdonald and Harbaugh, 1988). Flow paths were calculated using the MODPATH Package (Pollock, 1989). The Visual Modflow software package (Waterloo Hydrogeologic, 2007) was used to pre and post process the MODFLOW, and MODPATH files. Visual Modflow is an industry standard software package used for numerical groundwater modelling.

3.2 Grid

The model grid comprised 499 columns and 499 rows. The grid was refined to a cell size of 15 m across the ore zone. Cell size increased to 450 m regionally. The inferred aquifer extent, (controlled by the Paralana Fault marking the edge of the Flinders ranges to the west and by the elevated basement of the Poontana Inlier to the East) was simulated by assigning inactive cells to zones beyond the aquifer extent (Figure 2).

The model was constructed with 13 Layers from -40 to -110m to yield a total thickness of 70m (Figure 3). Layers were assigned a thickness of approximately 5m. All layers were modelled as confined units.

Layer elevations were constant throughout the model. This was considered an appropriate two dimensional model setup. This is because the aquifer remains confined at all times down-gradient of the Four Mile East orebody, and aquifer thickness is reasonably consistent. In this situation applying dip and strike to the model layers is not necessary to model lateral flow.

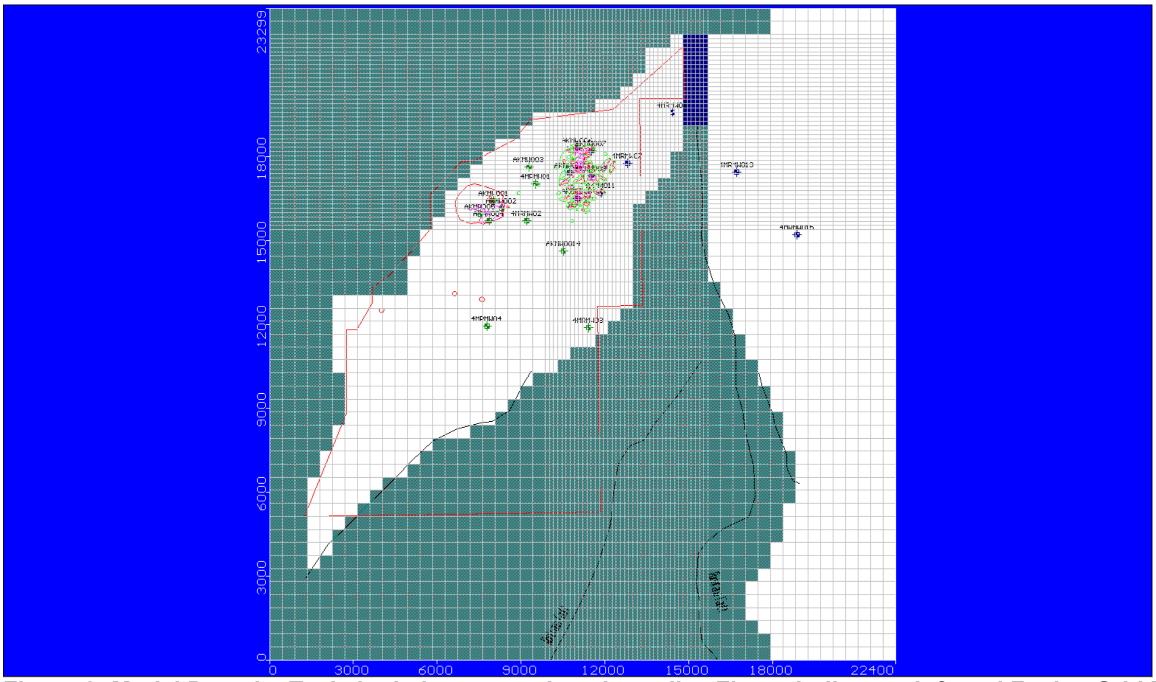

Figure 2: Model Domain, Teal shaded areas are inactive cells. Figure indicates; inferred Faults, Grid Mesh, Water level observation wells, inferred ore outline, Mine Lease Application Boundary and Transmissivity zones; white cells – Zone 1, blue cells Zone 2. Grid mesh is refined further than shown by a factor of 10 along the active flow path.

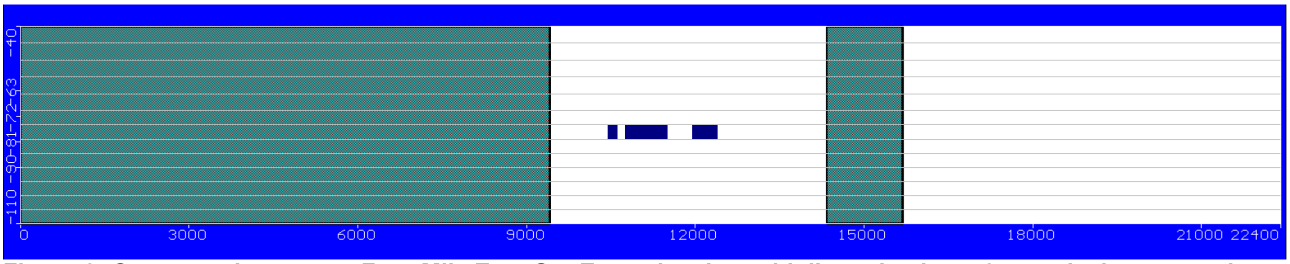

Figure 3: Cross section across Four Mile East Ore Zone showing grid discretisation. 50 x vertical exaggeration. Total Thickness is 70m. Layer 5 thickness is 5m. Blue cells ore zone

3.3 Parameters

The model was assigned two Transmissivity Zones. Vertical permeability was modified to reflect the aquifer anisotropy of 30:1. Transmissivity of these zones was varied as a calibration parameter as described in the Calibration section below. Zone 1 represents the Eyre Formation aquifer as tested at the FSMA. Zone 2 represents the Eyre Formation aquifer across the Poontana Fault Zone where the observed rapid aquifer pressure drop indicates reduced transmissivity.

3.4 Boundaries

Recharge into the modelled system was applied through a constant head boundary (CHB) with head of 60 mAHD applied up gradient of the Four Mile East ore zone. The position of this boundary was coincident with the measured aquifer pressure of 60 mAHD. Observation wells used to locate the CHB are presented in Table 1.

Table 1: Monitoring well data points used to position recharge CHB

WellID	Easting (GDA94_Z54)	Northing (GDA94_Z54)	RSWL (mAHD)
4MRMW02	356378	6663199	59.6
AKMW0014	357718.2	6662139	60.5
4MRMW01	356719	6664521	58.7

Discharge to the system was applied through a CHB with 14 mAHD head across the eastern extent of the Model. This boundary served to simulate lateral flow to the east followed by eventual discharge from Lake Frome.

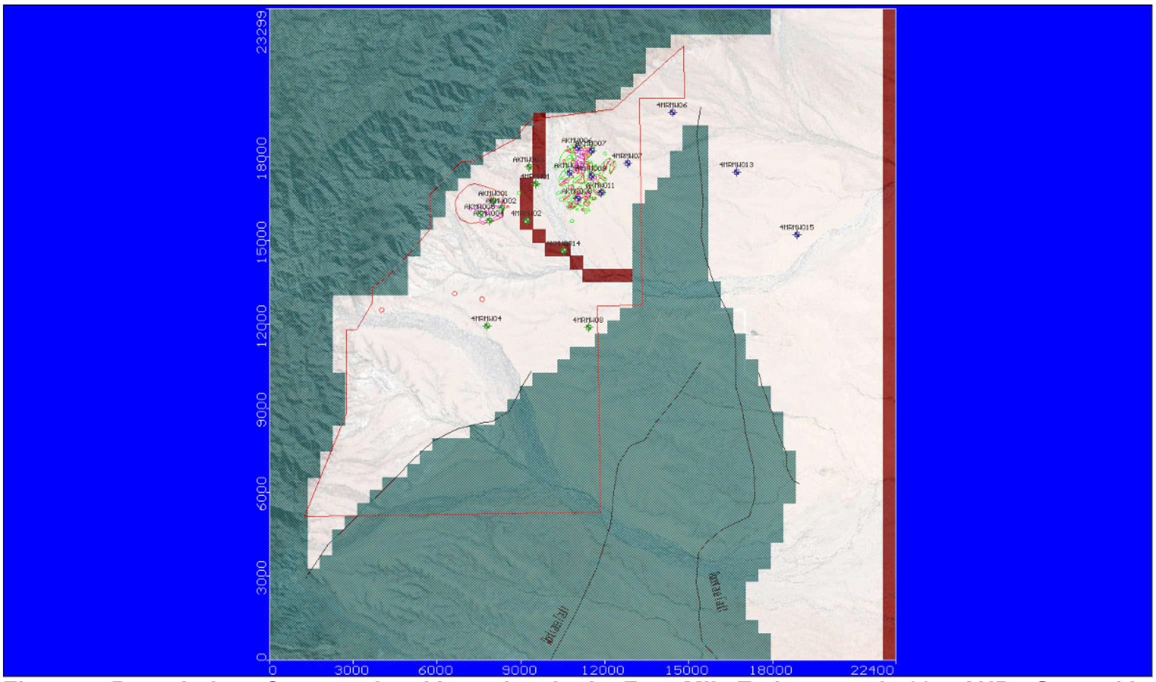

Figure 4: Boundaries. Constant head boundary in the Four Mile Embayment is 60 mAHD. General head boundary on the eastern model extent is 0 mAHD at a distance of 50km.

3.5 Density Driven Flow

Consideration was given to the significance of density driven flow, in the context of more saline mining fluids moving through less saline natural groundwater at Four Mile East.

Where density differences are significant relative to lateral groundwater movement, the heavier, more saline plume may plunge beneath the natural ground water, and move preferentially along the base of the aquifer. The higher density may also result in more rapid plume movement due to the pressure gradient between the heavy, saline plume and the lighter, less saline surrounding groundwater.

To assess the effect of density driven flow, the relative fluid densities were calculated using the program AquaC (UIT, 2008). Natural groundwater chemical data from samples taken from Four Mile East Orebody were used. AquaC was then used to calculate the composition of mining lixiviant, by addition of H_2SO4 to pH 1.7, and addition of hydrogen peroxide to ORP of 1086 mv. Charge balance was maintained through adjustment of Cl concentration. The composition of each fluid is shown in Table 2.

The significance of this density difference was investigated using the mixed convection ratio – basically the ratio of buoyancy (density) driven flow speed to advective (natural lateral) flow speed (Bear, 1972). When this ratio is greater than 1 density driven flow may dominate, whilst a ratio of less than 1 indicates that natural lateral flow will dominate. For the fluid compositions above the mixed convection ratio is 0.243, which indicates that density driven flow is a negligible component. When the anisotropy of the aquifer is taken into account (Simmons, pers. com., 2008), the mixed convection ratio is even less at 0.008 which indicates that density driven flow is even more negligible. Calculations are shown in Appendix 1. It is worth noting that dispersion of the plume will further reduced the density difference between the two fluids, and hence the potential for density driven flow.

This analysis demonstrates that density driven flow is not a significant factor in predicting mining fluid movement in the context of the Four Mile East mining proposal.

Table 2: Calculated fluid composition and fluid density.

Water Type		Natural Groundwater	Mining Solution
temp	c	35	35
pH		6.7	1.7
pE		0.02	17.77
Eh	mv	1.00	1086.75
Water	kg	1	1
TDS	mg/kg	3012	5203
Ionic Strength	mol/kg	0.0529	0.0839
EC_25c	uS/cm	3279	5202
Alkalinity	eq/kg	0.003	-0.38
Ca	mmol/kg	2.67	2.67
Mg	mmol/kg	1.07	1.07
Na	mmol/kg	39.97	39.97
K	mmol/kg	1.44	1.44
SO4	mmol/kg	1.46	28.00
DIC	mmol/kg	3.93	3.93
CL	mmol/kg	42.99	31.43
Density	**kg/L**	**1.0023**	**1.00403**

4 MODEL CALIBRATION

4.1 Overview

Model calibration was achieved by varying the transmissivity of zones 1 and 2 until the best possible match between measured and modelled aquifer pressure was achieved.

4.2 Methodology

Calibration data was applied from 10 monitoring wells completed in the Eyre Formation aquifer. Aquifer pressure was the average of repeat measurements taken from each well over 10 days in September 2008. Calibration data are presented in Table 3.

Table 3: Aquifer pressure calibration data.

WellID	Easting (GDA94_Z54)	Northing (GDA94_Z54)	RSWL (mAHD)
AKMW006	358200	6665802	57.6
AKMW007	358698	6665701	56.9
AKMW008	358197	6664000	60.0
AKMW009	358718	6664816	54.3
AKMW011	359047	6664200	57.9
AKMW012	357919	6664923	57.6
4MRMW06	361592	6667079	47.5
4MRMW07	359988	6665248	51.1
4MRMW013	363903	6664942	17.5
4MRMW015	366041	6662710	15.3

4.3 Results

The best model calibration was achieved with a transmissivity of 420 m^2/day and 56 m^2/day applied to Zones 1 and 2 respectively. Calibrated model aquifer pressure contours are presented on Figure 5. Calibration data scatter plots are presented on Figure 6.

Calibration Root Mean Squared (RMS) error is 3.3% which is well within the guideline calibration targets for good modelling practice of 5 to 10% (MDBC 2000).

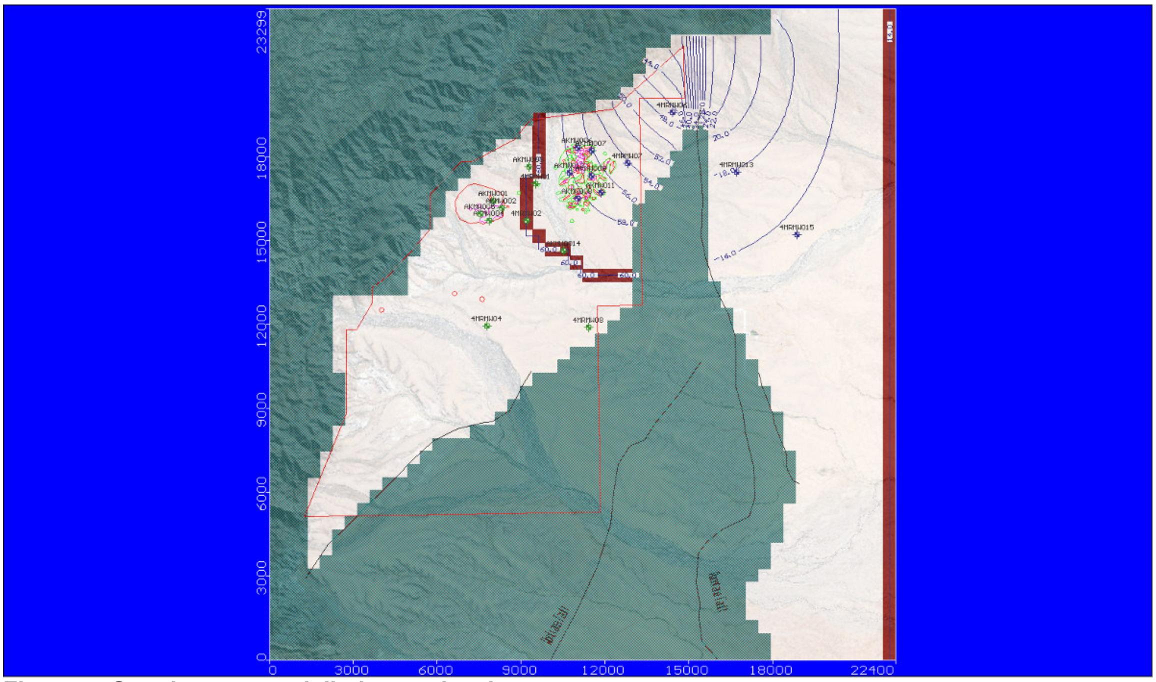

Figure 5: Steady state modelled water levels.

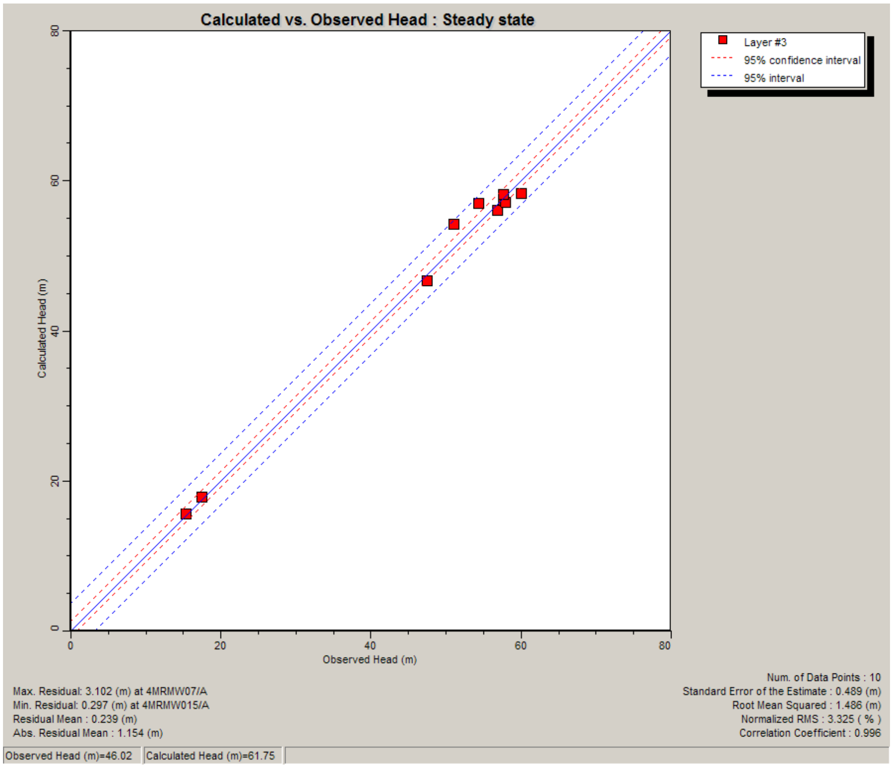

Figure 6: Steady state flow calibration. Observed vs. calculated aquifer pressure.

5 FLOW PATH MODELLING

5.1 Overview

Flow path modelling was undertaken using the MODPATH package (Pollock 1989). The aim of this work was to predict long term flow paths and velocity for groundwater and mining fluids which flow through the Four Mile East Ore Zone and continue to move down gradient. The predicted flow paths and flow velocities can be then used as inputs into geochemical modelling of natural attenuation. The geochemical modelling will consider water – rock reactions in two dimensions along these flow paths.

5.2 Methodology

Five particles were applied to the model. These were evenly spaced across the flow gradient within the Four Mile East Ore Zone. A sensitivity analysis approach was used to assessing flow paths whilst varying effective porosity values. The first model applied an effective porosity of 0.15. This value was considered at the low end of the possible range of porosity values and resulted in more rapid modelled groundwater velocity and hence represented the worst case scenario. The second model applied an effective porosity of 0.3. This was a more realistic estimate and represents the most likely scenario.

5.3 Results

Groundwater flow paths for these two scenarios are presented on Figure 8 and Figure 9.
Predicted groundwater flow over time for a porosity of 0.3 is presented as a scatter plot in Figure 10. This data shows that groundwater is expected to flow to the north east, through the hydraulic constriction across the Poontana Fault zone and then into the Lake Frome Embayment. For the likely scenario with a porosity of 0.3, predicted flow velocity in can be broken into 3 zones:

- Four Mile East ore zone 15 m/year
- Four Mile Embayment down gradient of ore zone 20 m/year
- Lake Frome Embayment 6 m/year.

These predicted flow velocities approximately double if porosity is halved to 0.15.

The flow path conceptual model that will be provided as input data for natural attenuation geochemical modelling studies can be presented fairly simply as shown in Figure 7.

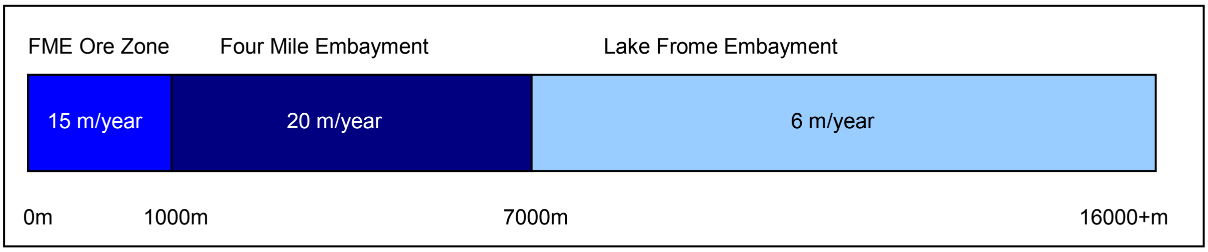

Figure 7: Flow Path Conceptual Model

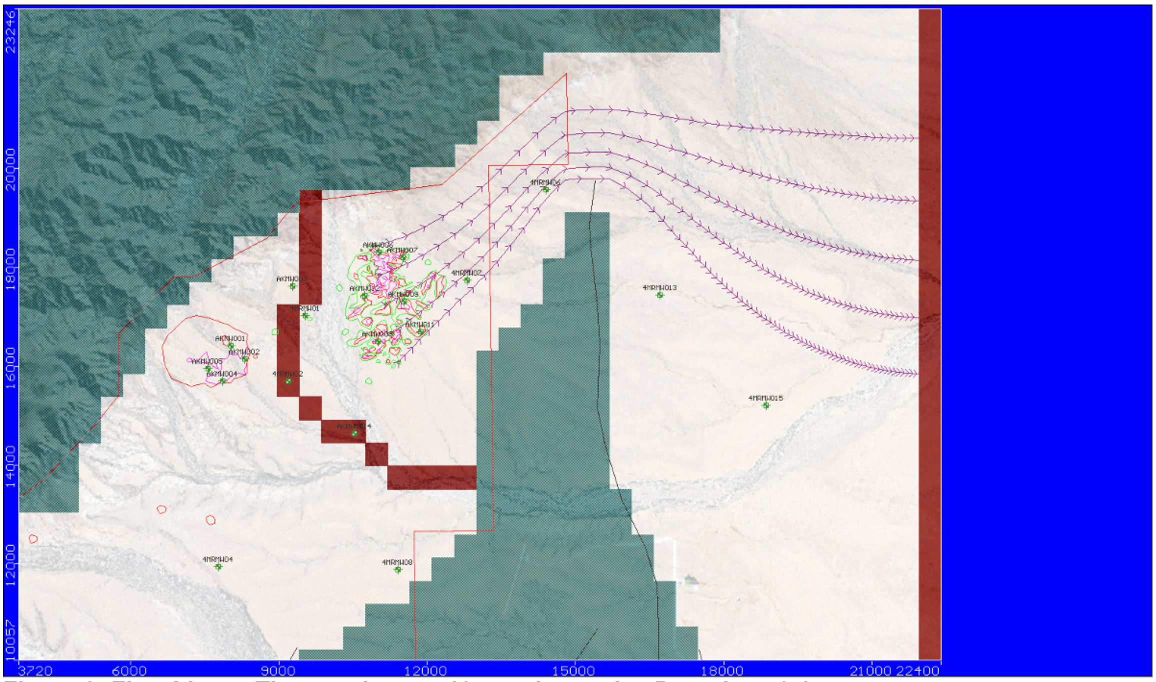

Figure 8: Flow Lines. Time markers at 10 year intervals. Porosity = 0.15

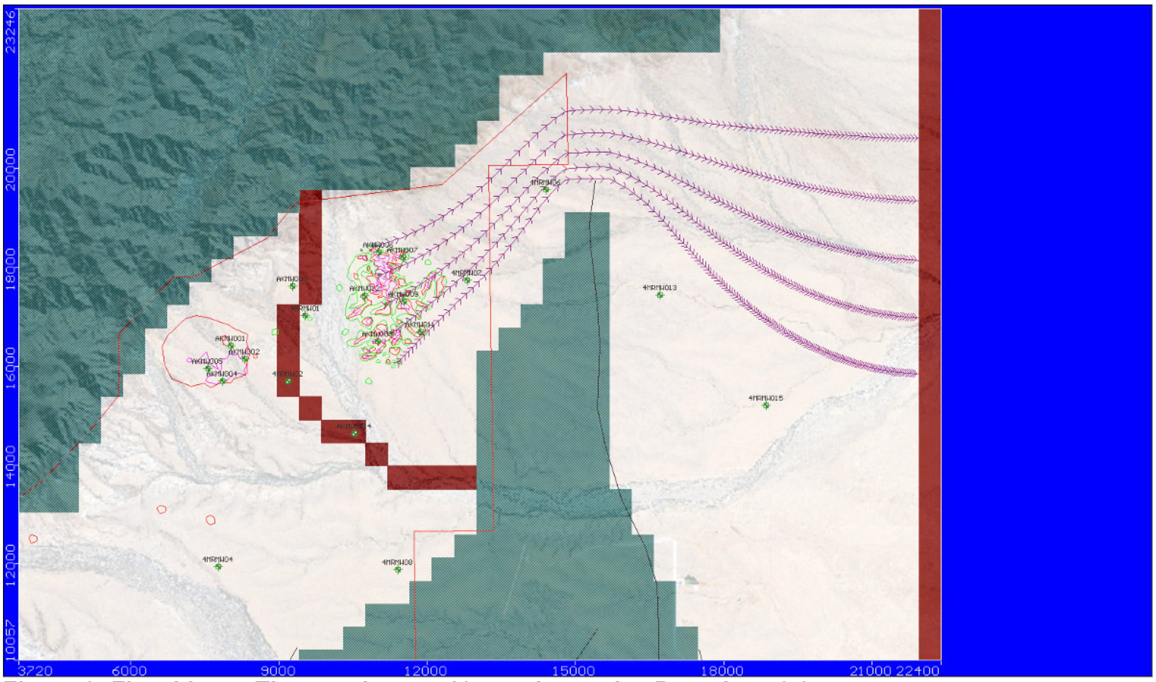

Figure 9: Flow Lines. Time markers at 10 year intervals. Porosity = 0.3

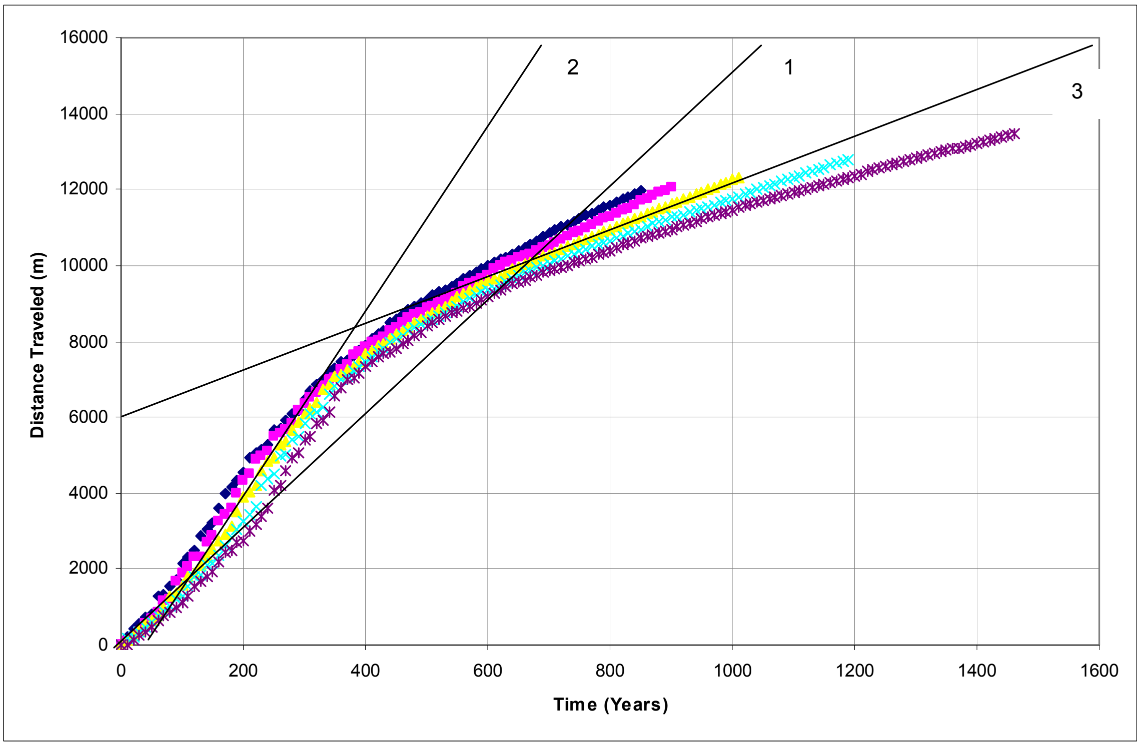

Figure 10: Predicted Flow Velocities – Porosity = 0.3. A separate data series is presented for each particle. Lines of best fit represent flow through; 1) Four Mile East Ore Zone, 2) Four Mile Embayment. 3) Lake Frome Embayment.

6 CONCLUSIONS

The groundwater flow modelling work was undertaken to achieve the following:

- Firstly, to confirm that the conceptual model is hydraulically feasible. I.e. that the model can be calibrated to measured water levels using realistic aquifer properties and boundary conditions that are supported by real data.
- Secondly, to predict flow paths and flow velocities which can be used as inputs into geochemical modelling of natural attenuation. The geochemical modelling will consider water – rock reactions in two dimensions along these flow paths.

The steady-state flow model was well calibrated with a RMS error of 3.3 %; well within industry guidelines. This indicates that the conceptual hydrogeological model is a plausible, simplification of the real system. This calibration does not indicate that the conceptual model is correct; it only confirms that it is possibly correct. A failure to calibrate the model would indicate that the conceptual model was incorrect, or oversimplified to the extent of being unrealistic.

The flow model was used to predict flow paths and flow velocities for a range of aquifer porosity values. This modelling showed that the flow paths could be categorized into 3 flow domains based on fluid velocity:

- Four Mile East ore zone 15 m/year
- Four Mile Embayment down gradient of ore zone 20 m/year
- Lake Frome Embayment 6 m/year.

Geochemical modelling of water – rock reactions is being undertaken separately using flow velocity and dilution data from this study. Water – rock reactions will reduce the concentration of mining fluid constituents through the following processes:

- dissolution and precipitation reactions
- ion Exchange reactions
- adsorption
- redox reactions

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8 APPENDIX 1 – MIXED CONVECTION RATIO CALCULATIONS

4M0008				
collar	138.5	mAHD		
screen	201-206	mBTOC	-67.5	
swl	56.29	m ADH		
head above base of plume	123.79	m		
plume thickness	3	m		
plume density	1.00403	T/cum		
aquifer water density	1.00233	T/cum		
regional hydraulic gradient	0.0025	m/m		
p = Rho . G .h				

	z	h (m AHD	h (m above	average density =[(3*plume density)+((z-3)*native fluid density)]/ z
at 1m BELOW bas	124.79	56.5858607	125.0859	1.00237
at base of plume	123.79	56.5835307	124.0835	1.0031
difference in average density				-0.0007
dh/dz		-0.00233		

-62
-63

Mixed Convection Ratio I.e. (bouyancy driven flow vel/advective flow v)

M = {(Kv * Δρ)/ρ)} / {(Kh∗Δh) / ΔL}

when M >> 1 Density driven flow may dominate
when M <<1 Advective flow dominates

at 4 Mile M = **0.009701287** suggests that vertical (density-driven) component is negligible when vertical anistropy is considered.
Further the effects of dispersion downflow will reduce the concentration and thus the plume density again reducing the value of M.

EVEN if the system is considered to be isotropic and homogeneous

at 4 Mile M = **0.291329941** In the absence of vertical anisotropy the M value suggests that density-driven vertical component of flow will be very small compared witl

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