



Report

MRM Phase 3 Development Project EIS - Groundwater

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Prepared for
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Introduction

1.1 Background

Mining and Energy Technical Services Pty Ltd (MET Serve) has asked URS Australia Pty Ltd (URS) to undertake groundwater modelling to assess and predict pit groundwater inflow and drawdown impact for the proposed McArthur River Mine Phase 3 Development (The Project) at the existing McArthur River Mine (MRM). A regional groundwater model has previously been developed by URS (URS, 2005) to predict groundwater impact associated with open pit dewatering. The Project proposes to expand and deepen the existing pit and an updated groundwater model has now been constructed. The predictive results of the new updated groundwater model will be used to support the Project's environmental impact statement.

1.2 Scope of Work

The scope of works contained in this report is limited to the determination of groundwater drawdown and inflows associated with the Project using available documented and field data.

1.3 Model Complexity

Although, according to the modelling guidelines (MDBA 2000) the groundwater model is classed as a moderate complexity model, the particular geological structural features, dolomite hydraulic conductivity variability and existing underground mine, add complexity to this model.

1.4 Model Audit

The groundwater model has been audited by Dr Frans Kalf of Kalf and Associates Pty Ltd. The audit report is presented in Appendix E.

1.5 Study Area

1.5.1 Location

MRM is located approximately 60 kilometres south-west of the township of Borroloola, 120 kilometres south of the Bing Bong loading facility on the Gulf of Carpentaria and 900 kilometres south-east of Darwin in the Gulf Region of the Northern Territory (Figure B1, Appendix B).

1.5.2 Climate

The McArthur River region is classified as a 'Grassland' climate, based on the Köppen classification system (Australian Bureau of Meteorology (BOM) 2011). This classification consists of two distinct seasons:

- the wet season from December to March; and
- the dry season from April to November.

Presented in Figure 1-1 are mean monthly rainfall data from 1968 to 2011 and mean daily evaporation data from 1975 to 2011 recorded at the McArthur River Mine weather station (014704). Mean monthly rainfall from 1968 to 2011 ranged from 0.4 mm in August to 208.4 mm in January. Mean annual rainfall for the mine site is 790.2 mm. Mean daily evaporation from 1975 to 2011 ranged from 9.9 mm in November to 5.8 mm in June. Mean annual daily evaporation at the mine site is 7.5 mm.

1 Introduction

Average daily minimum and maximum temperatures for McArthur River are 12.5°C to 29.8°C in June whilst in December they range from 24.9°C to 37.7°C.

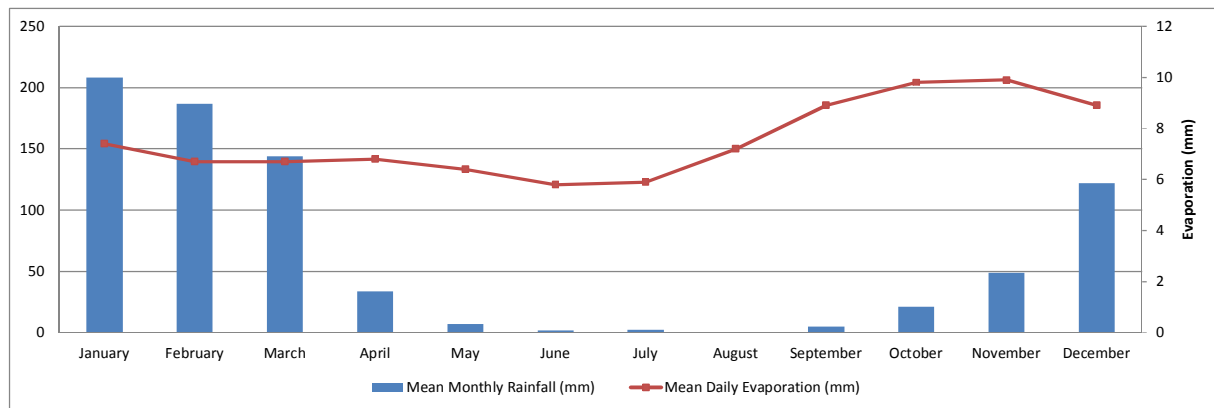


Figure 1-1 Long-term rainfall and evaporation data from McArthur River Mine weather station (014704)

The cyclone season at MRM and is from November to April, with peak activity in January and February. The BOM predicts 0.1 to 0.2 cyclones annually, on average. During cyclonic events, increased rainfall events may occur. The highest recorded daily rainfall was 197.5 mm on 15 February 1974.

Floods in the McArthur River are large and highly variable. The floodplain is regularly inundated up to 5 m deep, and rises in flood levels of 5 to 7 m over 24 hours are not uncommon (URS, 2006).

1.6 Previous Work

Detailed groundwater investigations and numerical groundwater flow models of the area were first undertaken by URS (URS 2005) as part of Environmental Impact Assessment for the McArthur River Mine Open Cut project. This model was used to predict open cut pit inflow rates and potential drawdown impacts on the Djirrinmini waterhole, on river flows and groundwater dependent ecosystems.

Other works include:

- Hydrogeological and Geotechnical Investigations conducted by Golders and Associates (Golders 2004).

Geological Setting and Hydrology

2.1 Overview

The data used in this work included:

- geologic data sourced from mineral exploration holes, groundwater investigation holes, geotechnical investigation pits and drillers logs;
- hydrologic data collected by MRM personnel from 1995 to present as part of regular monitoring programs; and
- hydraulic data obtained through field and laboratory hydraulic tests carried out by URS (URS 2005) and Golders Associate (Golders 2004).

The hydrologic data included groundwater levels from shallow monitoring bores, open pit and underground inflow and production bore pumping rates, river stages and flow for McArthur River and water quality. Surface water and groundwater monitoring sites are shown in Figure B2; Appendix B. Water quantity and quality data are collected on a monthly, or on a more regular basis. Rainfall and evaporation data is collected and made available to the public by the Bureau of Meteorology (BOM).

2.2 Geological Setting

2.2.1 Topography

The topography in the study area may be categorised into the following:

- high rocky sandstone plateaux and ridges mainly associated with the Lower Cambrian Bukalara Sandstone to the east of the study area;
- high level valleys and depositional plains with a series of linear ridges of erosion-resistant sedimentary rocks, which trend normal to the direction of drainage and inhibit the normal down-cutting of the streams, resulting in a tendency for water impoundment upstream of these transverse linear ridge features;
- broad or narrow fluvial corridors of drainage channels;
- river depositional flood plains; and
- level to gently undulating plains of unconsolidated, depositional materials.

The major topographic features dominating the area are the McArthur River (and associated tributaries), Barney and Surprise Creek, Barney Hill and the Bukalara Plateau. The Bukalara Plateau is composed of flat-lying Bukalara Sandstone, rising approximately 30 to 100 m above the surrounding countryside. The sandstone is characterised by its joint pattern, distinctive cross-bedding and slight feldspathic nature.

2.2.2 Geology and Lithology

The area is underlain by alluvium associated with the McArthur River, and bedrock of the McArthur Group. The McArthur Group is a thick sequence of Proterozoic formations extending from the Queensland boarder to Arnhem Land. These formations include an interbedded sequence of dolostones, sandstones, siltstone, and shales, with a composite thickness of greater than 4,000 m in the McArthur River Region.

2 Geological Setting and Hydrology

Basement formations in the area include Middle Proterozoic, interbedded cyclic dolostones, dolomitic siltstones, sandstone and shale of the McArthur Group. The McArthur Group is overlain by the Batten Subgroup which consists of shallow marine deposits, dolomitic sandstones, pyritic shale, quartz sandstone and evaporites. Much of the bedrock sequence is weathered at shallow depths.

The geology of the McArthur River Mine has been described by Large et al, and includes the Barney Creek Formation (which consists of the HYC Pyritic Shale, the main Talus Breccia, the HYC Pb-Zn Ore and the W-Fold Shale), Teena Dolomite, Mitchell Yard Dolomite and Mara Dolomite. The description of stratigraphical units is presented in Table 2-1 (Section 2.3.1). Figure 2-1 shows the McArthur River Geology in plan view, with a cross sectional view presented in Figure 2-2.

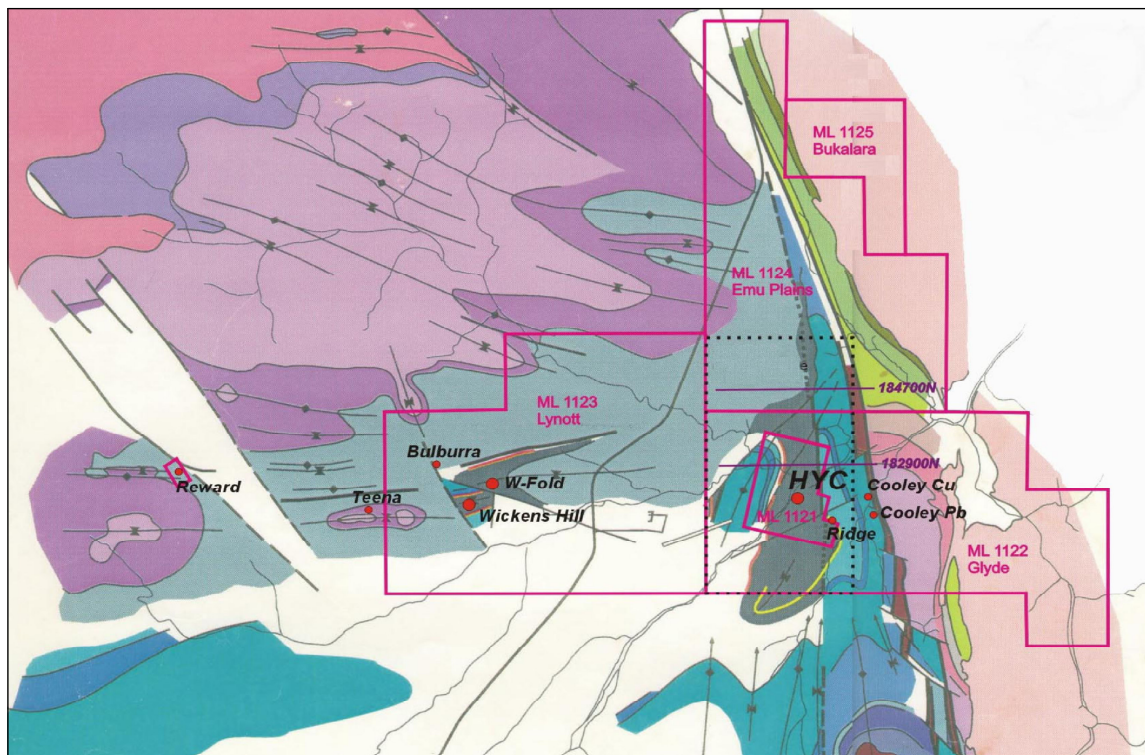


Figure 2-1 McArthur River Geology – Plan View

2 Geological Setting and Hydrology

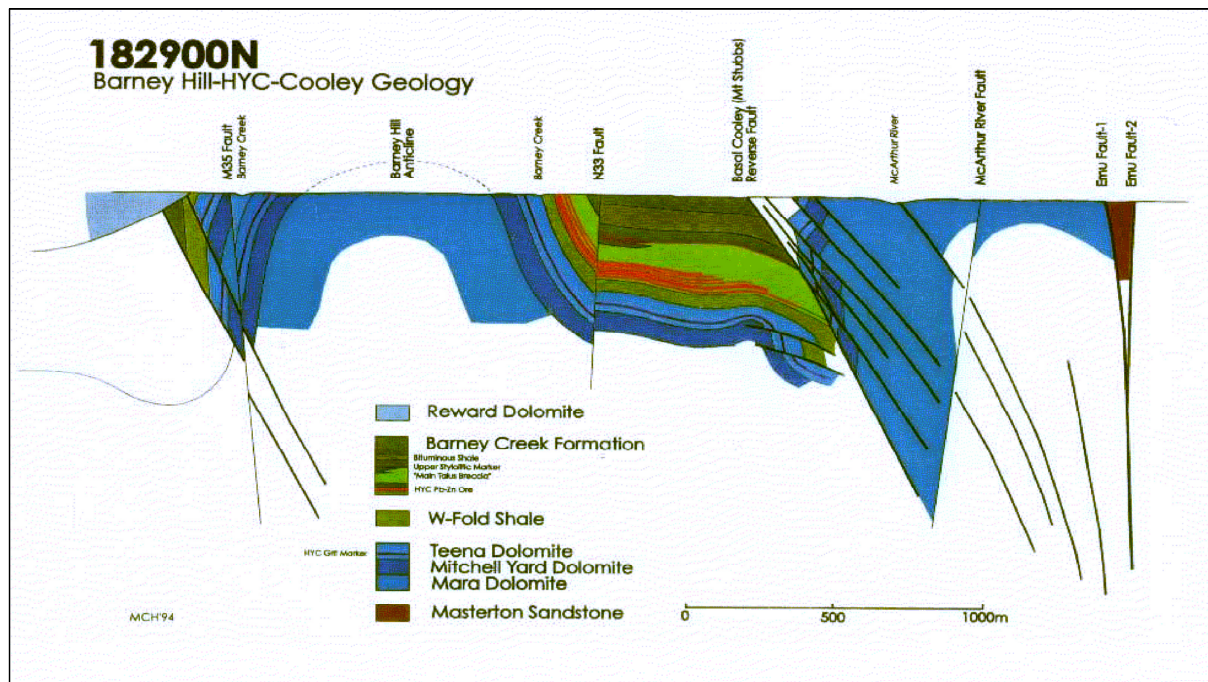


Figure 2-2 McArthur River Geology – Section View

2.3 Hydrology

2.3.1 Groundwater

Groundwater Occurrence

Groundwater in the study area occurs on local scale in both surficial deposits and bedrock. Extensive aquifers with intergranular permeability in the area are rare and are generally limited to the alluvium that occurs along the drainage channels of the rivers and creeks including a paleochannel that extends through the mine site area deposited at one time by the McArthur River channel. Historical inflows into the current open pit indicate that the permeable sections of the weathered bedrock at shallow depths can act as significant aquifers that receive rapid recharge from the ground surface and also serve as a source of recharge to fractured rock aquifers. The underground mine, which lies within the confines of the proposed pit, also has recorded inflows that occur from the mine strata and drainage from the current open pit to the underground.

The following groundwater aquifers can be distinguished in the area:

- local and or perched aquifers in the alluvium;
- local and or perched aquifers located at the interface between the soils and/or weathered bedrock and the more solid bedrock; and
- local fractured rock (i.e. fractures, joints, vugs, and possible solution channels) aquifers of the bedrock.

The aquifers are unconfined to semi-unconfined types with the underground mine forming a sub-surface void.

2 Geological Setting and Hydrology

Presented in Table 2-1 is a generalised stratigraphy, geologic and hydrogeologic characteristics of hydrostratigraphic units found within the study area with a description of the main aquifers in the vicinity of the mine, provided below.

Table 2-1 Generalised stratigraphy, geologic and hydrogeologic characteristics of alluvial deposits and bedrock in the study area

Period	Geologic Formation	Member/Unit Name	Lithological Description	Hydrogeological Description
Quaternary	Alluvium	Alluvium	Unconsolidated sand, silt, clay and other materials with fine texture that may have settled out after floods.	Productive unconfined alluvial aquifer where saturated. Published values of hydraulic conductivity ranges from 4.92E-02 to 3.37 m/d.
		Palaeochannel (buried channel) sediments	Mostly gravel and coarse sand with some boulders deposited in the McArthur River Paleochannel.	High yielding aquifer. Published values of hydraulic conductivity of the palaeochannel ranges from 21.6 to 35.2 m/d.
-	Weathered Bedrock	Weathered Bedrock	Weathered bedrock.	Published hydraulic conductivity values for weathered bedrocks ranges from 1.6 to 22.5 m/d.
Proterozoic	Barney Creek Formation	HYC Pyritic Shale	Pyritic Shale.	Results from packer tests indicated that the permeability of the shale is approximately 8.65E-05 m/d.
		Main Talus Breccia (Cooley Dolomitic Breccia)	Chaotic breccia, with clasts which range in size from a few millimetres to several tens of meters.	Reported hydraulic conductivity values of the breccia ranges from 2.59E-04 to 5.18E-04 m/d.
		HYC Pb-Zn Ore	Thin-bedded to laminated dolomitic siltstone characterised by a high carbonaceous content.	Can yield groundwater if fractured.
		W-Fold Shale	Green and red, dolomitic siltstone and shale with interbeds of green vitric tuff.	Reported hydraulic conductivity of the W-Fold Shale is 4.0E-04 m/d.
	Teena Dolomite	Coxco	Massive, dark grey and sometimes vaguely bedded dolostone with numerous interbeds orange-weathering, mudstones.	Fractures, joints and other geologic structures in otherwise these solid rocks are conduits through which groundwater flows.
		Lower Teena	Very thin bedded, massive, dark pink and grey dololomite.	

2 Geological Setting and Hydrology

Palaeo- protozoic?	Emmerugga Dolostone	Mitchell Yard Dolostone	Dark grey weathering, uniform, massive, karstic dololomite which has undergone extensive vadose alteration	Variably saturated karstic/fractured-rock aquifer. Fractures/vugs dominantly controls groundwater flow in the massive rocks. Reported hydraulic conductivity values obtained from boreholes completed in fractures and vugs ranges from between 3.37E-02 and 21.17 m/d. Fractures, joints and other geologic structures in this massive rock are conduits through which water flows. Gaven et al (2001) and, Yang et al (2004) assigned hydraulic conductivity value of 2.74E-01 m/d to the faults in their numerical investigation of fluid flow associated with the formation of the HYC deposit in the McArthur River Basin.
		Mara Dolostone	Laminated dololomite. interbedded with thin beds of flake and randomly orientated intraclast breccia, occasional recessive interbeds of fine dolomitic sandstone, dolomitic siltstone and silty massive dololomite. The silty units sometimes contain cherts.	

Alluvium

The alluvium comprises mainly of a mixture of low to moderate permeability silts, clays, and fine-grained sands. A higher permeability basal section of coarse-grained sands, gravels and cobbles/boulders occur along the deepest portion of the paleochannel. The base of this paleochannel is up to 34 m below ground surface (5 m AHD) and this represents the thickest known occurrence of the alluvium in the immediate mine area.

Weathered Bedrock

Aquifers occur locally in the weathered and partially weathered bedrock underlying the alluvium in the open pit area. The near-surface geology east of the pit is predominantly weathered dolomite (Cooley Dolomite), and to the west it is dolomitic siltstones, shale and dolomite (Teena Dolomite). The most significant aquifer occurs within the weathered dolomite which appears to have low to high permeability.

Faults that intersect the weathered and partially weathered zones are also considered transmissive and contribute to groundwater flows to the open pit where they intersect the wall.

Generally the base of weathered bedrock ranges between 5 and 22 m AHD (URS, 2006).

Bedrock

Groundwater can occur in open vugs or solution channels, fractures, joints and faults within the fresh bedrock. Open vugs and solution channels were observed in the drill cores extending below the zone of weathering to depths in excess of 300 m (-270 m AHD) (URS, 2006). These structures were predominantly in dolomite, located near the Mt Stubbs Fault north of the pit.

2 Geological Setting and Hydrology

Open joints and fractures can also allow the transmission of groundwater and these were observed within the open pit area between depths of 23 m (RL 7 m) and 152 m (RL -122 m), predominantly in dolomite and brecciated units, and occasionally in shales.

Joints and fractures appear to decrease in permeability with depth. From the core viewed, these structures were apparent between depths of 10 m and 240 m (20 and -210 m AHD). Open joints were most predominant above a depth of 100 m (-70 m AHD).

Groundwater Levels

Since 1995, a network of groundwater monitoring bores (Figure B2; Appendix B) has been established by MRM to monitor groundwater levels and quality. Groundwater levels fluctuate between wet and dry seasons. Wet season groundwater levels are between 1.3 and 5.9 m higher than dry season levels.

Groundwater Flow

Groundwater level contours in the bedrock across the mining area in 1995/97 are presented in Figures B3, Appendix B. The 1995/97 groundwater levels in the deep aquifers indicate a general easterly flow of groundwater from the Tailings Storage Facility (TSF) toward the EMU Borefield.

Regional watertable/potentiometric surface elevation contours of the alluvium and weathered bedrock water bearing zones reflect topographic elevation, with groundwater flow from high head to lower head towards the predominately ephemeral tributary streams and the McArthur River.

Groundwater Usage

Groundwater at the mine site is utilised for either raw water for mineral processing or for potable water. The combined consumption of raw and potable water is estimated at 1,796 ML per year.

2.3.2 Surface Water

Surface water bodies at the McArthur River Mine comprise the McArthur River (the major surface water body) and its tributaries; namely the Kilgour River, Barney Creek, Surprise Creek, Bull Creek, Glyde River and Emu Creek. The McArthur River flows in the north-east direction to the Gulf of Carpentaria and has a gradient of more than 250 m over a 330 km course.

Stream flow throughout the McArthur River Catchment is variable as a result of thunderstorms, cyclones or monsoonal rainfall. The majority of the water flow within the McArthur River drainage system is derived from rainfall associated with the wet season, although some tributaries are spring-fed, particularly within the sandstone ranges. The greatest flows occur during the wet season (November to April) with the majority of the wet season flows occurring in February and March. Stream flow, (particularly near the mine area), dries up to a series of isolated pools from August to September during the dry season although the nearby McArthur River maintains its flow during this period.

Mean annual stream flows are presented in Table 2-2. Statistical wet season streamflow data for the McArthur River recorded at the upstream gauging station between 1970 and 2002 are summarised in Table 2-3. Flow data for the McArthur River in terms of Average Recurrence Interval (ARI) flood event are 7,250 m³/s for 1 in 100 year event and 100 m³/s for a 1 in 2 year event.

2 Geological Setting and Hydrology

2.3.3 Stream-Aquifer Interaction

This section is based on data presented in Table 2-1. The observation stations are shown on Figure B2, Appendix B. Assuming that differences in upstream and downstream flow represent flow into or out of the aquifer system, the annual stream flow values presented in Table 2-1 indicate:

- groundwater discharges into the McArthur River between Glyde River Junction and the MIM pump station and between Emu Creek junction and Glyde River junction; and
- stream water discharges to the aquifer between Bull Creek junction and Emu Creek junction and between Barney Creek junction and Bull Creek junction.

The following are conclusions drawn from results of stream gauging in the McArthur River, taken in June 2005 (URS, July 2005) to characterise dry-season stream flow through the proposed expansion area:

- observations of stream flow salinity show that pools south west of the proposed pit are fed by groundwater to varying degrees;
- salinity and flows through Sections 1 to 6 (Figure B4; Appendix B) indicate that, with the exception of Sections 2 and 3, groundwater inflows were greater than evaporation (between 2.3 and 4.9 L/s) and probably in the order of 10 L/s;
- groundwater inflow to the river occurs above and below the proposed pit area but there was little net inflow or outflow through the pit area itself;
- groundwater inflow increases downstream of the pit area; and
- there is a reach with net outflow to groundwater just inside the western edge of the pit, between Sections 7a and 7c (Figure B4; Appendix B).

Table 2-2 McArthur River Catchment Annual Stream Flow (Source: URS 2006)

Station	Mean annual stream flow (ML/year)
Surprise Creek at McArthur River Junction	7,000
Barney Creek at McArthur River Junction	32,000
Bull Creek at McArthur River Junction	3,600
Emu Creek at McArthur River Junction	2,900
Glyde River at McArthur River Junction	102,000
McArthur River at MIM pump station	487,000

Table 2-3 Daily Average Stream Flow (m³/s) in the McArthur River during the Wet Season from 1970 to 2002 at the upstream Gauge Station (Source: URS 2006)

Flow Statistics	Daily Average Streamflow (m ³ /s)					
	Nov	Dec	Jan	Feb	Mar	Apr
Median Flow	0.1	0.5	4.5	12	5.4	0.4
80 th Percentile Flow	1.2	8.0	37	78	52	3.9
90 th Percentile Flow	4.2	25	100	264	183	14
95 th Percentile Flow	13	54	324	588	388	25

Conceptual Model

3.1 Modelling Approach

3.1.1 Input Data

Input data include borehole 3D (horizontal X,Y and elevation Z, Australian Map Grid - AMG) coordinates, land surface elevation, geologic and structural geologic maps, lithologic and stratigraphic data from boreholes, drill logs containing depths of geologic units below land surface, bottom elevation of weathered zones, cross sections, gridded data from previously constructed models, and hydrologically important faults and structures.

Boreholes x, y and z coordinates

The 3D X,Y,Z (m AMG), coordinates were defined by the location and depth from the land surface (the elevation of the top of the model layers was calculated by subtracting the depth from the land-surface elevation). If the land-surface elevation was not reported in the borehole records, Digital Elevation Models (DEMs) representing land surface height were used to interpolate the land-surface altitude at the borehole.

Topographic Data

Digital elevation data of the site with a grid spacing of approximately 25 m was combined with reported land-surface altitude at borehole locations.

Geologic Map

Data from 1:100 000 geological map for the McArthur River Region (Pietsch et al., 1991) was used to determine the extent of hydrogeologic units on the land surface.

Borehole Lithologic Data

Lithology logs provided the majority of information used in delineating the spatial extents and thicknesses of the model layers. Borehole lithologic data from the following sources were used: URS (2006); Golders (2004) and drillers' reports, MRM mine reports, previously compiled unpublished data collected by URS and borehole data from mineral exploration holes. The data were from numerous drilled and existing boreholes in the study area.

Geologic and Stratigraphic Cross Sections

Cross sections obtained from literature including Large et al, (2005) and URS (2005) were used as input to the model. The stratigraphic units in the cross sections in these publications were used to extract horizontal (X,Y) and altitude (Z) coordinates for the model layers along a given transect.

Faults and Other Geologic Structures

Maps showing the surface expression of faults and other structures and cross sections showing faults were incorporated. The faults were simplified in the model as vertical structures as they are known to be near to vertical.

3 Conceptual Model

Hydraulic Data

The hydraulic data included aquifer hydraulic conductivity, transmissivity, storage coefficient and specific yield were sourced from available literature (Table A1, Appendix A)

Existing Models

Data from the existing numerical groundwater flow models (URS 2006) was also used.

3.1.2 Gridding of Model Layers

The gridded surfaces defining the model layers were interpolated and extrapolated from the available data and information using the Natural Neighbour gridding method.

3.1.3 Model Construction

The model was constructed by using the cells that represent the top elevations of the model layers into three-dimensions.

3.2 Description of Model Layers

The model was vertically divided into 11 layers. A summary of field determined properties for the model layers is presented in Table 3-1. Where a layer is absent and therefore made to pinch out the thickness was set equal to 0.1 m. This was done for several layers because of the dipping structure of the ore body zone and adjacent geological units. Therefore these middle layers dip along the direction of the ore zone but to the west and east they pinch out.

The model layers are described below.

3.2.1 Model Layer 1: Alluvial Sediments

This layer represents the alluvium which includes:

- Quaternary recent alluvium consisting of silt, sand and gravel. This deposit occurs on the flood plains, levees, flood terraces and channel floors of the McArthur River and the Glyde River, and
- Cainozoic Tertiary to Quaternary sediments consisting of colluvial and outwash fan deposits, older alluvial and lacustrine deposits of clay, silt and sand and gravelly residual soils (underlain by bedrock).

The alluvial aquifer is directly connected to the McArthur River and contains good quality fresh water. The alluvial sediments may locally have high permeability due to the presence of sand and gravel deposits. The majority of the upper sediments of the alluvium are mixture of clay, silt, sand and gravel with moderate permeability. Only the basal few meters of the alluvium contain permeable coarse-grained sand, gravel and cobble/boulder deposits.

The main channel of the McArthur River contains up to 30 m saturated alluvial sediments.

The top of model Layer 1 is defined by land-surface elevations.

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3.2.2 Model Layer 2: The McArthur River Palaeochannel

The McArthur River Paleochannel was simulated as a separate layer and it is represented as model Layer 2. The McArthur River paleochannel is approximately 800 m wide and on average 8 m thick. The base is up to 34 metres below ground level (5 m AHD).

3.2.3 Model Layer 3: Weathered and Partially Weathered Bedrock

The locally occurring aquifers in completely and partially weathered bedrock are presented as model Layer 3. This layer lies beneath the alluvium. Faults that run through the weathered and partially weathered bedrock can act as conduits. Generally the base of the weathered horizon is between 5 m AHD and 22 m AHD.

3.2.4 Model Layer 4 and Layer 5: Eastern Dolomite

The dolomite to the east of the mine is presented in the model as Layer 4 and Layer 5. These layers extend from the Mt Stubbs and Woyzbun fault lines to the Bukalara Sandstone interface.

Drilling activities in the area indicates that groundwater occurs also in geological structures (faults, joins, fractures, vugs and possibly solution channels) and within fresh bedrock, as evident in bore holes EMU 5 and MAC1P. Analysis of drill logs indicate the presence of open vugs and solution channels in dolomites located near the Mt Stubbs Fault at depths in excess of 300 m (-270 m AHD). At borehole EMU 5 vuggy dolomite was intercepted at depth of 65 m depth (-35 m AHD). Open joints and fractures have been intercepted in the open cut pit at depths of 23 m (7 m AHD) and 152 m (-122 m AHD), predominantly in dolomite and brecciated units and occasionally in shale.

Model Layer 4 extends vertically from the bottom of the weathered zone to a depth of -92 m AHD.

Model Layer 5 extends vertically from the bottom of Layer 4 to a depth of -400 m AHD. This depth represents floor elevation of the final open pit.

To the west of the mine where Layers 4 and 5 lithological zones around the mining zone are absent, they are represented by a thin layer of 0.1 m thickness.

3.2.5 Model Layer 6: HYC Pyritic Shale

This is thin-bedded to finely laminated dolomitic, carbonaceous and pyritic shale and siltstone, coarse sedimentary breccias and tuffaceous horizons.

3.2.6 Model Layer 7: Cooley Dolomite Breccia

This is a chaotic breccia, with clasts which range in size from a few millimetres to several tens of metres.

3.2.7 Model Layer 8: Ore Zone (HYC Deposit)

This layer is shallow-dipping and it is about 1.5 km long and 1.0 km wide and up to 70 m thick (McGoldric and Large, 1998). The average thickness of the ore zone is estimated at 55 m. This layer has been eroded along its western margin, where it is covered with about 30 m of alluvium and soil. On the eastern margin, layer 8 thickens and is folded to form the fault zone which has a strike length of at least 600 m. The south eastern corner is down faulted by about 110 m along the northeasterly trending Woyzbun Fault. Lying on the western margin of this layer is the Hinge zone, a sub-vertical

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zone with a strike length of 1.0 m and a vertical height of 200 m. The northern margin inter-finger with the breccias (Model Layer 7) and the southern margin grades into pyritic siltstone.

3.2.8 Model Layer 9: W-Fold Shale

This consists of dolomitic siltstone and shale with interbeds of tuff. The top and bottom elevation of this layer has been identified in drilling logs up to 1,600 metres depth.

3.2.9 Model Layer 10 and Layer 11

These layers represent the dolomite west of the mine. The bottom elevation of Layer 10 varies between -92 m AHD and -400 m AHD. The top of Layer 10 is the bottom of the weathered zone. Layer 11 extends vertically from the bottom of Layer 10 to a depth of -600 m AHD.

As groundwater flow in the vicinity of an open pit or underground mine is three dimensional, the model was vertically extended to -600 m AHD (175 m below the final bottom of the pit configuration) to reasonably simulate vertical inflow to the bottom of the mine.

Table 3-1 Summary of Model Layers

Model Layer	Description	
	Geologic Unit	Top and Bottom of Layers
Layer 1	Alluvium	Top at land surface from land surface contours. Bottom at bottom of alluvial deposits
Layer 2	Palaeochannel	Top at bottom of Layer 1. Bottom at the bottom of palaeochannel
Layer 3	Weathered Rock	Top at the bottom of Layer 2. Bottom at bottom of weathered rock or top of bedrock
Layer 4	Eastern Dolomite	Top at bottom of weathered zone (Layer 3). Bottom up to -92 m AHD
Layer 5	Eastern Dolomite	Top at bottom of Layer 4 and bottom up to -400 m AHD
Layer 6	HYC Pyritic Shale	Top at bottom of Layer 5 and bottom at bottom of HYC Pyritic Shale
Layer 7	Breccia	Top at bottom of HYC Pyritic Shale. Bottom at top of orebody
Layer 8	Ore Horizon	Top ranges between 32 m AHD and -466 m AHD. Bottom at the top of W Fold Shale
Layer 9	W Fold Shale	Top at top of W Fold Shale and Bottom at bottom of W Shale Fold
Layer 10	Western Dolomite	Top at bottom of W Shale Fold.
Layer 11	Western Dolomite	Top at bottom of Layer 10. Bottom at -600 m AHD

3.3 Model Conceptual Boundaries and Fluxes

3.3.1 No Flow

Based on Figure B3; Appendix B, the north and south no flow boundaries are based on the predominately west to east groundwater flow direction. The eastern no flow boundary is due to the assumed low transmissivity sandstone bedrock and any groundwater flow in the sandstone is considered insignificant.

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3.3.2 Inflow Flux

Inflow to the aquifer system includes rainfall recharge to the water table, groundwater flow across the model western boundary, streamflow infiltration and infiltration of disposal of tailings to the TSF.

Rainfall Recharge

Rainfall recharge has been applied only to the top model layer. This recharge was initially applied as spatially uniform time-averaged net infiltration recharge to this layer and was assumed to occur at a constant rate in the steady-state model, whereas in the transient model it was assumed to vary with time. Later gross variable recharge rate was applied together with evapotranspiration.

The mean monthly annual rainfall at the study area is presented in Table 1-1 (Section 1.5.2).

Lateral Inflow from the Western Boundary

Hydraulic gradients determined from a regional potentiometric map (Figure B3; Appendix B) indicate that flow occurs across the model western boundary. Further discussion about how this was set up in the model is given in Section 4.2.1 below.

3.3.3 Outflow Flux

Outflow occurs from extraction bores, to the abandoned underground workings and from mine dewatering activities and into the rivers and creeks.

Lateral Outflow

Hydraulic gradients determined from a regional potentiometric map (Figure B3; Appendix B) indicate that groundwater flow across the north, south and the eastern boundaries of the model are not significant.

Historical Groundwater Outflows to Underground Mine Inflow – During Operation

Historical groundwater outflows into the underground mine have been identified to occur through the Hinge Zone Fault, paleochannel sediments intercepted by the Eastern Vent rise and the Northern Fault. The underground mine water balance provided by MRM in May 2003 indicates groundwater outflows to the underground mine from these sources is about 2,410 kL/day (2.41 ML/day) (Table 3-3).

Table 3-2 Historical Underground Mine Inflows

Source	Aquifer Type	Average Groundwater Inflow Rates (kL/day)
Eastern Vent Rise	Alluvium aquifer	600
Hinge Zone	Fractured bedrock	860
Northern Fault	Fractured bedrock	600
Other sources	Joints	350
Total		2,410

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Groundwater Extraction

MRM previously utilised three operational borefields – the MIMEX, Emu and Donkey borefields – to supply process water. The MIMEX borefield is made up of 5 production bores, the Emu borefield is made up of 7 production bores and the Donkey borefield is made up of 4 production bores. Groundwater pumping started around 1995 in Emu Bore Fields to supply water for use in the mine camps and to support mining activities. Presently, the MIMEX borefield is used for potable water supply and good quality process water for the mill. All other borefields have been decommissioned. Additional process water is sourced from the underground void.

There is limited continuous pumping rate data to develop a complete history of groundwater extraction.

Mine Dewatering

Open Pit

Historical dewatering of the pit has relied upon self-draining (seepage) into the pit and the underground workings. Horizontal drain holes have been installed on the western side of the pit wall within dolomite to lower head pressures and assist with open pit dewatering. Peak inflows during wet seasons are estimated at between 5.2 and 6.9 ML/day, predominantly from the western dolomite wall, fault/fractures, at the contact between dolomite and the ore body and alluvial sediments and weathered bedrock in the north eastern portion of the pit.

Groundwater inflows during dry season have been estimated generally at less than 1.5 ML/day.

Reported volumes of water in the pits at the end of the months January, February March and in mid April in 2011 are 63.6, 230.4, 922.6 and 283.3 ML, respectively. It is noted that the volumes are made up of rainfall run off and groundwater inflow.

Underground Workings

- During operations

There is no available underground mine dewatering data during the operational period. It is assumed that the dewatering rate was not less than the historical mine inflow rate of 2.41 ML/d.

- Post Closure

Dewatering of the underground workings since its closure commenced in October 2008 by use of 2x130 kW pumps installed at a depth of 300 m in the raise bore shaft. The pumps are each designed to pump 3.0 ML/day at 300 m, giving a total discharge rate of 6.0 ML/day.

Post closure historical water levels and extraction rates data from the underground void is presented in Figure 3-1. Record keeping of extraction rates from the shaft begun in late March, 2009.

3 Conceptual Model

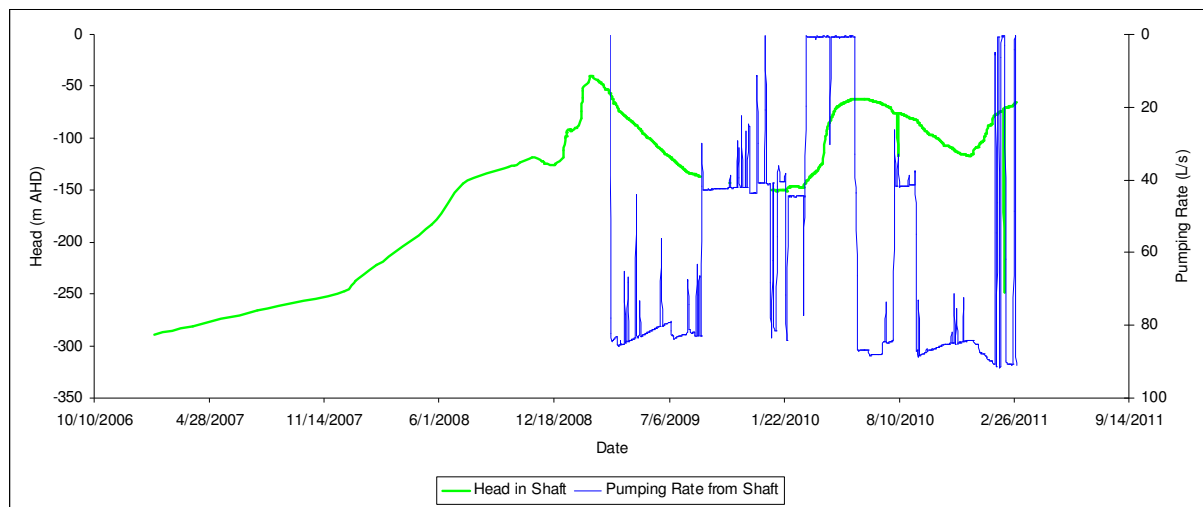


Figure 3-1 Groundwater Head and Pumping Rate from Mine Shaft

Numerical Model

4.1 Numerical Model Extent and Discretisation

4.1.1 Model Construction

The hydrogeologic data sets were discretised to develop the input arrays required for the model. The datasets were discretised at constant cell dimensions of 50 m spatially and within each of the 11 layers. Further details are provided in Section 4.1.5 below.

4.1.2 Code Selected

Groundwater flow was simulated with MODFLOW-SURFACT v3 (HydroGeoLogic Inc., 1996) with related packages. MODFLOW-SURFACT is a computer program that simulates three-dimensional groundwater flow through a porous medium using a block-centred finite-difference method for solving the governing equations for steady (time invariant) and transient (time variable) flow under variably saturated conditions.

MODFLOW-SURFACT was selected because it:

- simulates 3-D variably saturated flow and therefore easily handles desaturation and resaturation of cells;
- facilitates simulations of dewatering due to its efficient robust solver and enhanced capability to handle de-saturation over standard MODFLOW;
- has a recharge-seepage face boundary condition package (RSF4) that enables simulations of seepage faces and recharge to low-conductivity unconfined systems;
- has a Newtown-Raphson linearization package (NRB1) with a backtracking scheme for step control. This package can greatly improve efficiency of solutions for difficult slow converging model;
- has an adaptive time stepping and output control package (ATO4) schemes that automatically adjust time-step size to the nonlinearities of the system, to optimise the solution stability and efficiency;
- has been widely used by the groundwater scientific community for mine dewatering projects
- is thoroughly documented; and
- has program developers who were readily accessible for consultation.

The PCG5 solver in MODFLOW-SURFACT with RSF4 option and the Automatic Time Stepping Option (ATO4) package was used for simulations that provide solution speed improvements. The Newton Raphson Options with backtracking factor of 0.15 and residual reduction factor of 35 was used. The head change error criterions used were in the range 0.01 to 0.05 m.

Pre- and post-processing were accomplished by using Groundwater Vistas Version 6 (Environmental Simulation, Inc, 2011).

4.1.3 Units and Datum Used

The units used for time is days and that for space is meters.

Horizontal and vertical datum used are the Australian Map Grid (AMG) coordinate system and the Australian Height Datum (m AHD), respectively.

4 Numerical Model

4.1.4 Model Lateral Extent (Doman)

Figure 4-1 is the modelled area. The model lateral boundary was extended up to 5.8 km (between 4.2 and 5.8 km) outside of the final pit boundary and includes the TSF to have reasonable correlation with the flow regime, allow for the determination of impacts from operations on groundwater levels, and groundwater discharge associated with mine dewatering.

The western boundary of the model is defined as the edge of the Bukarala Sandstone.

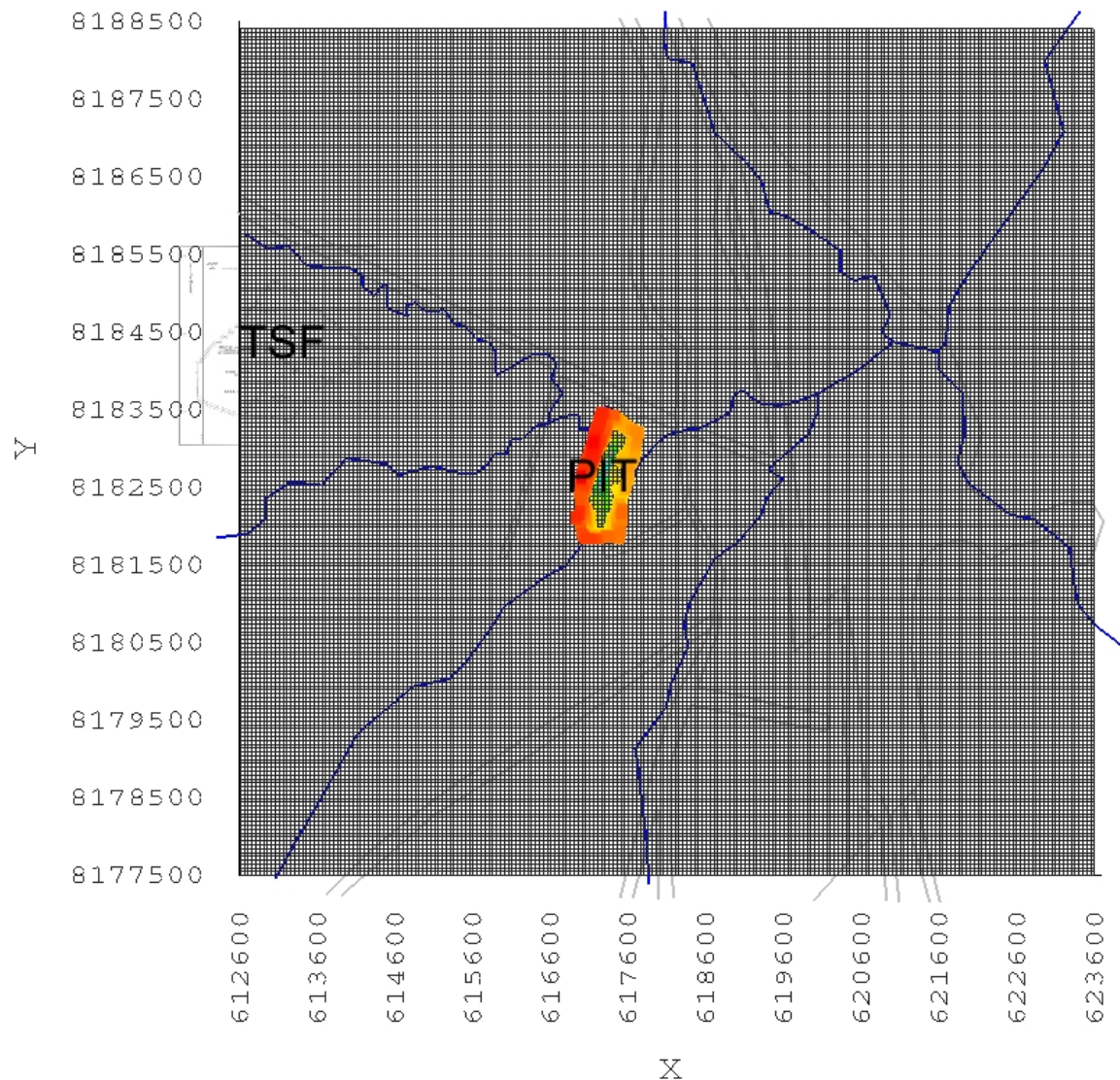


Figure 4-1 Model Grid

4 Numerical Model

4.1.5 Spatial Discretisation

The model is horizontally discretised using uniformly spaced cell sizes with dimensions 50 by 50 m with a total of 219 rows and 220 columns (Figure 4-1). The model was vertically discretised into 11 layers of varying thickness. All the layers were simulated as convertible (layer type 3) between confined and unconfined layer types. This yielded a total number of 529,980 cells many of which were set as 'no flow' (eastern part of the model). This number of cells resulted in manageable run times.

4.1.6 Time Discretisation

Only one time step was used for the steady state simulation, the results being used to set the 1990 initial water levels for transient simulation when there was no pumping in the region. During the transient phase the model stress periods were set to monthly intervals and time steps computed automatically by the MS code to achieve the best possible convergence and minimum solution time.

The monthly stress periods were those extending from the beginning of January 1990 to end of December 2011.

Although development of the McArthur River underground mining began in midyear 1993, 1990 was chosen when the mining began in the model.

4.2 Numerical Model Boundary Conditions

The flow of water within, into and out of the model was simulated with various packages available in MODFLOW-SURFACT. These packages were selected for their applicability to the physical and hydrologic conditions at various boundaries.

4.2.1 Lateral Boundaries

Western Boundary Flow

The western lateral boundary is set as Constant Head Boundary (CHB) to simulate groundwater flow entering the model area. Constant heads in the range 33.8 and 35.5 m AHD was assigned to model layers 10 and 11 representing bedrock west of the mine.

Northern Eastern and Southern no-Flow Boundaries

The base of the model and the lateral boundaries on all sides of the model except for the western side were designated as no-flow boundaries.

As mentioned in Section 3.3.1 the northern and southern boundaries of the model area are designated as no flow boundaries as a consequence of the boundaries been defined as groundwater flowpath on the basis of 1995/97 groundwater contour map (Figure B3, Appendix B).

The eastern boundary of the model area was designated as no flow as flow exchange between the modelled area and the Bulkara Sandstone is assumed to be insignificant. Groundwater contour map (Figure B3, Appendix B) constructed for the aquifer using 1995/97 data indicate that the contours are perpendicular to the edge of the Bukarala Sandstone.

The flow across the base of the model area from underlying rocks was treated as insignificant and assumed to be zero in the numerical model.

4 Numerical Model

4.2.2 Internal Boundaries

The internal boundaries of the model include specified-flux and head-dependent-flux boundary cells. The specified-flux boundary is applied to groundwater recharge and groundwater abstraction and injection. The head-dependent boundaries include streams, creeks, TSF and groundwater seeps in the open pit and underground mine.

Rainfall Recharge and Evapotranspiration

Recharge from infiltration of rainfall was simulated using the Recharge and Surface Ponding Packages from MODFLOW-SURFACT. 10% of monthly rainfall was applied as recharge to the uppermost active cell in the model.

Groundwater discharge through evapotranspiration was simulated using MODFLOW Evapotranspiration (ET) Package. Evaporation extinction depth of 2 m and maximum evapotranspiration rate of 65% of mean daily pan evaporation was specified.

Groundwater Extraction/Injection

- Extraction Bores

Groundwater extractions using bores, except mine dewatering, were simulated using the Well Package. Extraction rates varied monthly, however, constant average groundwater extraction rates were used in the simulations.

Streams

Interaction between the aquifer system and the McArthur River was simulated using the Stream Package (STR1) in MODFLOW-SURFACT.

The McArthur River was divided into five segments. A channel width of 50 m and channel depth of 8.3 m was used. Stream roughness of 0.08, sinuosity of 1.1 and a bed slope of 0.0003 m/m were used. Stream conductance was calculated based on model cell size, thickness of stream bed (assumed 0.3 m) and calibrated vertical hydraulic conductivity values of the stream bed.

The McArthur River tributaries, namely the Barney Creek, Surprise Creek, Bull Creek, Emu Creek and Glyde River, were simulated using the River Package. It is assumed that these are aquifer fed tributaries. The stages of these rivers/creeks were set at 0.001 m above the bottom of the river cells in model Layer 1. The thickness and the hydraulic conductivity of the tributary bed were assigned values 0.25 m and 0.001 m/d, respectively.

Tailings Storage Facility (TSF)

The TSF was simulated as a head dependent boundary using the Changing Head Boundary (CHB). A head of 45 m AHD was assigned to the cells representing the TSF.

Mine Dewatering

- Open Pits

The Open Pit is not actively dewatered. It is designed to act as a system of seepage faces. Seepage face drain cells were placed within the open pit mine, along with the transient scheduled mine floor elevations.

4 Numerical Model

The Seepage Face Package allows groundwater to discharge to the pit when groundwater level rises above the elevation of the pit floor.

- Underground Mine

Dewatering of the underground mines was simulated using the DRAIN Package (DRN1) with drain cells placed within the underground mine area. The drain cells were applied within model Layer 8 in the underground workings zone. The drains heads (elevation) was set to 0.001 m above the bottom the drain cells.

Model Calibration and Sensitivity Analysis

5.1 Model Calibration

The calibration of the numerical models involved:

- selecting and evaluating observed water-levels in bores (hydraulic heads) to be used as observations for calibrating the model;
- defining discrete areas of the model cells, (referred to as zones), where aquifer properties were assumed to be uniform; and
- adjusting the distributions of zones and the values of aquifer properties in the zones to provide the best match between observed and simulated hydraulic head, and the observed underground void inflow and open pit inflow.

The model parameters adjusted include:

- aquifer properties such as horizontal and vertical hydraulic conductivities, specific yields, and specific storage; and
- boundary condition properties such as recharge, conductance, and heads.

The water-level and pit inflow data for calibration were mostly available for the area near the pit and the TSF. Water level data for calibration were limited for other areas and at depth in the dolomite.

The models were calibrated by using the “trial-and-error” method: Recharge, horizontal and vertical hydraulic conductivity, specific storage, specific yield, stream conductance and drain cell conductance were manually adjusted to match simulated and observed water levels, and pit inflows. The model was considered calibrated when the lowest value of the root-mean-square error (RMSE) between simulated and observed water levels and stream flow was obtained, and simulated pit inflow rates reasonably matched measured pit inflow rates.

Model calibration was focused on the period of intensive data collection, which was from May 2005 to present.

5.1.1 Calibration Targets

Combined 1995 and 1997 Groundwater Levels

These groundwater-level targets were obtained from literature and drillers logs.

The observed 1995 and 1997 groundwater levels were one-time measurement including measurement taken within short time intervals after the bores had recovered from the drilling and testing period. This data were used to calibrate 1990 through 2005 period.

2005 to 2011 Groundwater Levels

Continuous observed heads measured from 2005 to 2011 were used to calibrate the 2005 through 2011 period. All available water-level data were used during this period, except for bores whose RL were not known.

Pit Inflow Rates

Measured open pit and underground mine inflows rates for dry season periods in years 2008, 2009

5 Model Calibration and Sensitivity Analysis

and 2010 (Hatch, 2011) were used as calibration target. Flows during the wet season were not used because surface inflow confounded the groundwater flow contribution to the open pit and underground that are connected.

5.1.2 Calibration Results

Simulated groundwater levels, groundwater-level changes and mines inflows were compared with calibration targets to determine the accuracy and precision of the simulation in reproducing historical hydrologic conditions.

Quantitative measures employed to evaluate differences between simulated and measured values included:

- the mean difference (the mean of all differences between simulated and measured values);
- the mean absolute difference (the mean of the absolute value of the difference between simulated and measured values); and
- the root-mean-squared (RMS) difference (the square root of the mean-squared differences between simulated and measured values).

The fit of calibration was also evaluated by dividing the standard deviation of model residuals, the absolute mean and the RMS Error by the overall range of water-level observations.

Steady State Simulation

Simulated Steady State Groundwater Head

Simulated 'pre-development' ('pre-1990') heads are presented in Figures B5 to B8, Appendix B. There was no observed head data available to be used as calibration targets because the earliest measurements of water levels in the study area were made in 1995 and 1997.

Transient

1995/1997 Groundwater Levels

The simulated pre-development groundwater levels were used as starting groundwater levels for the 1990 through 2005 period.

Comparison of simulated heads against and observed heads for 1995 and 1997 is presented in Figure 5-1. The correlation coefficient (r^2) is 0.9216.

The deviation of observed heads from simulated heads (residuals) is presented in Table 5-1. Differences between simulated and measured groundwater level ranged from 0.27 to 3.59 m. The RMS error and the scaled RMS were 1.99 m and 9.42%, respectively. The calculated coefficient of determination was 1.12.

The calibration criterion, based on MDBC guidelines, was to attain a scaled RMS of 5% or less of the total range of groundwater levels from highest to lowest across the system.

The potential sources of errors associated with the 1995/97 data are one or combination of the following factors.

5 Model Calibration and Sensitivity Analysis

- the data used as target was one-time measurement of groundwater levels including measurement taken within short time intervals after the bores had recovered from drilling and testing period;
- some of the water level data used were from production bores and monitoring bores closed to the production bores; and
- a degree of uncertainty in the accuracy of groundwater extraction and underground mining dewatering rates in 1995 and 1997.

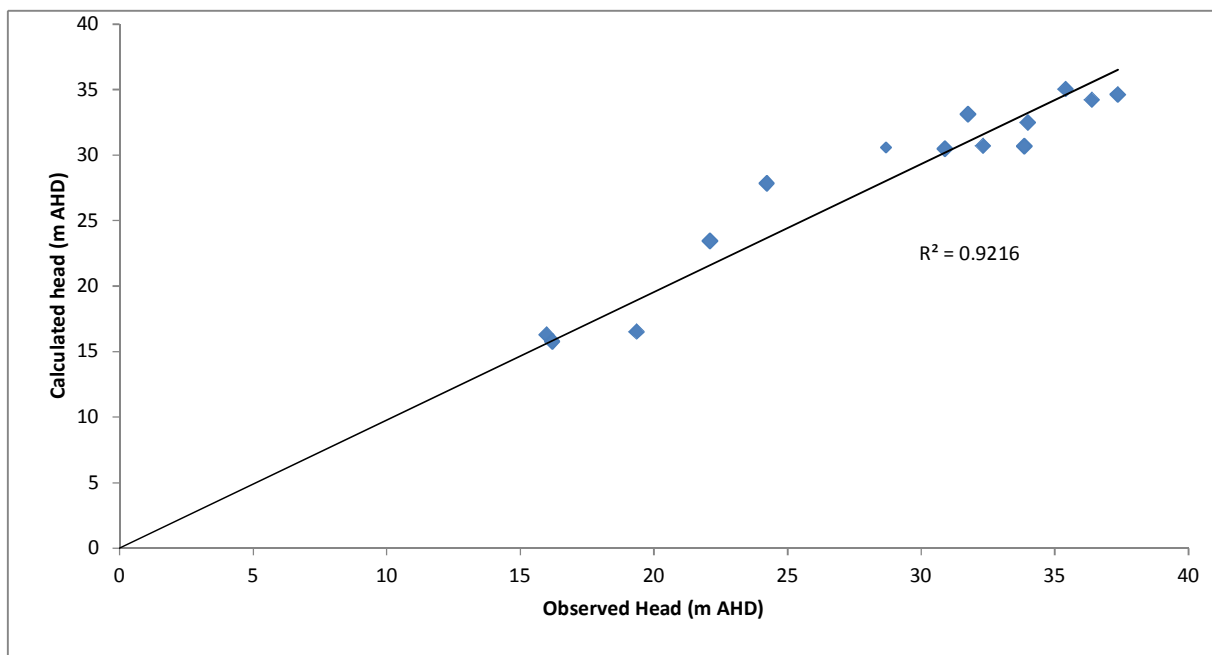


Figure 5-1 Observed versus Calculated Head Graph for 1995/97 Groundwater Head Data

5 Model Calibration and Sensitivity Analysis

Table 5-1 Observed and Calculated 1995/97 Groundwater Heads

Observation Bore ID	Observed Head (m AHD)	Calculated Head (m AHD)	Residual (m)
GW4	28.68	30.58	1.90
GW5	22.11	23.41	1.30
GW6	31.77	33.10	1.33
GW8	35.42	35.01	-0.41
GW9	37.37	34.59	-2.78
GW10	36.40	34.19	-2.21
GW11	34.00	32.45	-1.55
GW12	32.33	30.69	-1.64
GW13	30.90	30.46	-0.44
GW14	33.87	30.66	-3.21
EMU1_OB	15.99	16.26	0.27
EM2_OB	16.20	15.74	-0.46
EMU4	24.23	27.82	3.59
EMU5OB	19.36	16.51	-2.85
RMS (m)	1.99		
Scaled RMS (%)	9.42		
Coefficient of determination [-]	1.12		

2005 through 2011 Groundwater Levels

The Simulated 2005 groundwater levels were used as starting heads for the 2005 through 2011 transient simulation. The simulated heads were compared with observed heads by using hydrographs from 22 monitoring bores completed in the alluvium, the weathered bedrock and the bedrock aquifers in the model domain.

Plots of simulated heads against observed heads for the period 2005 through 2011 are presented in Appendix C. The calibration statistics is summarised in Table 5-3. A linear plot of simulated against observed groundwater head is presented in Figures 5-2 and 5-3.

The differences between the simulated and the observations can be attributed to:

5 Model Calibration and Sensitivity Analysis

- insufficient representation of the local variability of aquifer parameters, recharge and evapotranspiration.
- inaccurate representation of groundwater levels
- the assumption that the pumping/injection rates are constant during each season/stress period, or
- combination of these factors.

However, at this site the availability of recorded inflows that were used in calibration provides additional confidence in the range of parameters used for the MRM model as discussed below.

Table 5-2 2005 through 2011 Calibration Statistics – Groundwater Levels

Calibration Parameter		
	Layer 1	Layer 3
# of observations	453	252
Range of Observations (m)	35.45	14.35
Residual Mean (Mean Difference) (m)	3.03	0.69
Standard Deviation of Residual (m)	5.68	1.72
Absolute Mean Difference (m)	5.08	1.59
RMS Error	6.44	1.85
Scaled Residual Standard Deviation	0.160	0.120
Scaled Absolute Mean	0.143	0.11
Scaled RMS	0.182	0.129

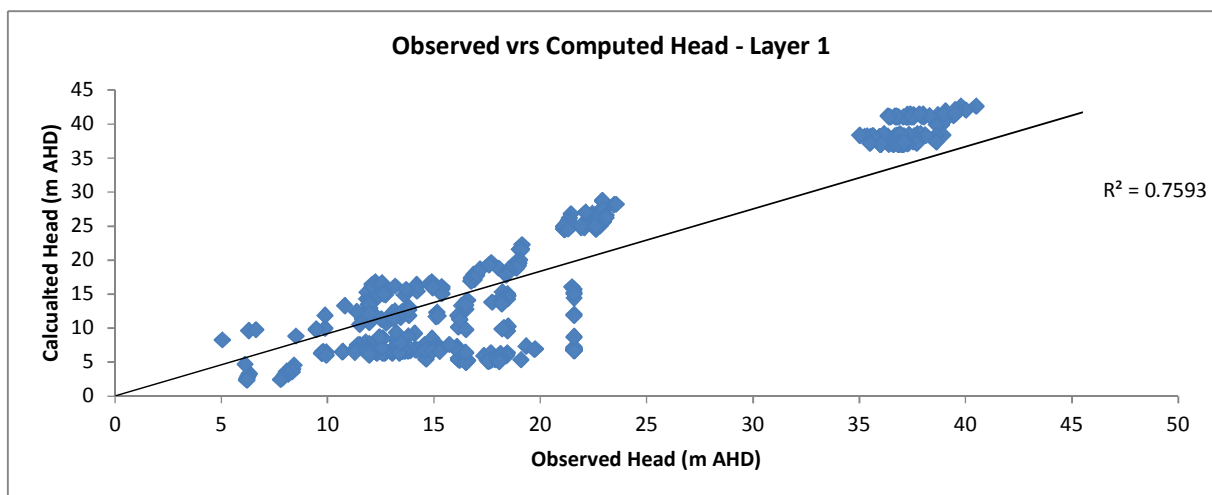


Figure 5-2 Linear plot 2005 - 2011 Observed against Computed Head – Layer 1

5 Model Calibration and Sensitivity Analysis

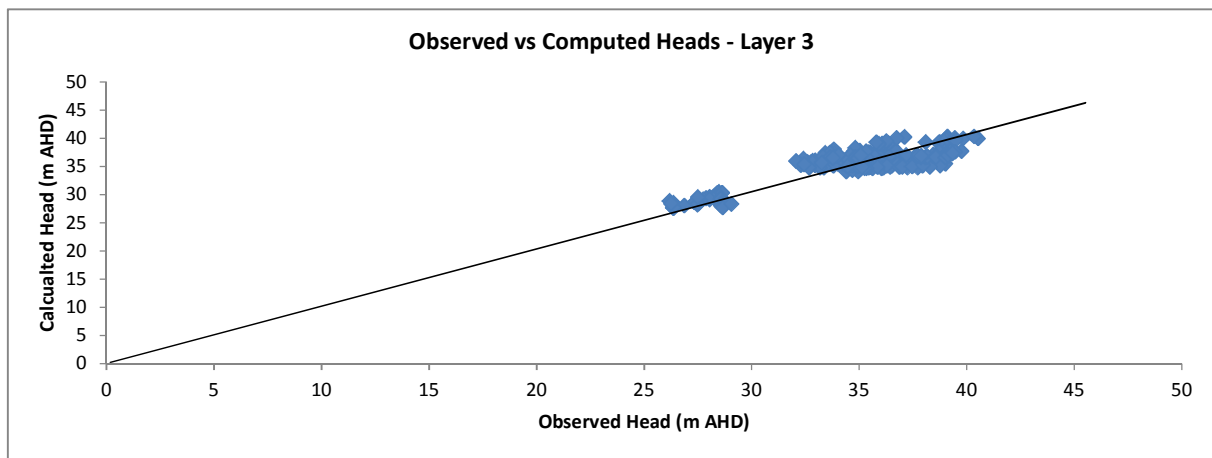


Figure 5-3 Linear plot 2005 – 2011 Observed against Computed Head – Layer 3

Mine Inflow

A comparison of simulated dry season underground mine and open pit inflows against measured inflows for the years 2008, 2009 and 2010 is presented in Table 5-4 and in Figures 5-4 to 5-6.

Table 5-3 Observed and Simulated Pit Inflow

	Dry Season Inflow into Mines (ML/d)			
	Underground Mine		Open Pit Seepage	
Year	Measured	Simulated	Measured	Simulated
2008	2.5	2.51	2.75	2.05
2009	2.5	2.48	1.94	2.91
2010	2.5	2.46	3.31	3.11

5 Model Calibration and Sensitivity Analysis

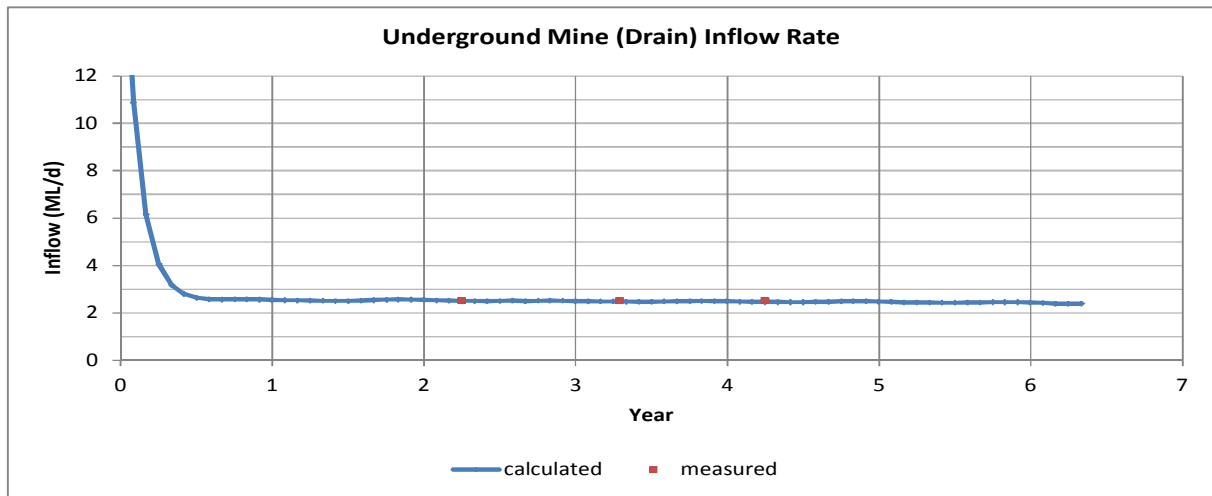


Figure 5-4 Observed and Simulated Underground Mine Inflow Rate

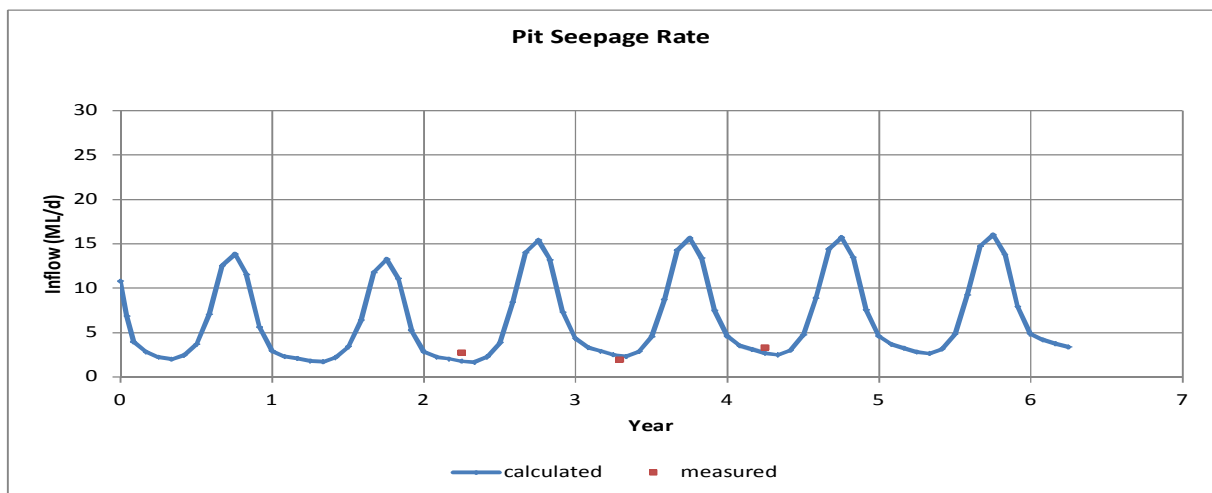


Figure 5-5 Observed and Simulated Open Pit Seepage Rate

5 Model Calibration and Sensitivity Analysis

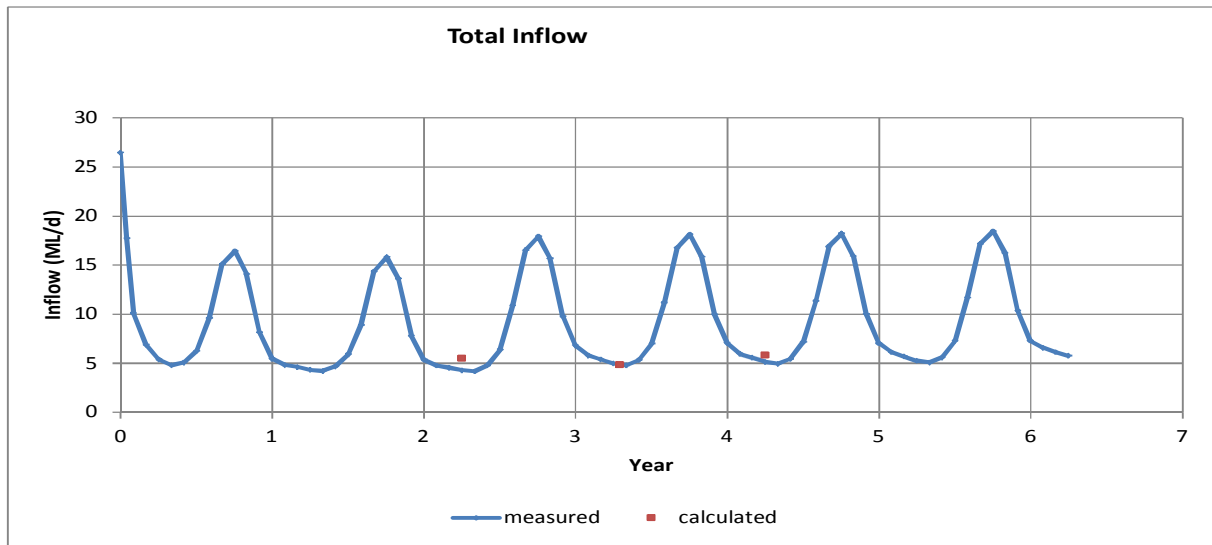


Figure 5-6 Combined Observed and Simulated Underground Mine Inflow and Open Pit Seepage Rate

Calibrated Model Aquifer Parameters

Recharge and evapotranspiration rates applied to the model are presented in Table 5-4 and Table 5-5, respectively. The calibrated aquifer hydraulic parameters are presented in Table 5-7 and Figure 5-7.

5 Model Calibration and Sensitivity Analysis

Table 5-4 Applied Recharge Rates

				Applied Recharge
Month	Season	Mean Monthly Rainfall (m)	Mean Daily Rainfall Rate (m)	10% of Mean Daily Rainfall (m)
November	Wet	0.0491	0.001637	1.634E-04
December	Wet	0.1221	0.003939	3.939E-04
January	Wet	0.2084	0.006723	6.723E-04
February	Wet	0.1867	0.006668	6.668E-04
March	Wet	0.1430	0.004635	4.635E-04
April	Wet	0.0337	0.001123	1.23E-04
May	Dry	It was assumed that recharge during these months (which represents the dry season) is zero.		
June	Dry			
July	Dry			
August	Dry			
September	Dry			
October	Dry			

5 Model Calibration and Sensitivity Analysis

Table 5-5 Applied Evapotranspiration Rates (BOM Station 014704)

Month	Season	Mean Daily Evaporation (mm)	Mean Daily Evaporation (m)	APPLIED Evapotranspiration 0.65 x Mean Daily Evaporation (m)
November	Wet	9.9	0.0099	0.00644
December	Wet	8.9	0.0089	0.00579
January	Wet	7.4	0.0074	0.00481
February	Wet	6.7	0.0067	0.00436
March	Wet	6.7	0.0067	0.00436
April	Wet	6.8	0.0068	0.00442
May	Dry	6.4	0.0064	0.00416
June	Dry	5.8	0.0058	0.00377
July	Dry	5.9	0.0059	0.00384
August	Dry	7.2	0.0072	0.00468
September	Dry	8.9	0.0089	0.00579
October	Dry	9.8	0.0098	0.00637
Annual	-	7.5	0.0075	0.00487

5 Model Calibration and Sensitivity Analysis

Table 5-6 Calibrated Model Aquifer Parameters

Layer	Material	Hydraulic Property				
		Kx (m/d)	Ky (m/d)	Kz (m/d)	Sy (-)	Ss (1/m)
1	Alluvial	0.5 – 1.0	0.5 – 1.0	1E-03 – 1E-02	1E-02	1E-06
	River Bed	5.0	5.0	0.5	1E-02	1E-06
2	Paleochannel	5.0	5.0	0.1	1E-03	5E-07
		0.05 – 1.0	0.05 – 1.0	1E-03 – 5E-02	1E-03	5E-07
3	Weathered Bedrock	0.05 – 1.0	0.05 – 1.0	1E-03	1E-02	1E-06
4	Dolomite	5.0	5.0	0.5	1E-03	5E-07
	Bedrock	3.72E-05	3.72E-05	3.72E-05	1E-03	5E-07
	Fault	0.25	0.25	0.025	1E-03	5E-07
5	Dolomite	2.5	2.5	0.25	1E-03	5E-07
	Bedrock	3.72E-05	3.72E-05	3.72E-05	1E-03	5E-07
	Fault	0.25	0.25	0.025	1E-03	5E-07
6,7	Dolomite	2.5	2.5	0.25	1E-03	5E-07
	Bedrock	3.72E-05	3.72E-05	3.72E-05	1E-03	5E-07
	Fault	0.25	0.25	0.025	1E-03	5E-07
8	Dolomite	2.5	2.5	0.25	1E-03	5E-07
	Bedrock	3.72E-05	3.72E-05	3.72E-05	1E-03 – 1E-02	5E-07
	Fault	0.25	0.25	0.025	1E-03	5E-07
9	Dolomite	2.5	2.5	0.25	1E-03	1E-07
	Bedrock	3.72E-05	3.72E-05	3.72E-05	1E-03	1E-07
	Fault	0.25	0.25	0.025	1E-03	1E-07
10	Dolomite	0.2 – 1.0	0.2 – 1.0	0.02 – 0.10	1E-03	1E-07
	Fault	0.25	0.25	0.025	1E-03	1E-07
11	Dolomite	0.1 – 0.5	0.1 – 0.5	0.01 – 0.05	1E-03	1E-07
	Fault	0.25	0.25	0.025	1E-03	1E-07

5 Model Calibration and Sensitivity Analysis

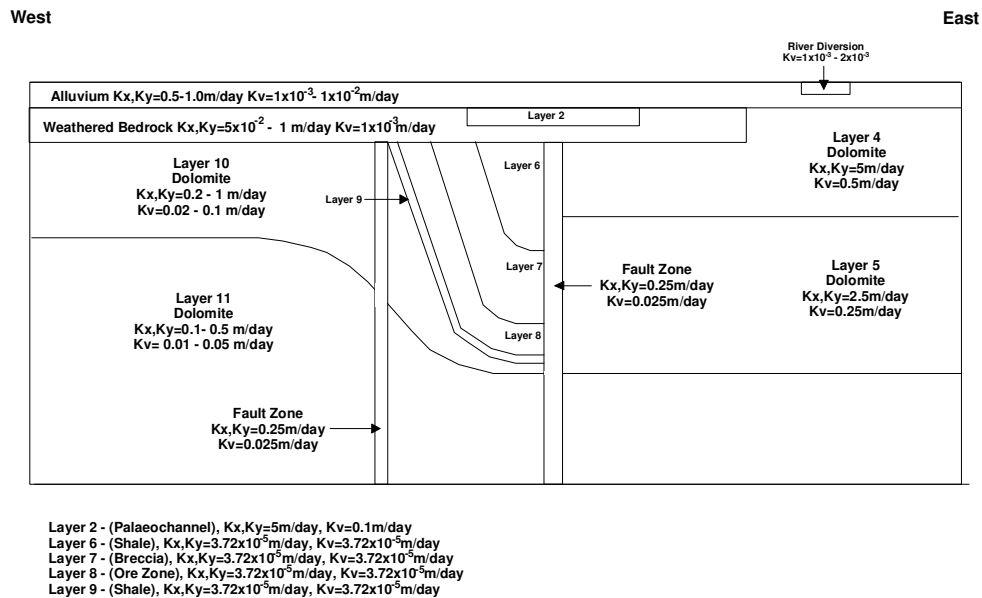


Figure 5-7 West-East conceptual cross-section showing relationship between stratigraphic property zones and model layers

5.2 Sensitivity Analysis

The sensitivity analysis was done using a series of model calibration runs against measured dry season mine inflow rates. The sensitivity of mine inflow rates to fault hydraulic conductivity and evapotranspiration and recharge rates were examined.

5.2.1 Fault Hydraulic Conductivity

Figures 5-8 to 5-10 show variance in groundwater inflows with changes to the base case of 0.25 m/day fault hydraulic conductivity to 2.5 and 5 m/day.

In terms of using the pit inflow as a measure of the model sensitivity, the model is extremely sensitive to changes in the hydraulic conductivity of the faults.

5 Model Calibration and Sensitivity Analysis

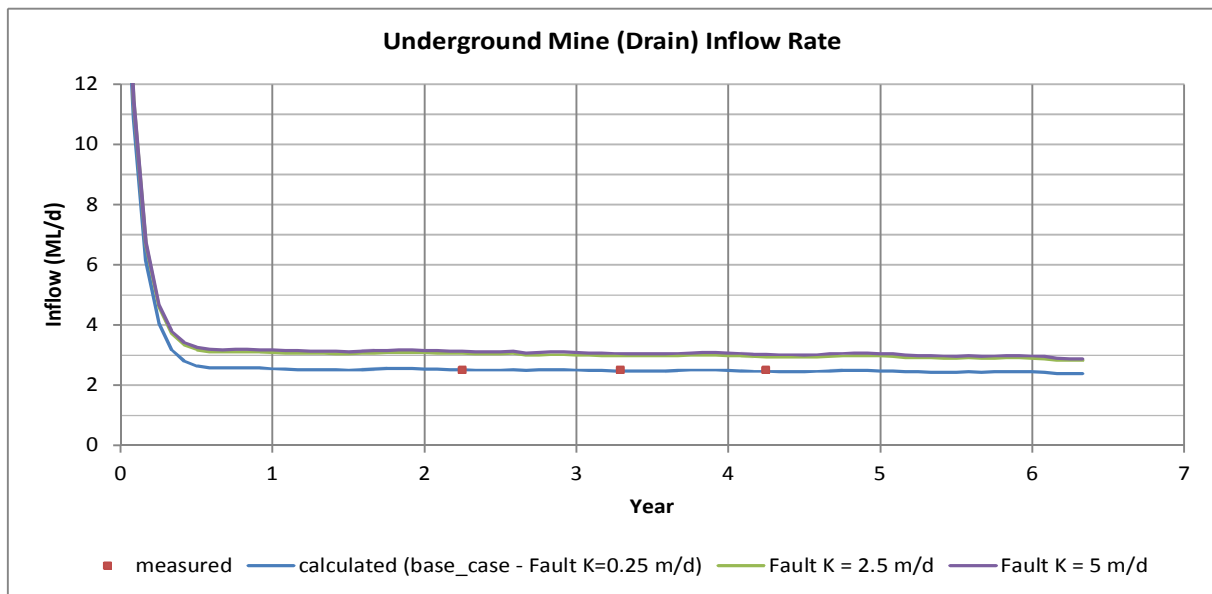


Figure 5-8 Fault Hydraulic Conductivity – Underground Mine Inflow Rate

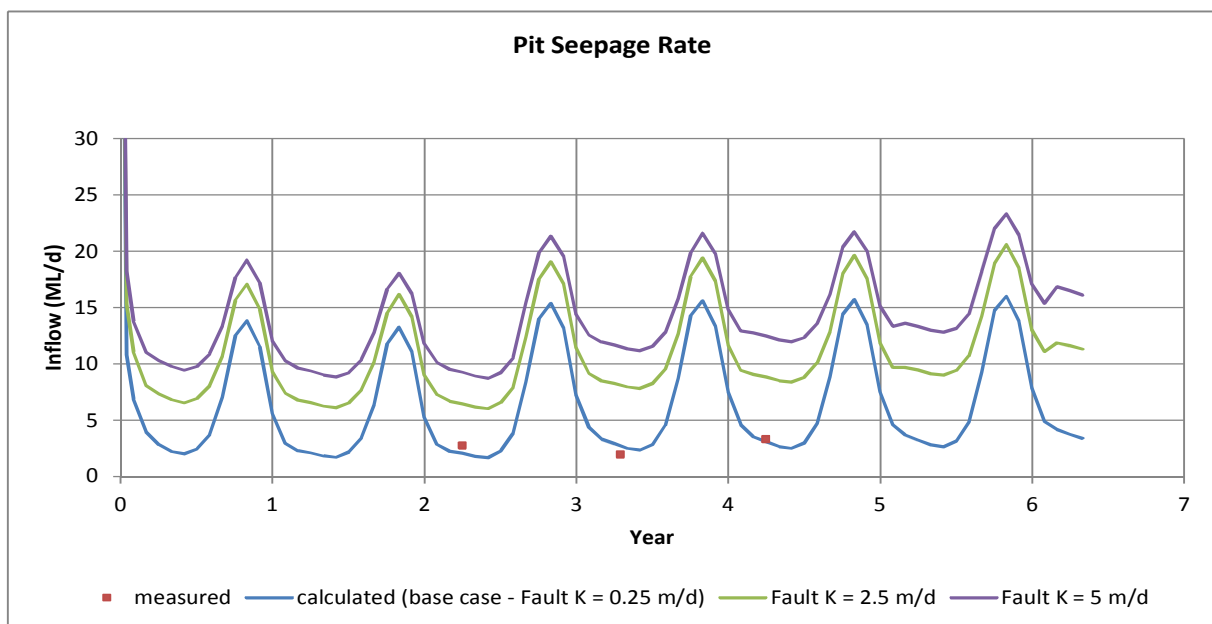


Figure 5-9 Fault Hydraulic Conductivity – Pit Seepage Rate

5 Model Calibration and Sensitivity Analysis

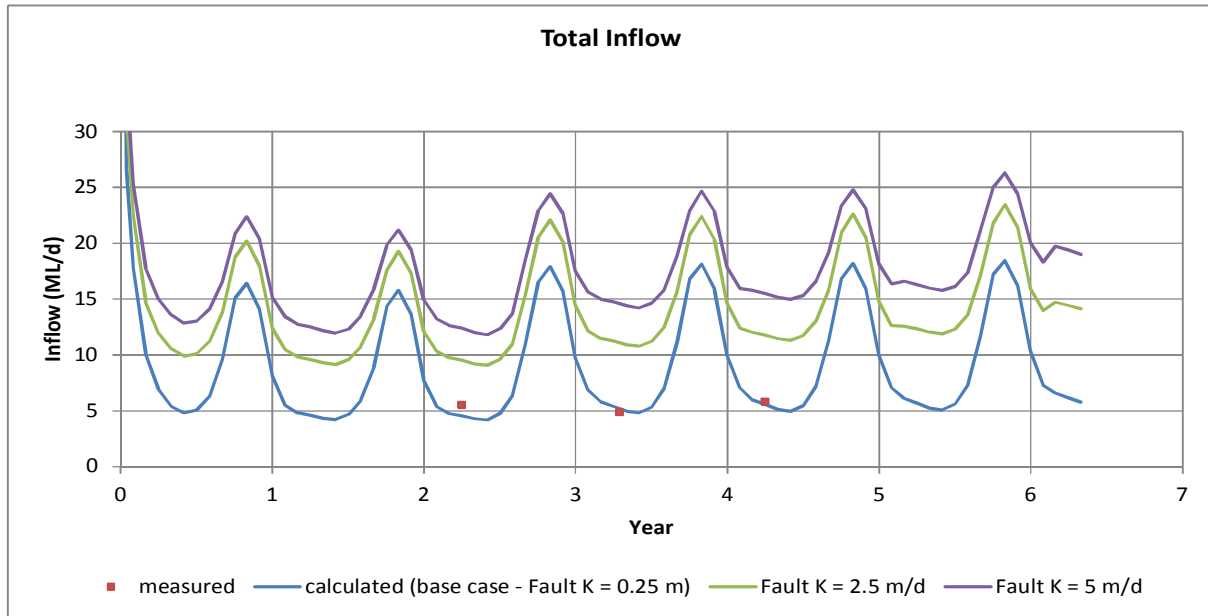


Figure 5-10 Fault Hydraulic Conductivity – Total Inflow

5.2.2 Evapotranspiration Rate

Figures 5-11 to 5-13 show variance in groundwater inflows with changes to the base case of 65% evapotranspiration rate to 50% and 25%.

In terms of using the pit inflow as a measure of the model sensitivity, the model is moderately sensitive to changes in the evapotranspiration rate.

5 Model Calibration and Sensitivity Analysis

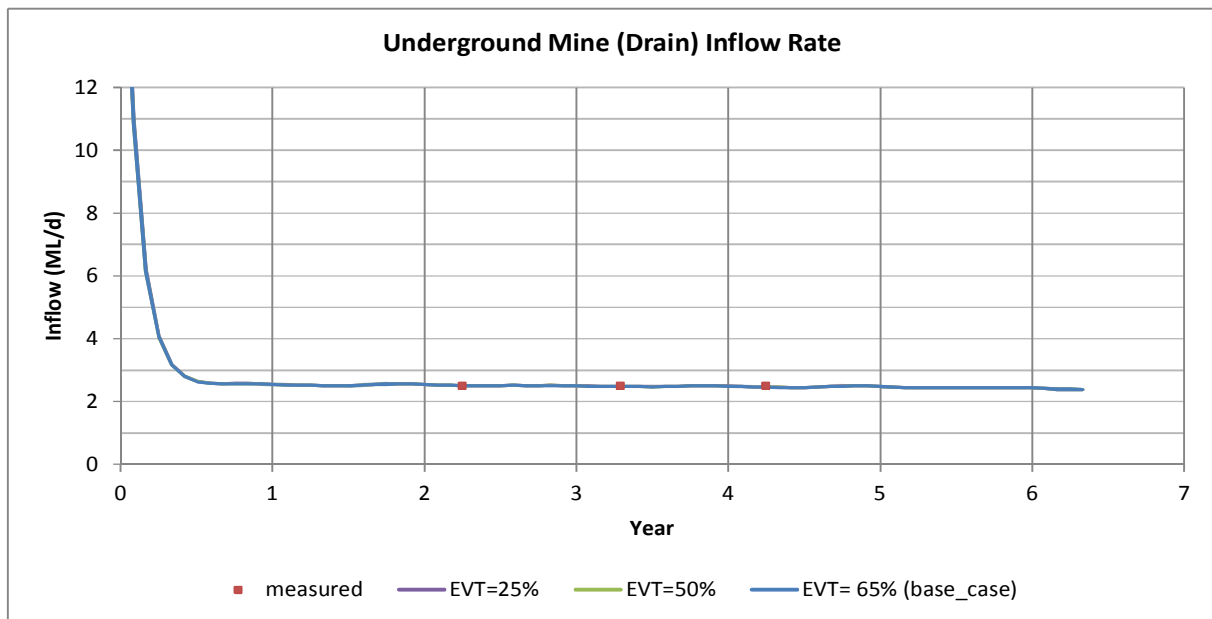


Figure 5-11 Evapotranspiration Rate – Underground Mine Inflow Rate

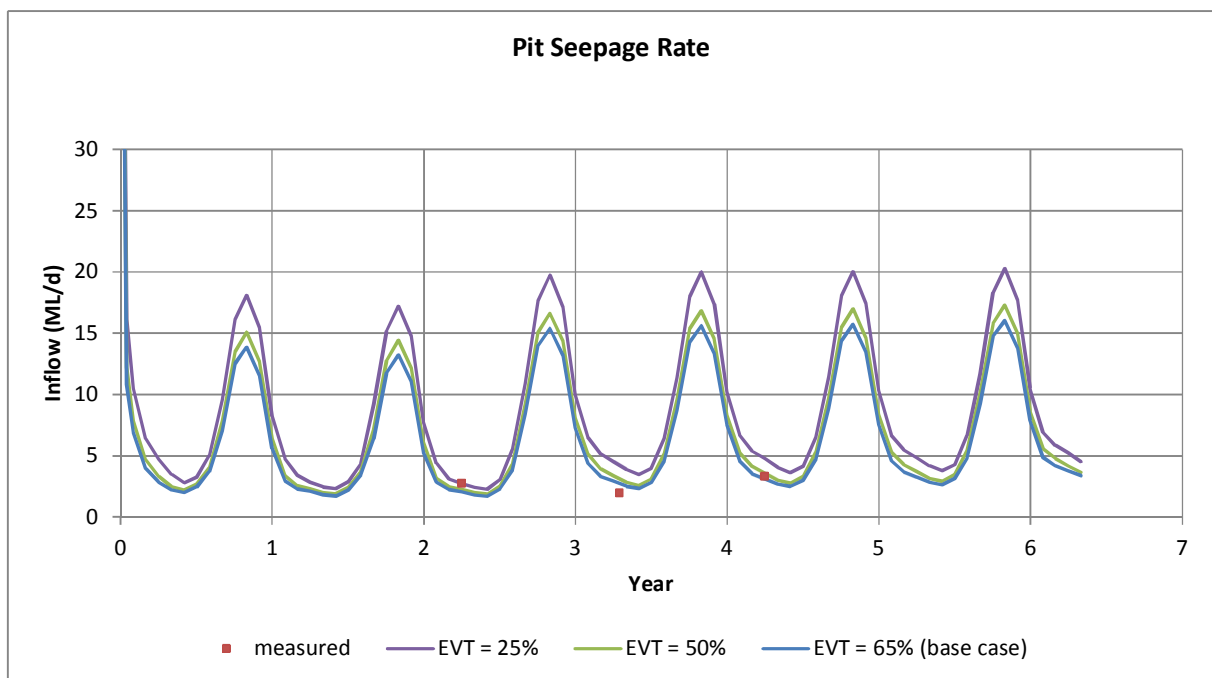


Figure 5-12 Evapotranspiration Rate – Pit Seepage Rate

5 Model Calibration and Sensitivity Analysis

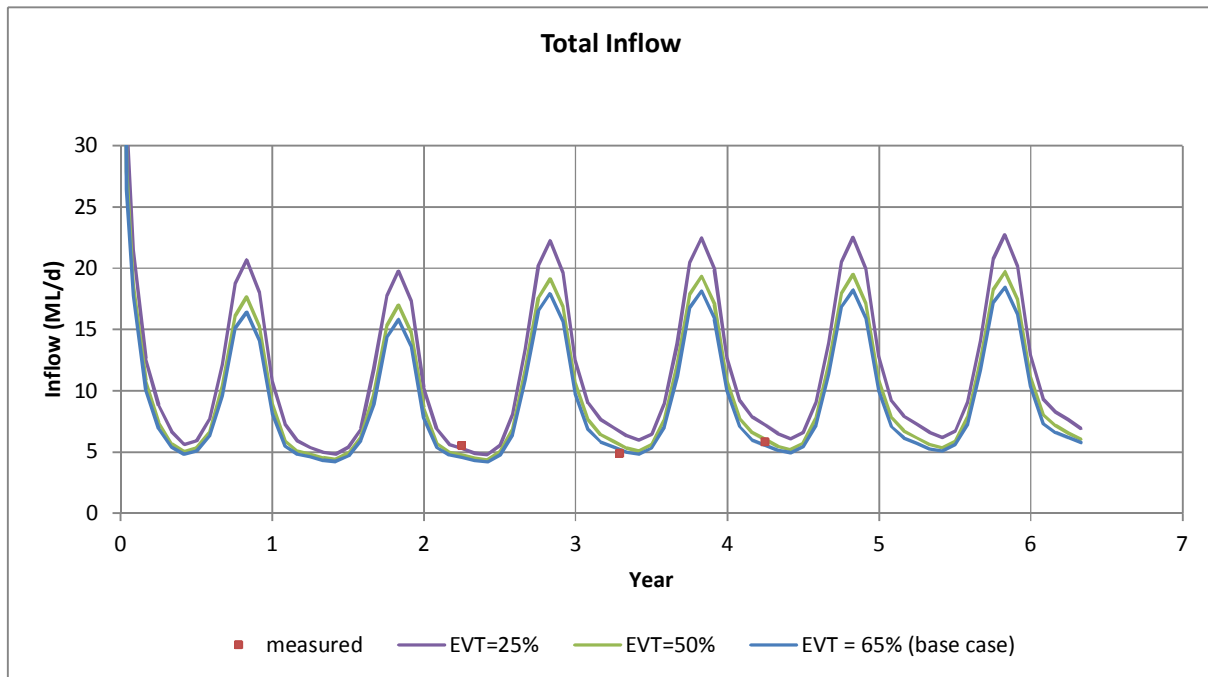


Figure 5-13 Evapotranspiration Rate – Total Inflow

5.2.3 Recharge Rate

Figures 5-14 to 5-16 show variance in groundwater inflows with changes to the base case of 10% recharge rate to 5% and 15%.

In terms of using the pit inflow as a measure of the model sensitivity, the model is highly sensitive to changes in recharge rates.

5 Model Calibration and Sensitivity Analysis

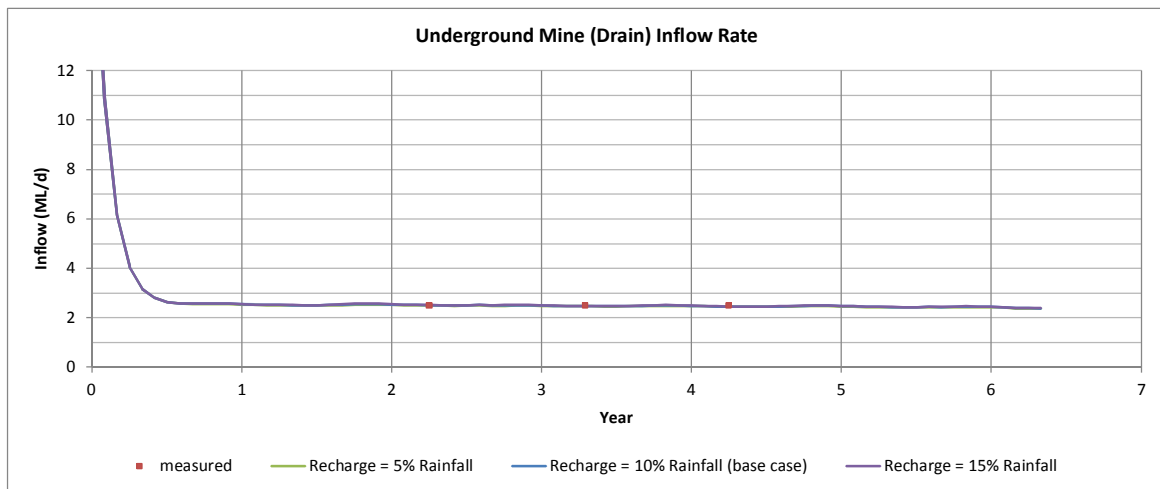


Figure 5-14 Recharge Rate – Underground Mine Inflow Rate

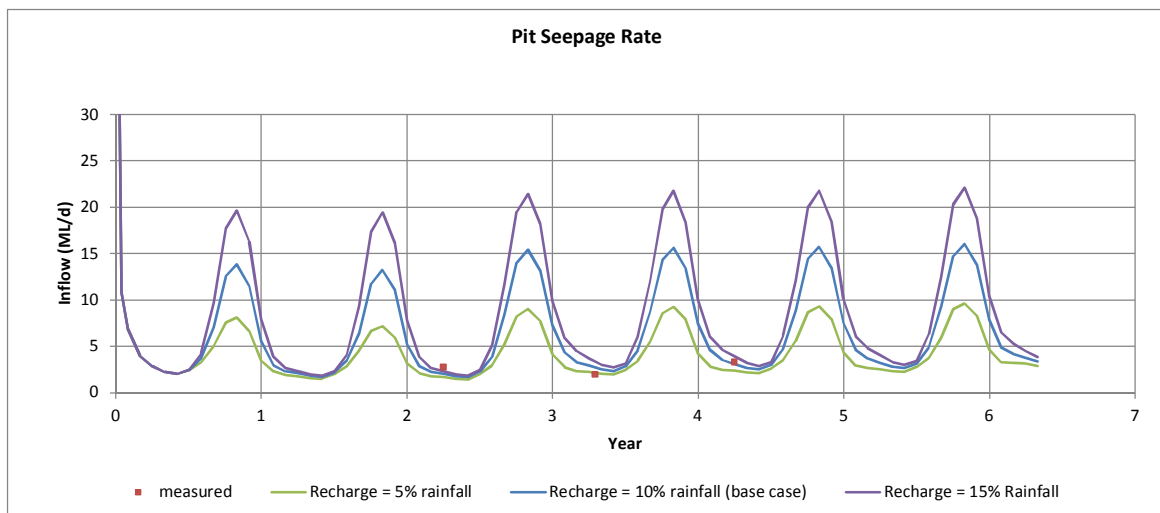


Figure 5-15 Recharge Rate – Pit Seepage Rate

5 Model Calibration and Sensitivity Analysis

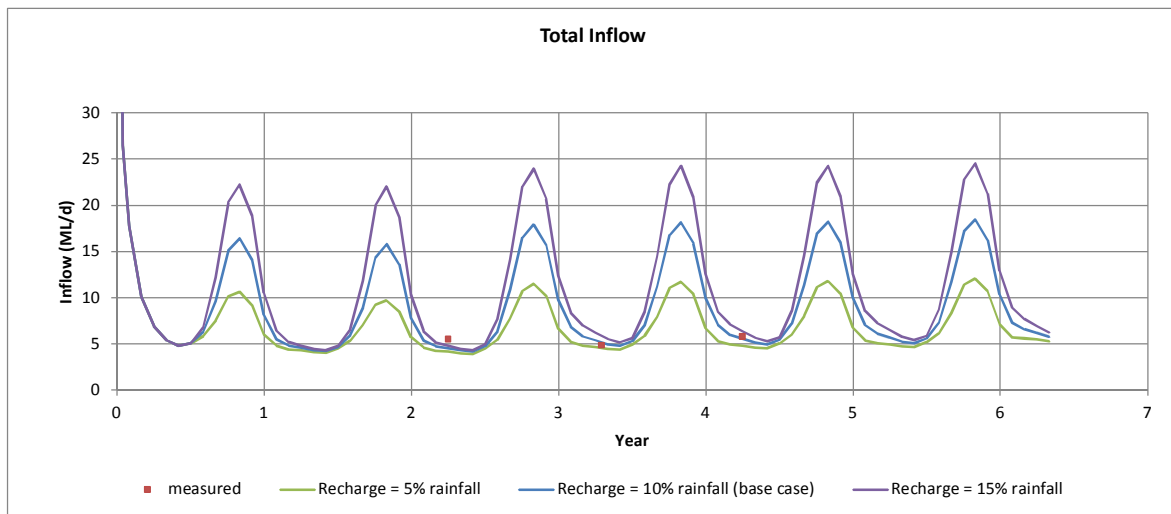


Figure 5-16 Recharge Rate – Total Inflow

Model Assumptions and Use

6.1 Assumptions

It was assumed that:

- the one-time measurement of groundwater levels (or within a short time interval) taken in 1995 and 1997 after the bores had recovered from the drilling and testing period was a good indication of the pre-mining regional groundwater conditions in the study area;
- the water table is a subdued replica of the topography and that flow of groundwater in the alluvial and the weathered rock aquifers is in the direction of the decreasing topographic elevation and drainage therefore occurs towards the major river system;
- the permeability of the Bulkara Sandstone to the east of the mines is so low that flow within this formation does not substantially affect regional flow;
- groundwater flow exchange between the modelled area and the Bulkara Sandstone is assumed to be insignificant;
- the Barney Creek, Surprise Creek, Bull Creek, Emu Creek and Glyde River are drainage channels and were simulated as drains; and
- at elevation -600 m AHD which represents the bottom of the model flow is dominantly horizontal.

6.2 Use of Model

As designed and calibrated, the model is best used for analysing of inflow of groundwater into the open pit. Interpretation of short term inflows is not recommended because the model was developed to focus long-term time scales.

A model only is as good as the data that were used to develop it. The accuracy and reliability of model prediction is related to the quality and distribution of available data. For areas and zones that have limited data, the uncertainty of model predictions is higher. For example, model uncertainty for the faults and the fault zones is generally higher than for other simulated areas because limited data from a single production bore was used to estimate hydraulic properties for faults.

The faults can have a significant effect on the flow of groundwater into the pit. Therefore, in order to accurately simulate groundwater into the pit, the location and hydraulic properties of the faults must be well understood. However, the locations and geometries of faults within the model domain are uncertain because limited data are available. As more information becomes available, the locations of faults may be revised and additional faults may be included in the model.

Except in the close vicinity of the pit, there has been limited groundwater observation data in the model domain. Therefore, data concentration in the near vicinity of the pit constrains the calibration of the transient model in areas away from the pit.

There is limited depth-dependent water-level data in the area. To better understand vertical flows, depth-dependent water-level data are needed, especially near the pit and multi-piezometers placed adjacent to the river diversion.

Predictive Simulations

7.1 Overview

The calibrated numerical model was utilised to predict the hydrologic regime during mining operations from April 2011 through to December 2036 using open pit plan provided by MRM. The dimensions of the proposed staged expansion of the mine are presented in Table A2, Appendix A.

The open pit mining dimensions were input into the model using the mining sequence information provided by MRM and simulated using the model drain seepage face package. Seepage face drains representing each stage of mining were turned on (i.e. became active) at each in accordance with the mining sequence provided.

For the predictive simulation, recharge was calculated as 10% of rainfall and evaporation was calculated as 65% of published evaporation rate.

The model simulated changes to the groundwater flow system during mining operations using the end of the calibration-period simulation (2011) as an initial condition. The following outputs were generated by the model:

- Average mine inflow rates;
- Mine influenced water levels ; and
- Model mass balance.

7.2 Predictive Simulation Results

7.2.1 Predicted Mine Inflow Rates

The model calculated groundwater inflows into the underground and open pit mines are presented in Figure 7-1. These inflows are predicted to increase from an average value of 13 ML/d in the first year to an average value of 17 ML/d in the final year when the pit reaches its deepest depth with a range between 10 to 13 ML/day during the dry season and 20 to 24 ML/day during the wet season. It can be expected that inflow will not be as regular as depicted in these figures. There could be some peak short term higher inflows depending on whether any localised vuggy/fractures zones are encountered not represented in the model.

7 Predictive Simulations

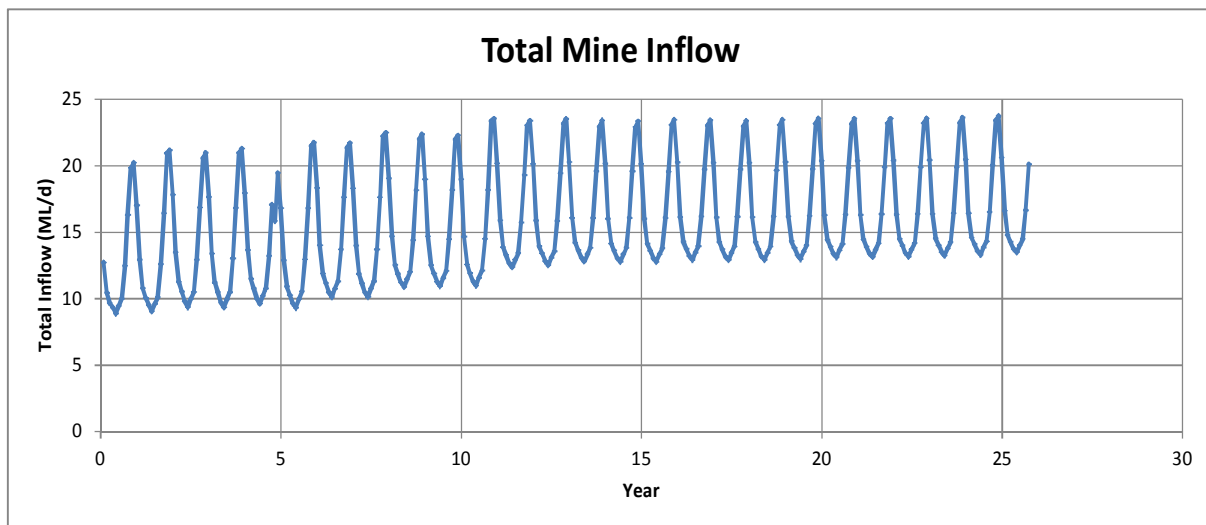


Figure 7-1 Predicted Total Mine Inflow

7.2.2 Predicted Drawdown

Simulated drawdown for 2016, 2026 and 2036 resulting from mine expansion simulations are shown in Figure D1 through Figure D3; Appendix D for Layer 2 (palaeochannel). Within the open pit area, the water table has been lowered to a maximum amount of approximately 382 m below ground surface (about -414 m AHD) within bedrock and faults.

The Djirrinmini Billabong is located in the current McArthur River, and the downstream end of Djirrinmini Billabong is located on low permeability weathered bedrock, but the banks at the upstream end of this pool are in alluvium, underlain partially by a palaeochannel. The groundwater model predicts drawdown in 2036 of 0.7 m that may result in a decrease in the depth and extent of the pool at the end of the dry season, prior to being replenished in the following wet season. This reduction will not occur until after 25 years of mining and prior to this, the drawdown will be significantly less. The existing groundwater monitoring network will allow for the confirmation of the predicted effects and provide an early warning of potential environmental impacts allowing management of such impacts.

7.2.3 Post-Mining Groundwater Rebound

Groundwater Levels

A post mining simulation was undertaken to predict the time taken for groundwater levels to rebound after the cessation of mine dewatering.

Recharge and evapotranspiration rates applied were 10% of rainfall and 0.005 m/d, respectively. Surface run-off into the pit was not simulated.

Figure 7-2 presents the simulated rebound groundwater level at GW37 (T5_3) which is located at the centre of the pit. The results of the simulation indicate that the groundwater levels will reach a dynamic equilibrium (fluctuating between about 18.2 m AHD in the dry season and about 21.2 m AHD in the wet season), 1.5 years after the cessation of mine dewatering.

7 Predictive Simulations

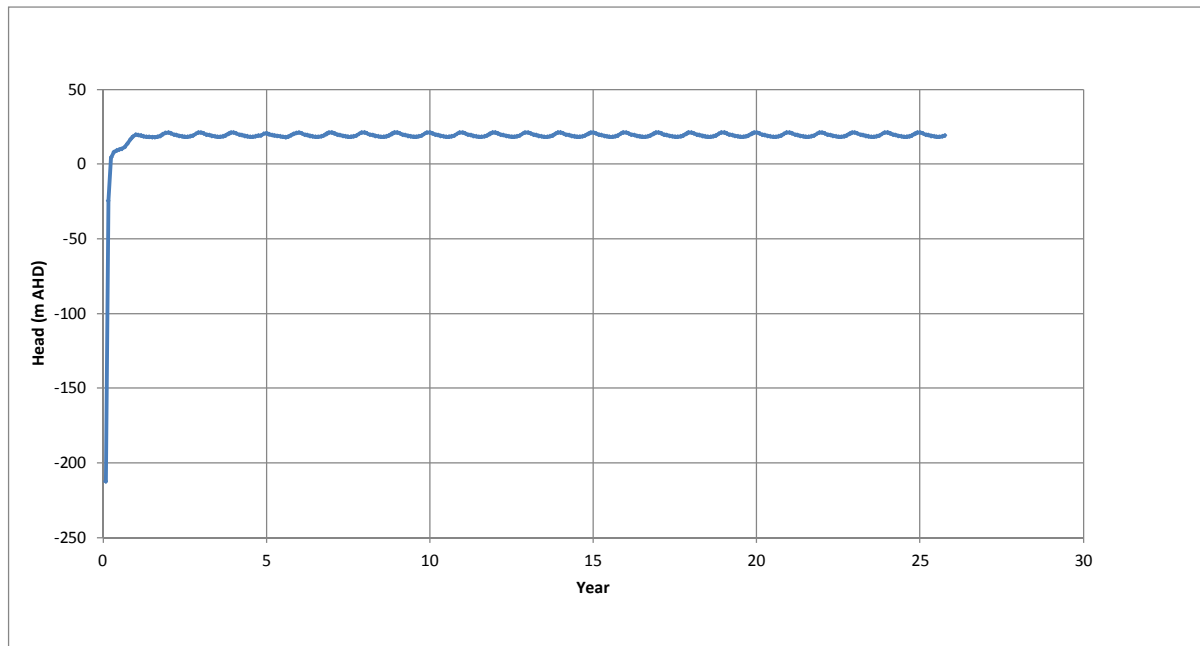


Figure 7-2 Predicted Post-mining Groundwater Level Rebound

Pit Void Infill

A post mining simulation was undertaken to determine the time taken for the final pit void to fill after the cessation of mine dewatering and mine closure.

WRM Water & Environment Pty Ltd provided run-off and lake evaporation for a 111 year period. Run-off volumes were calculated using the AWBM rainfall-runoff model for a rehabilitated catchment area of 252 ha, and 195 ha final pit void. It was assumed all rainfall applied to the pit void was converted to runoff. Lake evaporation coefficients between 50 and 80% were simulated to account for reduced wind, shading effects from the walls of the pit and higher relative humidity. The lake evaporation coefficient considered for a full pit void is 70%.

The results of the simulation are presented in Figure 7-3. For the 70% lake evaporation scenario, the pit void will fill and stabilise at about -15 m AHD, below the capacity of the pit as the rate of groundwater seepage into the pit slows as the pit water level rises. The water level stabilises at the point evaporation matches groundwater seepage and rainfall run-off.

Results indicate it is likely to take some 300 to 400 years for water levels to stabilise.

7 Predictive Simulations

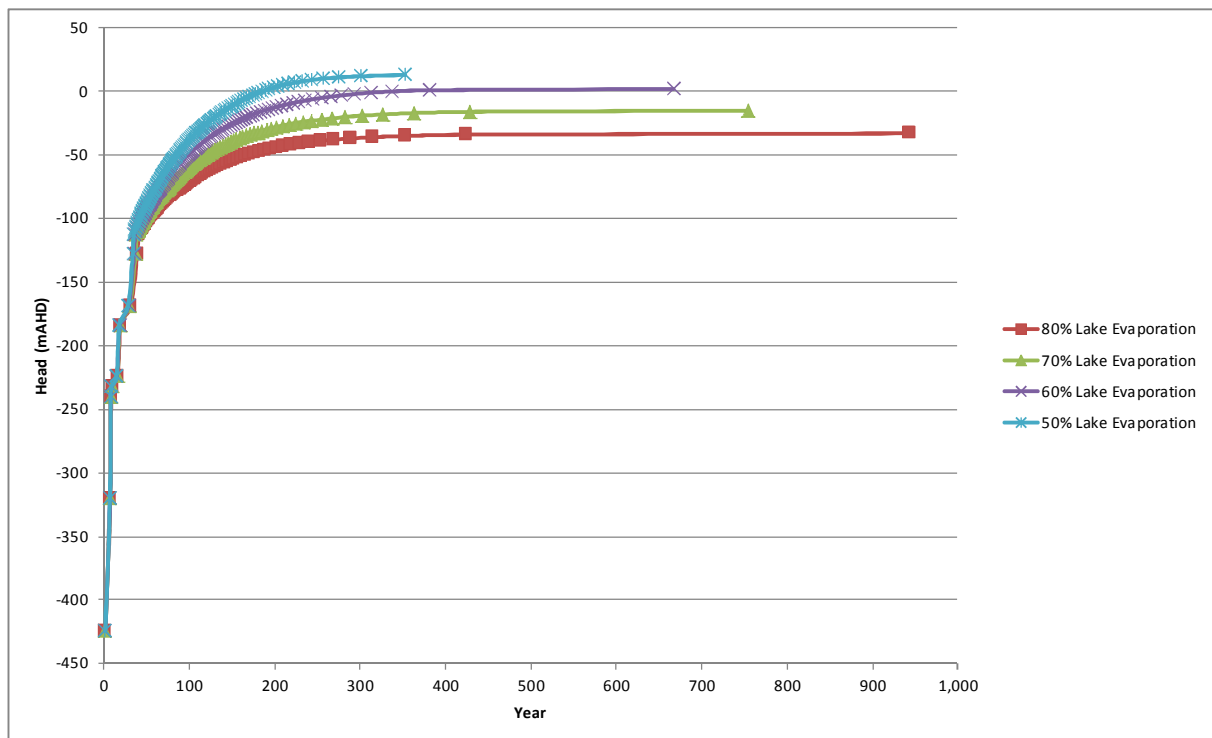


Figure 7-3 Predicted Post-mining Pit Void Level Rebound

Model Uncertainty and Limitations

Intrinsic to the model is the error and degree of uncertainty associated with the approximations, assumptions, and simplifications that was made and the input data, particularly groundwater extraction rates and model layer elevations.

8.1 Model Uncertainty

There are uncertainties in the groundwater flow field simulated in this work. These uncertainties are due to the simplifications and assumptions in the design of the model, uncertainty in the boundary conditions and input parameters, and the limited data that is available to calibrate the model to the observed groundwater flow systems at location away from the pit and at depth as only one test hydraulic test was available for these structures. The uncertainty in model simulated pit inflow rates is high because knowledge of the locations of vuggy/fracture zones that can occur in dolomite is meagre particularly at depth. This also includes knowledge about the range of fault zone hydraulic conductivity.

Groundwater flow in the model area is likely to be very complex because it occurs in bedrock, voids/vugs, fractures, fractured zones, weathered rocks and alluvium. The groundwater model assumes that groundwater flow in the bedrock occurs only as porous media flow and that the hydraulic properties of the bedrock are relatively uniform. Therefore, there is a high degree of uncertainty in flow field simulated by the model for the bedrock (model layers 4 – 11).

The predicted groundwater inflow rates to the open pit represent the rate at which groundwater needs to be extracted assuming a dewatering system is installed to lower groundwater levels ahead of mining. Current operations allow partial dewatering via seepages into the open pit.

Owing to uncertainty in some parameters used in the model, especially in the mine inflow rates, and hydraulics and hydrology of the faults and the dolomite bedrock, model results from the predictive simulation should be used with caution. The model is not ideally suited for predicting absolute changes mine inflow rates.

8.2 Model Limitations

The model limitations are the consequence of a combination of (1) input data, (2) representation of the physical processes by the algorithms of the model, and (3) parameter estimation during the calibration procedure.

The following are some of potential sources of model limitations that could limit the application of the model.

- Input data on model layer elevation and thicknesses, groundwater levels (where the ground elevation was extrapolated from elevation map), and hydraulic properties represent only approximations of actual values at depths less than 100m. There is no hydraulic data available for either the faults or the dolomite at depths proposed for the open pit (~ RL -400m);
- The dolomite can display localised vuggy and fracture zones of higher permeability whereas in the model an overall uniform hydraulic conductivity had to be applied to layers representing this rock type;
- Model-discretisation errors (including effects of averaging elevation information over the model cell size) result from inaccuracies in the geometric representation of model layers, in the representation of the orebody, and location of the fault zones;

8 Model Uncertainty and Limitations

- The accuracy of individual gridded surfaces depended on the accuracy of the available data and the complexity of the geologic layers modelled. For example, because of their relatively simple geometry, the alluvium can be represented accurately with only a few data points, whereas faulted and folded rocks with more complex geometries are much more difficult to represent even with a large number of data points;
- The gridded surfaces for the alluvium, the weathered horizon and the W-Fold Shale were relatively well defined by numerous well-distributed data. Other gridded surfaces, such the ore zone were less well defined;
- Unidentified errors associated with the ground surface elevation data used;
- All the physical processes could not be adequately represented or “captured” in the numerical model;
- Local scale heterogeneity in hydrologic properties, recharge, and discharge and transfer of water from the pit and the old underground workings were only approximated in the groundwater flow model constructed for this study;
- Errors in parameter estimates that may occur when improper values are selected during the calibration process. Various combinations of parameter values can result in low residual error, but they may improperly represent the actual system;
- The acceptable degree of agreement between simulated and measured values does not guarantee that the estimated model-parameter values uniquely and reasonably represent the actual parameter values;
- The calibration process was undertaken with the emphasis on observed dry season groundwater inflows to the open pit mine. This was due to the unknown surface water inflow confounding the determination of the groundwater inflow rates; and
- The available groundwater level data, spatial distribution of existing groundwater bores, and limited depth extent (generally very shallow bores less than 100 m), confined mainly to the alluvial deposits, palaeochannel sediments and weathered bedrock meant that the hydraulic data for the fault zones and dolomite at depth had to be estimated.

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Mining & Energy Technical Services Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report.

It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 1 April 2011.

The methodology adopted and sources of information used by URS are outlined in this the Report.

Where this report indicates that information has been provided to URS by third parties, URS has made no independent verification of this information unless required as part of the agreed scope of work. URS assumes no liability for any inaccuracies in or omissions to that information.

This Report was prepared between June 2011 and January 2012. The information in this report is considered to be accurate at the date of issue and is in accordance with conditions at the site at the dates sampled. Opinions and recommendations presented herein apply to the site existing at the time of our investigation and cannot necessarily apply to site changes of which URS is not aware and has not had the opportunity to evaluate. This document and the information contained herein should only be regarded as validly representing the site conditions at the time of the investigation unless otherwise explicitly stated in a preceding section of this report. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

This report contains information obtained by inspection, sampling, testing or other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. The borehole logs indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the frequency and method of sampling, and the uniformity of conditions as constrained by the project budget limitations. The behaviour of groundwater and some aspects of contaminants in soil and groundwater are complex. Our conclusions are based upon the analytical data presented in this report and our experience. Future advances in regard to the understanding of chemicals and their behaviour, and changes in regulations affecting their management, could impact on our conclusions and recommendations regarding their potential presence on this site.

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this report, URS must be notified of any such findings and be provided with an opportunity to review the recommendations of this report.

Whilst to the best of our knowledge information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time. Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

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It is the responsibility of third parties to independently make inquiries or seek advice in relation to their particular requirements and proposed use of the relevant property.

Any estimates of potential costs which have been provided are presented as estimates only as at the date of the Report. Any cost estimates that have been provided may therefore vary from actual costs at the time of expenditure.

Appendix A Tables

Appendix A

Table A1 Aquifer Hydraulic Properties

Site	Depth tested (m)	Lithology	Transmissivity (m ² /d)	K (m/d)	Storage Coefficient/ Specific Storage	Method
BHC5	14.4 – 17.4	Silty Sand		6.91E-01		In-situ falling/constant head
BHC8	7.0 – 10.0	Sandy gravelly cla/clayey sand and gravel		5.01E-01		In-situ falling/constant head
BHC12	9.7 – 12.7	Gravel, Gravel/silty clay		1.21E-01		In-situ falling/constant head
BHC13	9.8 – 12.8	Silty clay with gravel		1.30E+00		In-situ falling/constant head
BHC14	10.3 – 13.3	Gravelly sand		6.74E-01		In-situ falling/constant head
BHC15	4.8 – 7.8	Silty clay/Gravelly Clay		4.92E-02		In-situ falling/constant head
BHC20	12.5 – 20.0	Sandy Gravel		1.21E-01		In-situ falling/constant head
BC21	21.6 – 24.6	Gravel		3.37E+00		In-situ falling/constant head
BHC30	12.0 – 18.0	Silty Sand /Gravel		2.51E-01		In-situ falling/constant head
BHC31	3.0 – 5.0	Clayey Gravel/Silty Clay		3.28E+00		In-situ falling/constant head
MAC3P	20.35 – 26.5	Basal gravels		2.14E+01		48-hour constant rate pumping/recovery test (Pumping bore)
GWM103	16.5 – 23.0	Basal Gravels	631 - 753	3.47E+01		48-hour constant rate pumping/recovery test (observation bore)
GWPB01c			530 - 573			48-hour constant rate pumping/recovery test (observation bore) (Theis and Papadopolus-Cooper method)
BHC1	6.1 – 12.7 9.1 – 12.7	Sandstone Sandstone		3.46E-04		Packer Test
BHC16	3.1 – 12.7	Sandstone		2.59E-04		Packer Test
BCH18	9.0 – 12.2	Breccia		5.18E-04		Packer Test
BCH19	6.6 – 15.6	Breccia		2.59E-04		Packer Test
BCH21	26.0 29.8	Shale/Breccia		5.18E-04		Packer Test
BHC22	14.6 20.2	Shale		4.32E-04		Packer Test
BHC23	6.0 – 22.7 12.0 – 22.7 18.0 – 22.7	Shale/Dolomite Shale/Dolomite Shale/Dolomite		1.73E-04 2.59E-04 4.32E-04		Packer Test
BHC25	5.1 – 9.5	Breccia		3.46E-04		Packer Test
BHC28	5.0 – 13.9	Breccia/Shale		2.59E-04		Packer Test
BHC30	22.0 – 25.9	Breccia/Shale		5.18E-04		Packer Test
BHC31	6.1 – 9.5	Shale		3.46E-04		Packer Test
MAC1P	11.23 – 43.89	Dolomite	5.4 – 9.2			Pumping and Recovery
MAC2			96	8.33E-01	1.00E-04	Gringarten-Witherspoon
MAC3P	20.23 – 26.50	Sand/Gravel	785	-		Theis Recovery method
GWM103 (observation bore located 10.9 m away from			631 753			Theis Method Cooper-Jacob/ Papadopolus-Cooper methods

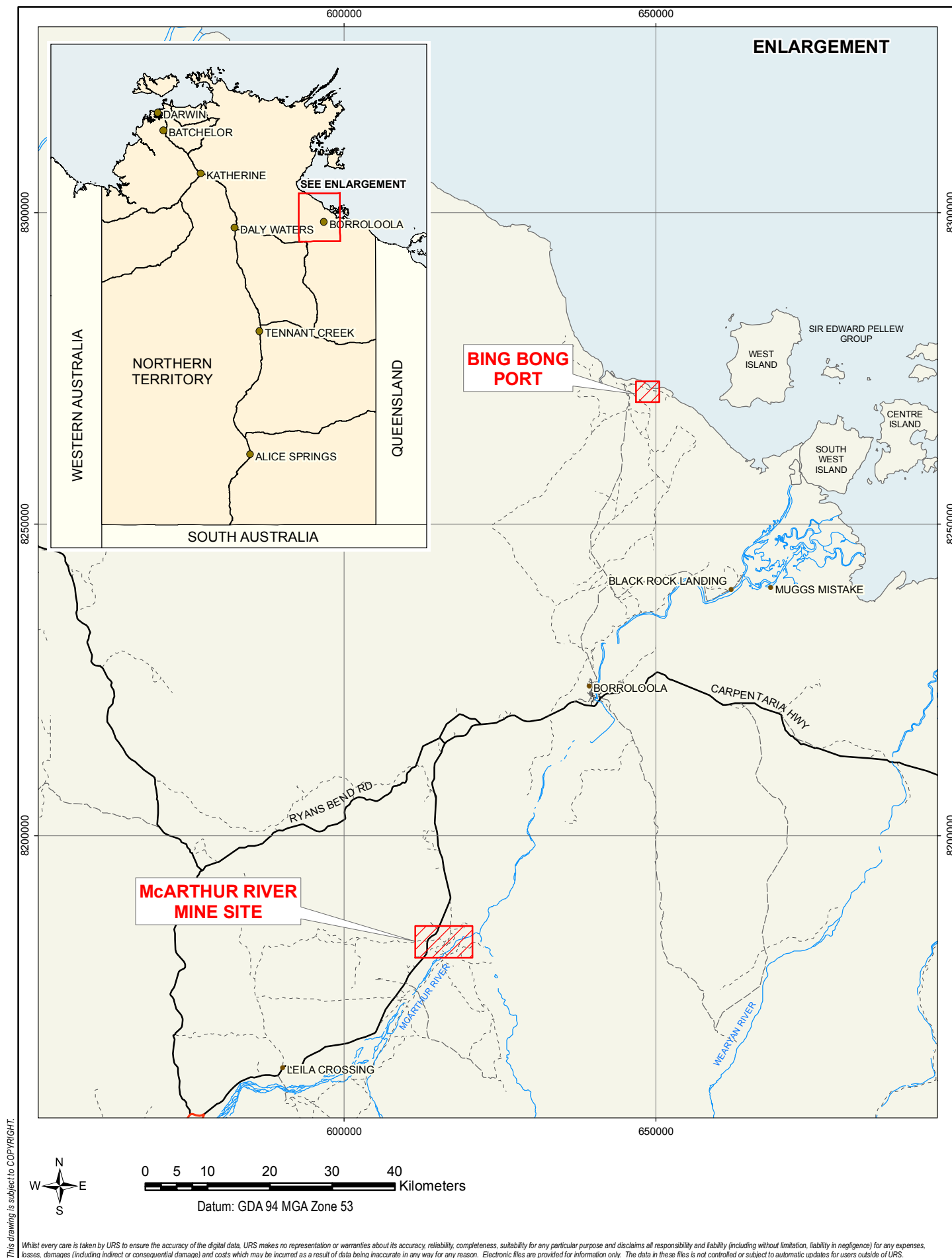
MAC3P)						
GWPB01b(observation bore located 17.2 m away from MAC3P)			530		0.002	Theis Method
			574		0.001	Cooper-Jacob method
SC01	10 - 16	Gravel, Dolomite Broken Black Shale	86.2	14.4	9.98E-04	-
SC03	7.5 – 13.5	Weathered Shale	135	22.5	4.84E-09	Theis Recovery with Jacob Correction
SC04	8 - 14	Clay stone + shale	97.6	16.3	7.41E-04	
SC05	6 - 18	Shale, Laterite, weathered shale	59.8	5.0	1.4E-06	Theis Recovery with Jacob Correction
SC06	6 - 12	Laterite and shale	115	19.2	1.51E-02	-
SC07	8.5 – 14.5	Broken shale with gravels and clay	127	21.2	3.37E-02	-
SC08	9 - 15	Weathered Shale	9.8	1.6		-
SC11	9 - 15	Shale	5.6	0.9	1.13E-03	Theis Recovery method
SC13	12 - 18	Coarse Gravel with some clay	550	91.7	1.13E-05	Agawal, Theis Recovery with Jacob Correction
SC14	17 - 23	Shale	297	49.5	1.11E-15	Theis Recovery method
SC15	17 - 23	Shale	31.3	5.2	8.5E-05	Theis Recovery with Jacob Correction
MW01B	11.75 m thick		86.2	7.34	9.98E-04	Double porosity
MW05	8.56 m thick		115	13.5	1.51E-02	Theis Recovery with Jacob Correction
MW10B	12.41 m thick		97.6	7.86	7.41E-04	Double porosity

Appendix A

Table A2 Stages of Future Open Pit Mining

Date	Absolute_Pit_Bottom_(m_AHD)									
	G mini	G Mjr	F Mjr	Stg H	Stg I	Stg J	Stg K	Stg L	Stg M	Final
2011_Apr - 2011_Jun	-96	-96	-96	-	-	-	-	-	-	-
2011_Jul - 2011_Sep	-112	-112	-112	-	-	-	-	-	-	-
2011_Oct - 2011_Dec	-112	-112	-112	-	-	-	-	-	-	-
2012_Jan - 2012_Mar	-112	-112	-112	-	-	-	-	-	-	-
2012_Apr - 2012_Jun	-112	-112	-112	-	-	-	-	-	-	-
2012_Jul - 2012_Sep	-112	-112	-112	-112	-	-	-	-	-	-
2012_Oct - 2012_Dec	-112	-112	-112	-112	-	-	-	-	-	-
2013_Jan - 2013_Dec	-112	-128	-128	-128	-128	-128	-	-	-	-
2014_Jan - 2014_Dec	-112	-128	-136	-136	-136	-136	-	-	-	-
2015_Jan - 2015_Dec	-112	-128	-160	-160	-160	-160	-160	-	-	-
2016_Jan - 2016_Dec	-112	-128	-168	-168	-168	-168	-160	-	-	-
2017_Jan - 2017_Dec	-112	-128	-168	-184	-184	-184	-184	-184	-	-
2018_Jan - 2018_Dec	-112	-128	-168	-184	-184	-184	-184	-184	-	-
2019_Jan - 2019_Dec	-112	-128	-168	-184	-208	-208	-208	-208	-208	-
2020_Jan - 2020_Dec	-112	-128	-168	-184	-224	-224	-224	-224	-224	-
2021_Jan - 2021_Dec	-112	-128	-168	-184	-224	-232	-232	-232	-232	-
2022_Jan - 2022_Dec	-112	-128	-168	-184	-224	-232	-240	-240	-240	-240
2023_Jan - 2023_Dec	-112	-128	-168	-184	-224	-232	-240	-264	-264	-264
2024_Jan - 2024_Dec	-112	-128	-168	-184	-224	-232	-240	-296	-296	-296
2025_Jan - 2025_Dec	-112	-128	-168	-184	-224	-232	-240	-296	-296	-296
2026_Jan - 2026_Dec	-112	-128	-168	-184	-224	-232	-240	-296	-296	-296
2027_Jan - 2027_Dec	-112	-128	-168	-184	-224	-232	-240	-312	-312	-312
2028_Jan - 2028_Dec	-112	-128	-168	-184	-224	-232	-240	-312	-312	-312
2029_Jan - 2029_Dec	-112	-128	-168	-184	-224	-232	-240	-312	-312	-312
2030_Jan - 2030_Dec	-112	-128	-168	-184	-224	-232	-240	-320	-320	-320
2031_Jan - 2031_Dec	-112	-128	-168	-184	-224	-232	-240	-336	-320	-336
2032_Jan - 2032_Dec	-112	-128	-168	-184	-224	-232	-240	-336	-320	-344
2033_Jan - 2033_Dec	-112	-128	-168	-184	-224	-232	-240	-336	-320	-352
2034_Jan - 2034_Dec	-112	-128	-168	-184	-224	-232	-240	-336	-320	-368
2035_Jan - 2035_Dec	-112	-128	-168	-184	-224	-232	-240	-336	-320	-384
2036_Jan - 2036_Dec	-112	-128	-168	-184	-224	-232	-240	-336	-320	-424

Appendix B Figures



MINING AND
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MRM PHASE 3 DEVELOPMENT PROJECT EIS - GROUNDWATER

LOCATION OF STUDY AREA

URS

MRM STAGE 3

File No: 42213965-001.mxd

Drawn: JD

Approved: KO

Date: 06-07-2011

Figure: **B1**

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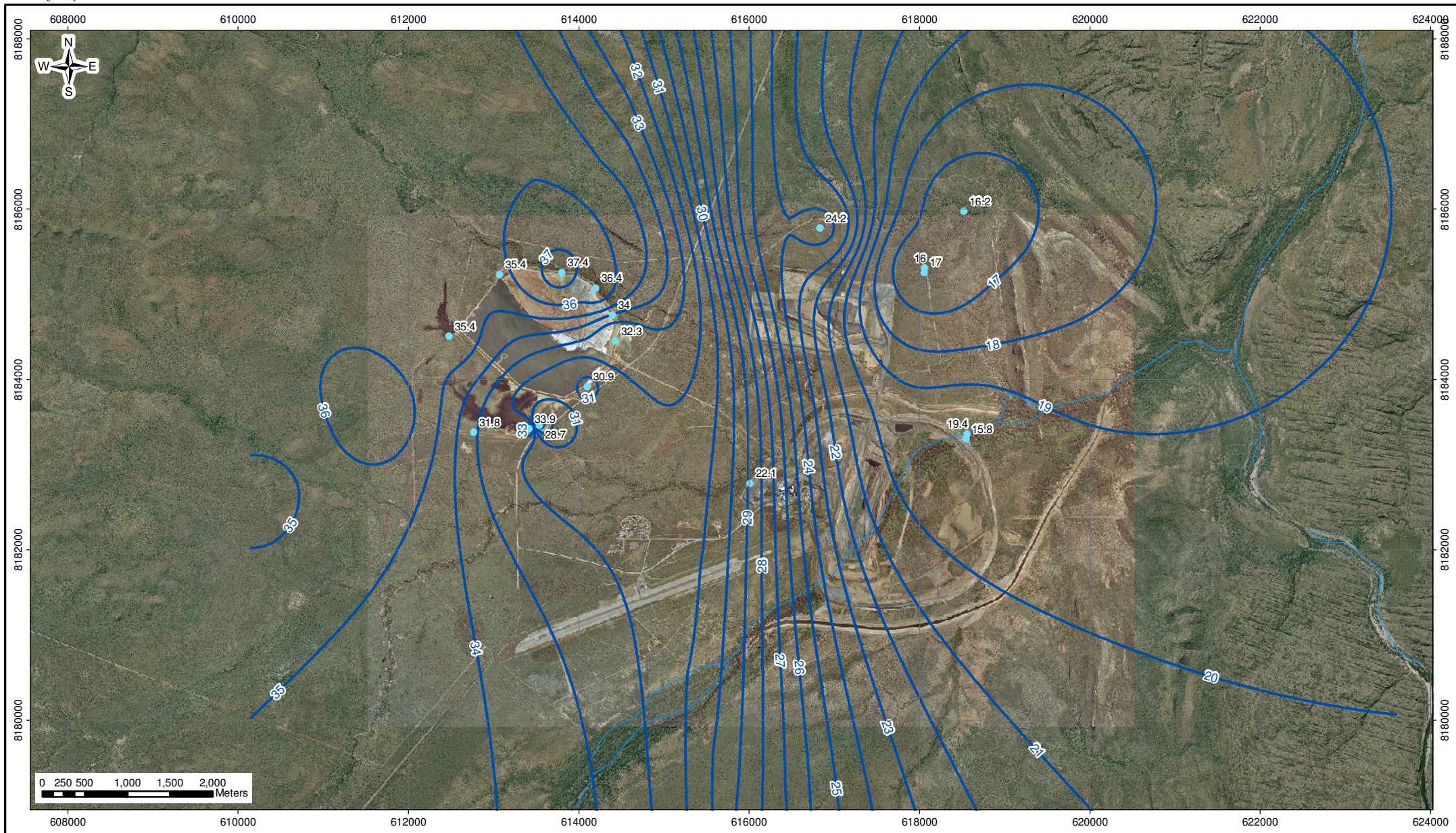
SURFACE WATER AND GROUNDWATER MONITORING SITES



Date: 07-07-2011

Rev. A A4





MINING AND
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MRM PHASE 3 DEVELOPMENT PROJECT EIS - GROUNDWATER

Legend

● Observed Head Locations — Groundwater Contours

1995/97 REGIONAL GROUNDWATER CONDITIONS IN THE BEDROCK

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Figure: **B3**

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MRM PHASE 3 DEVELOPMENT PROJECT EIS - GROUNDWATER

Legend

● Groundwater-Surface Water Interaction Investigation Sites — Watercourses

JUNE 2005 GROUNDWATER-SURFACE WATER INTERACTION INVESTIGATION SITES

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Figure: **B4**

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Appendix B

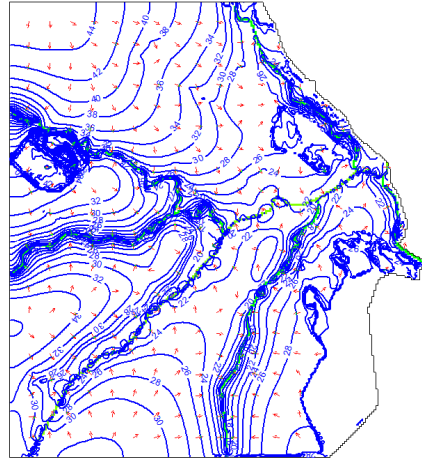


Figure B5 Model Simulated Layer 1 Predevelopment Head

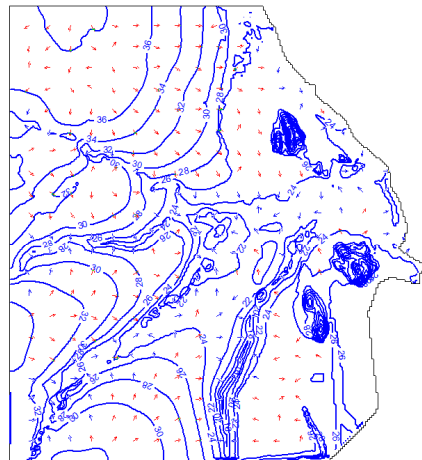


Figure B6 Model Simulated Layer 2 Predevelopment Head

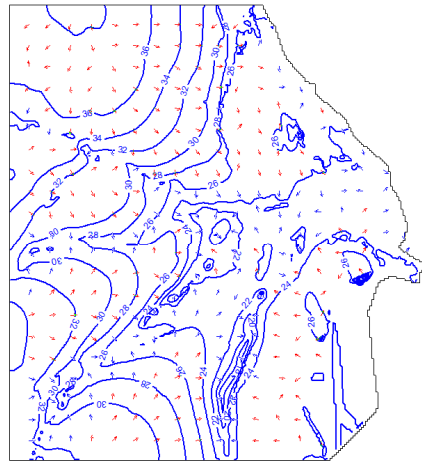


Figure B7 Model Simulated Layer 3 Predevelopment Head

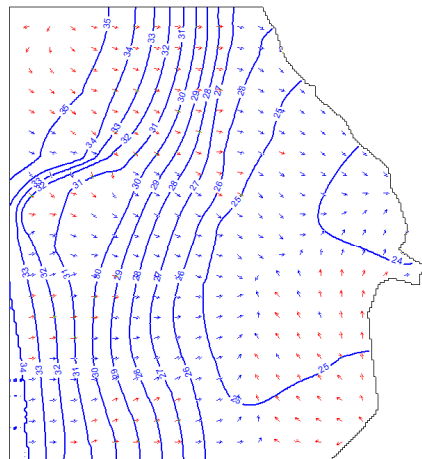
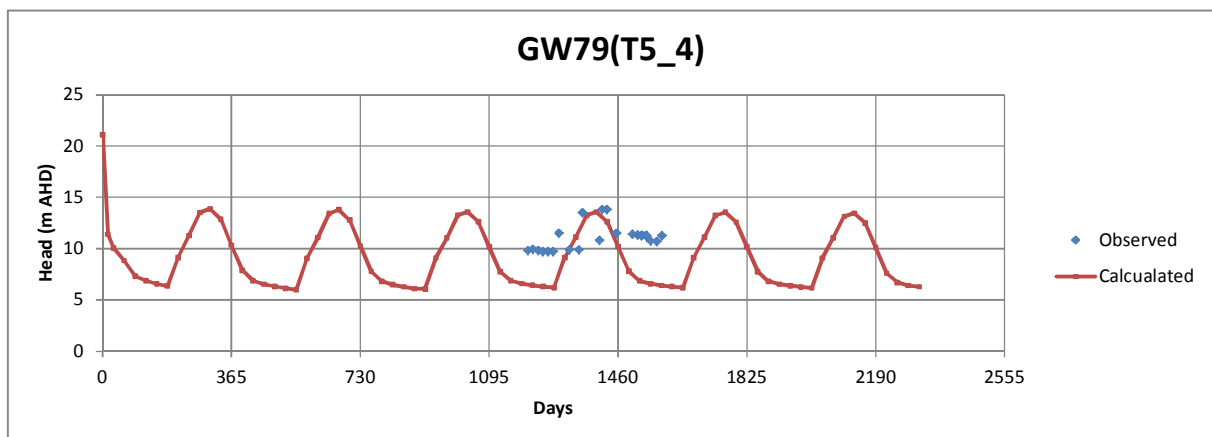
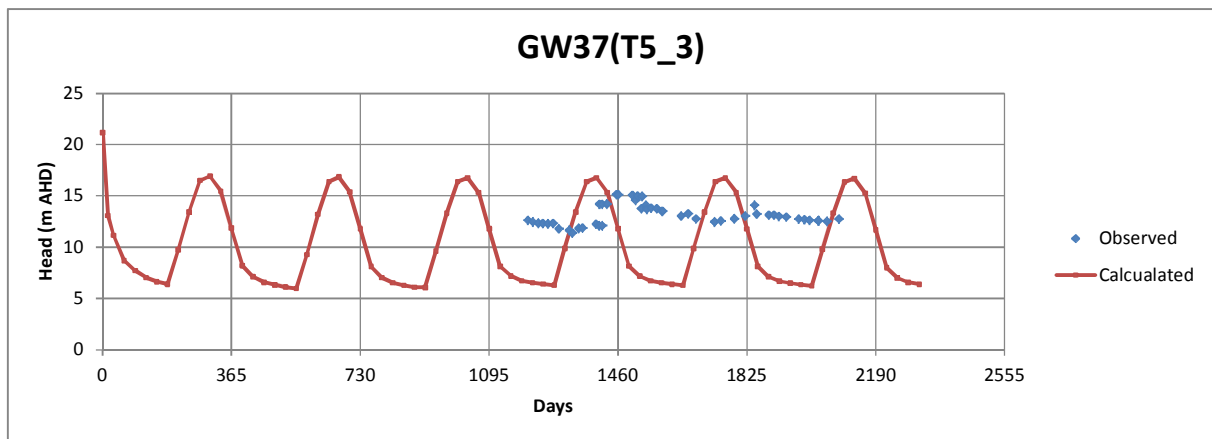
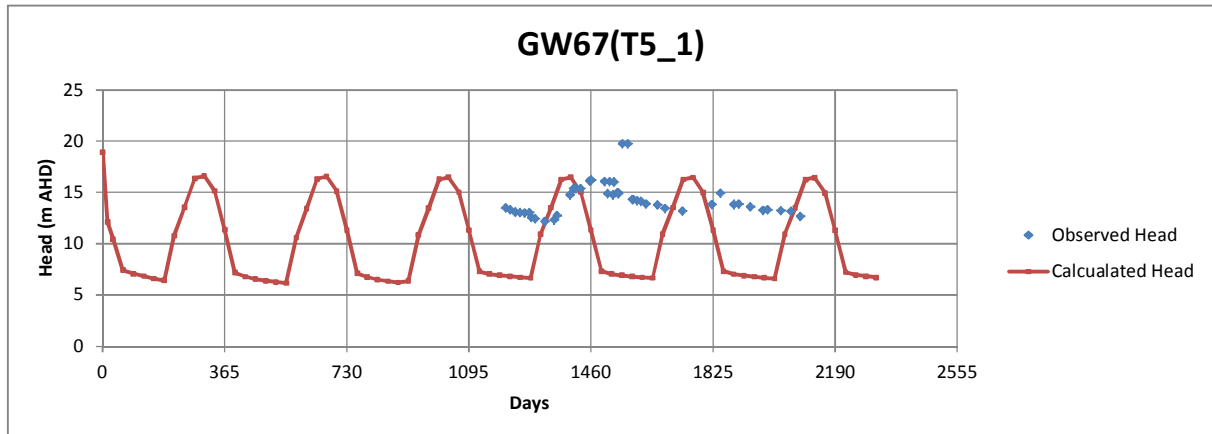


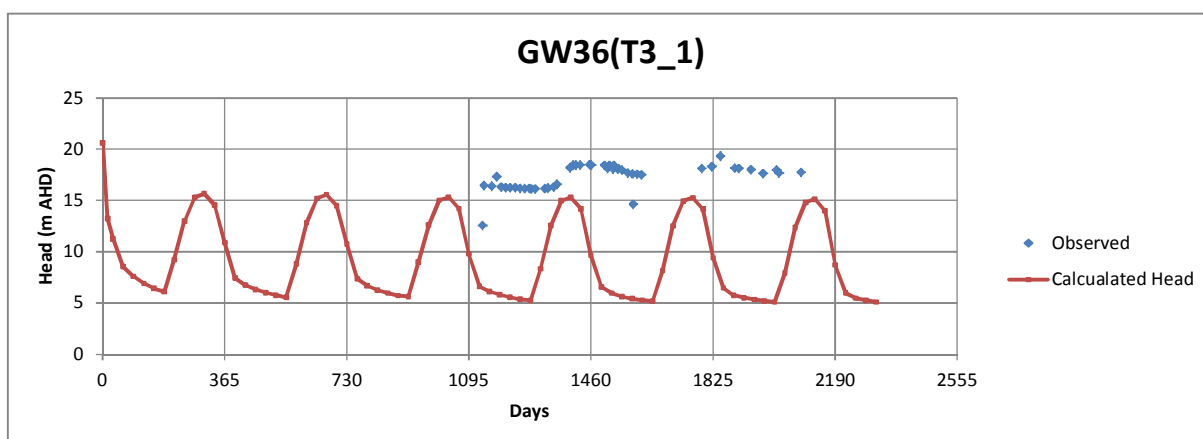
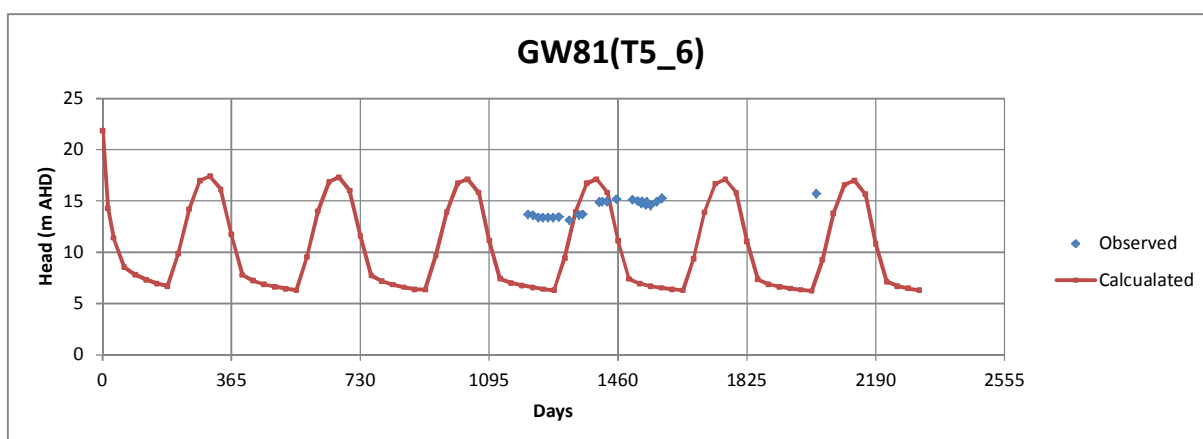
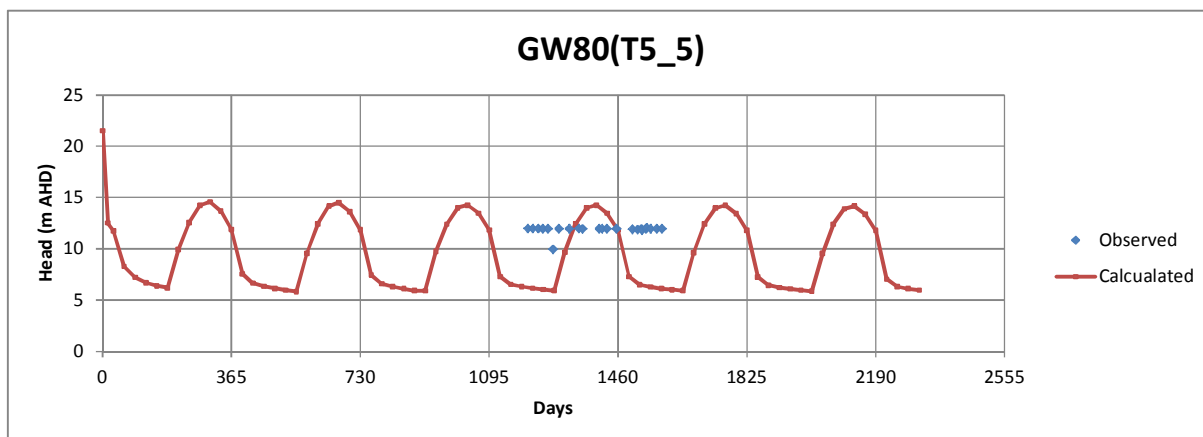
Figure B8 Model Simulated Layer 11 Predevelopment Head

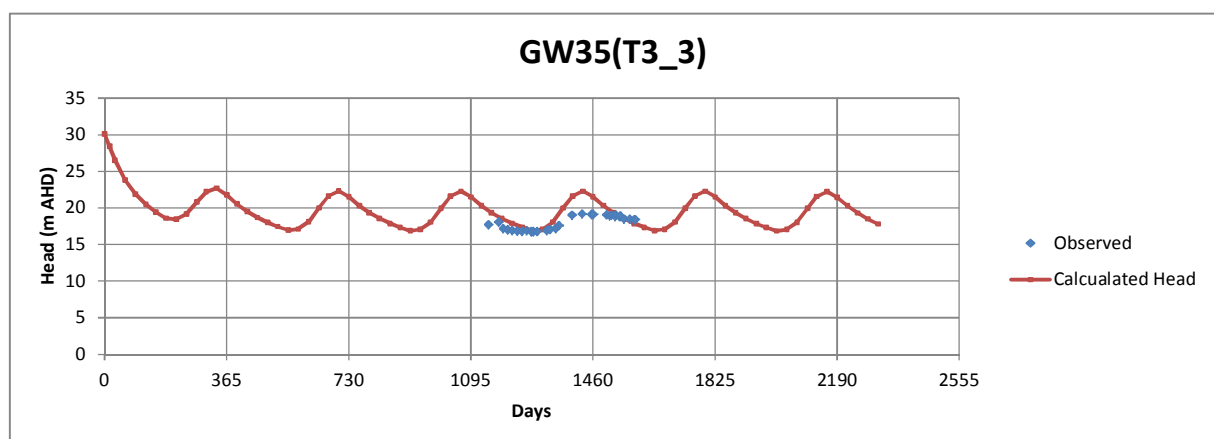
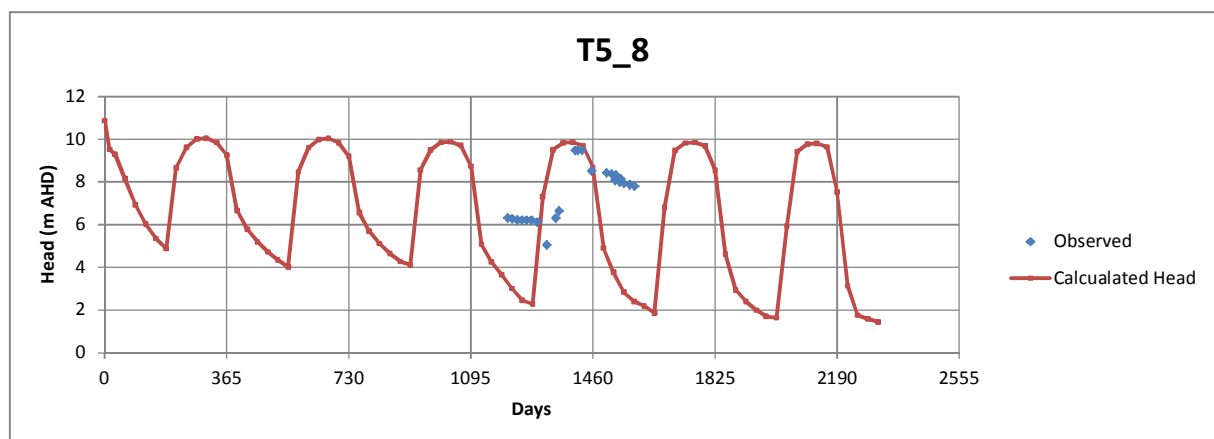
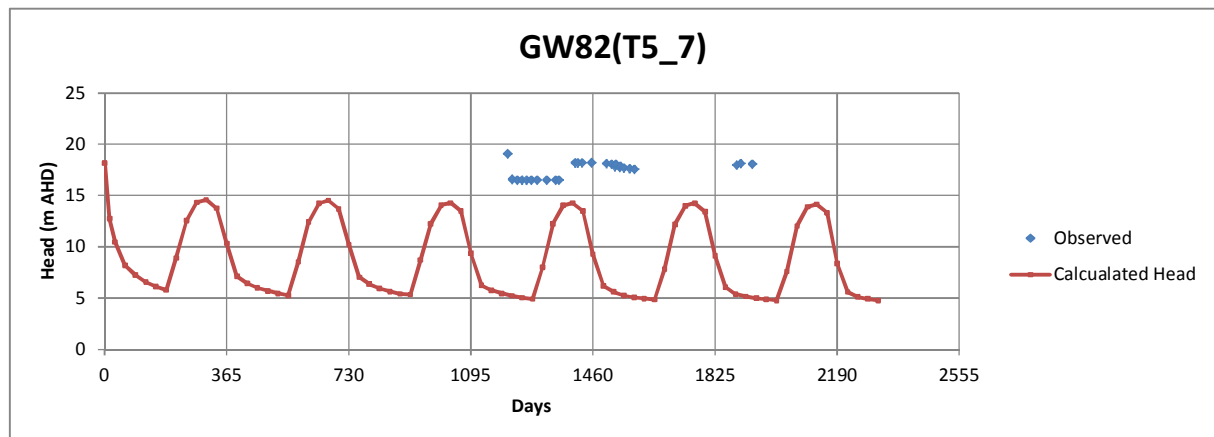
Appendix C Calculated versus Observed Head Hydrographs

Hydrographs from Alluvium (Model Layer 1)



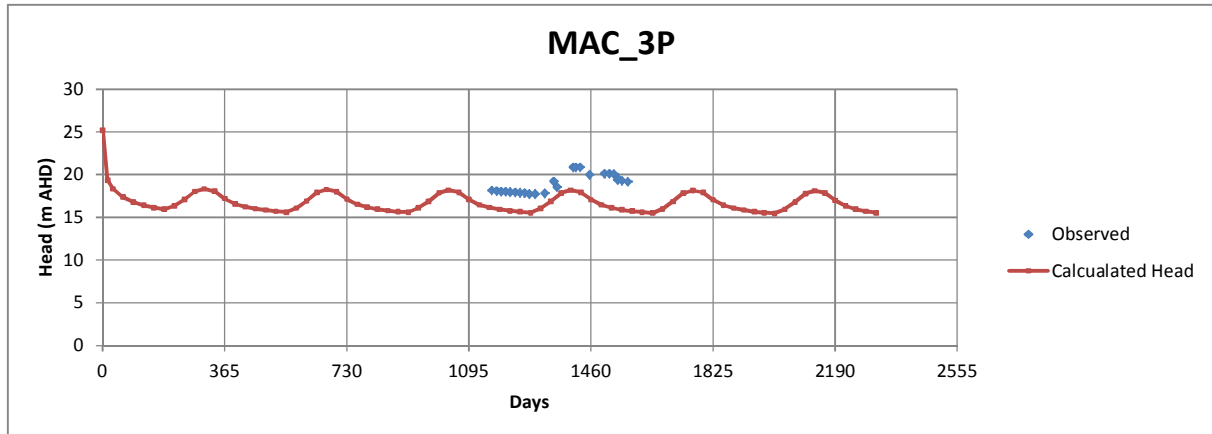
Appendix C



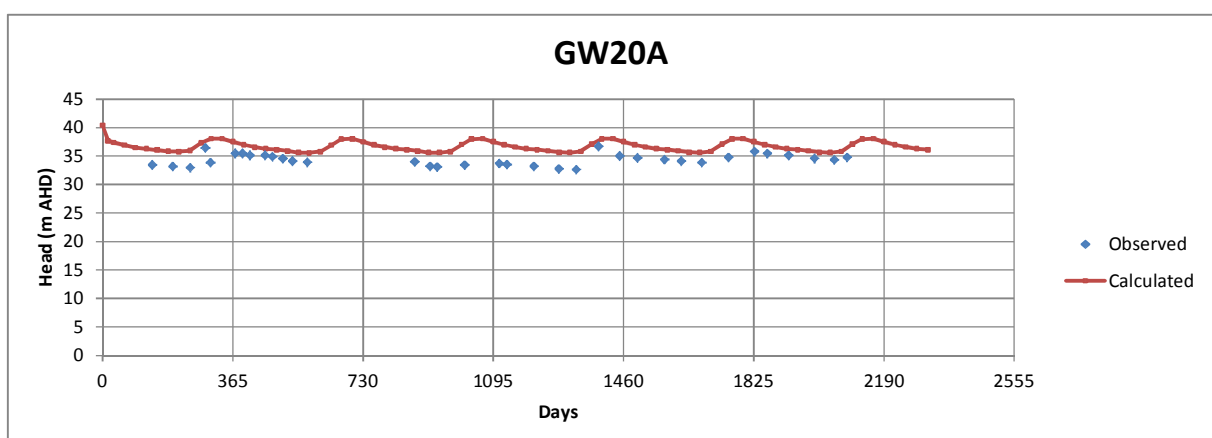
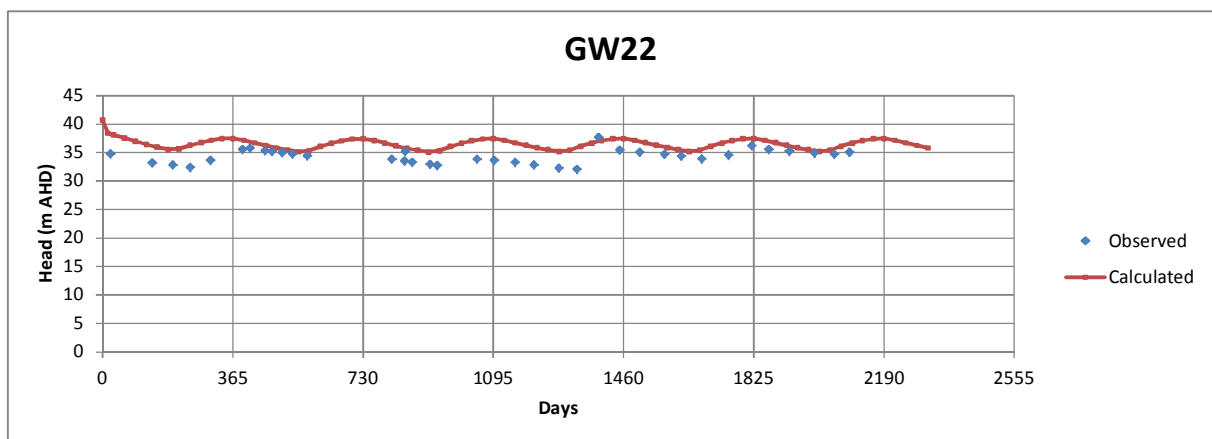
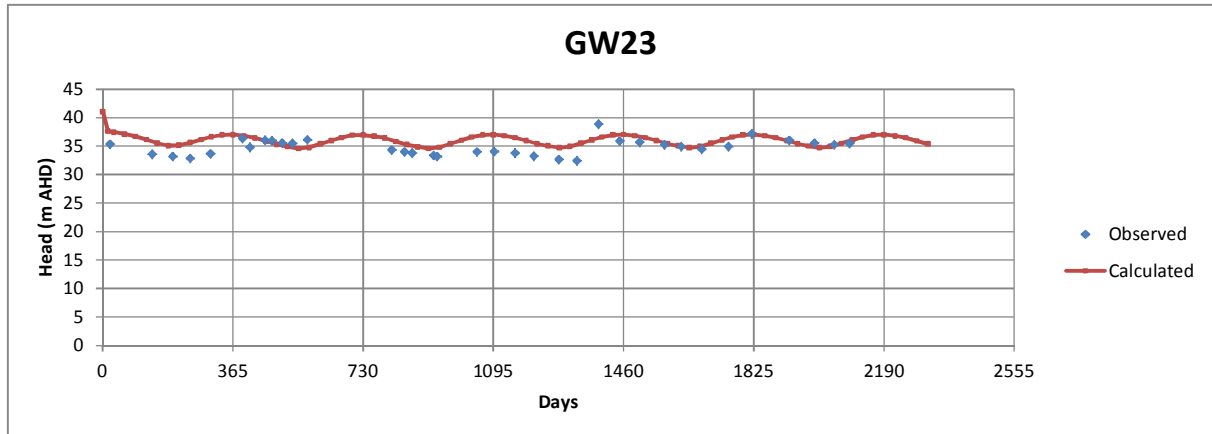


Hydrographs from Paleochannel (Model Layer 2)

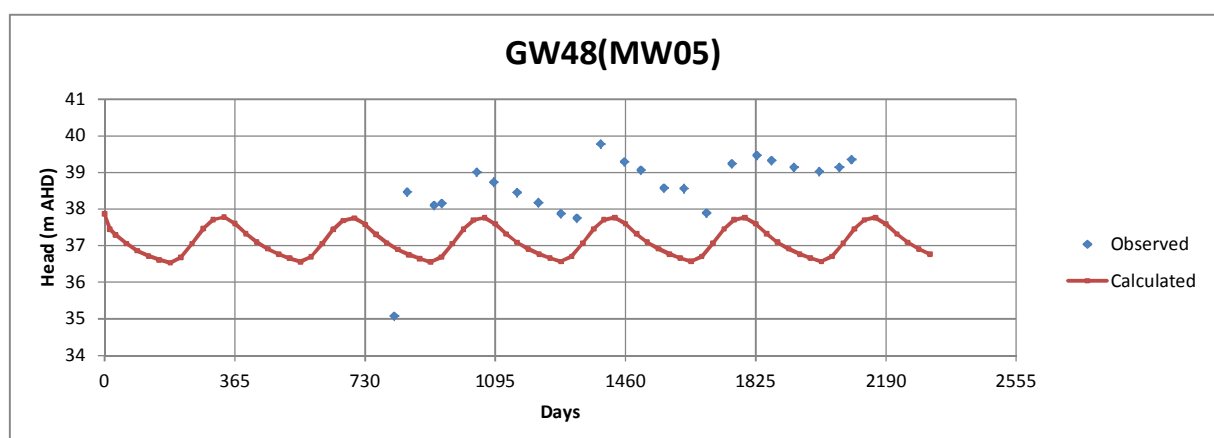
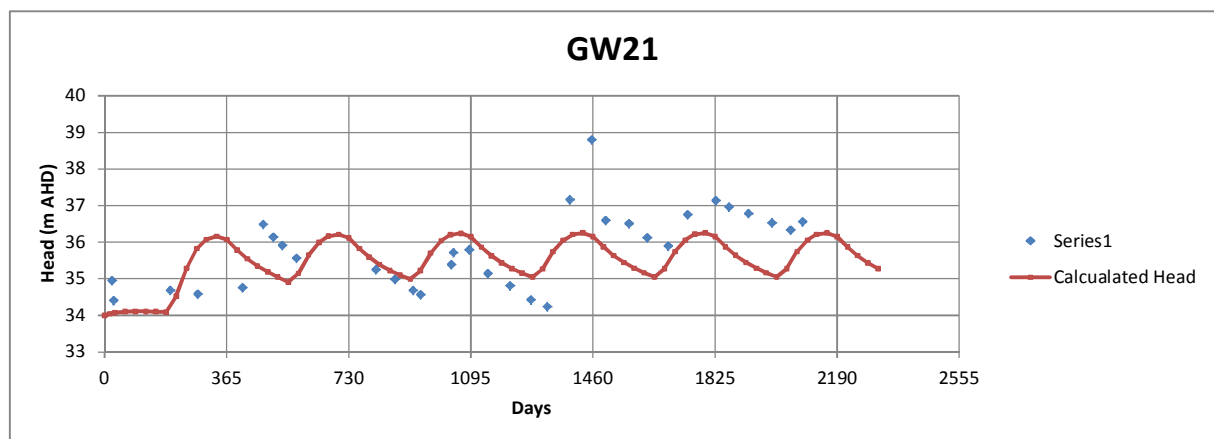
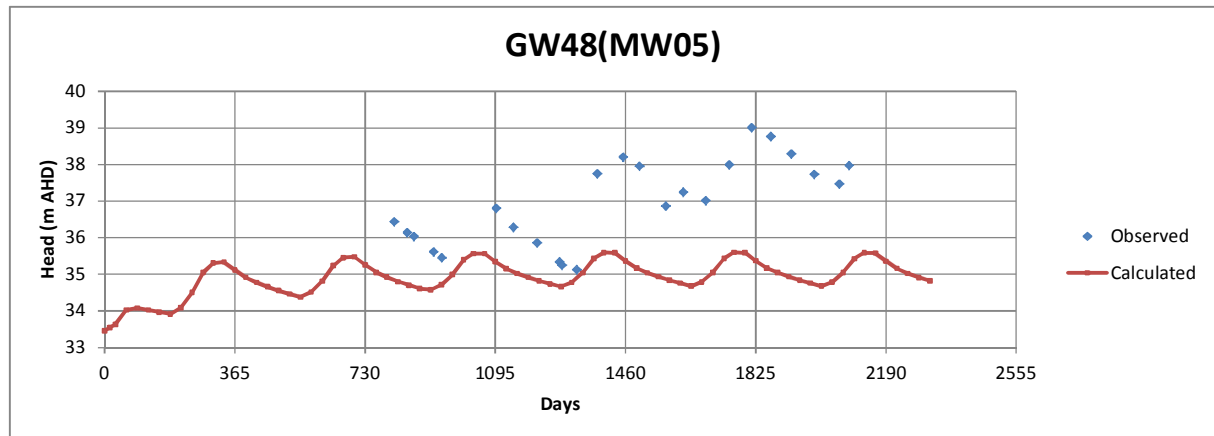
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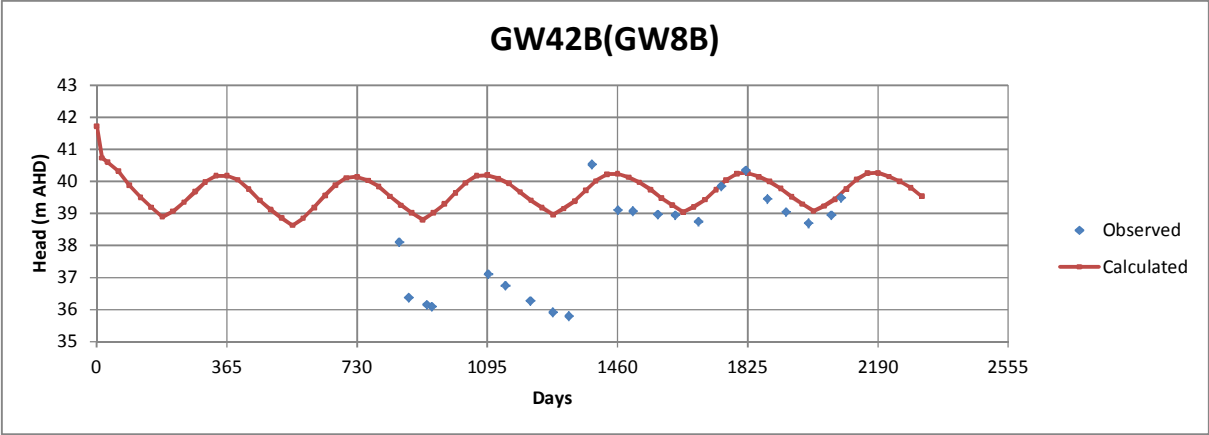


Hydrographs from Weathered Rock (Model Layer 3)



Appendix C

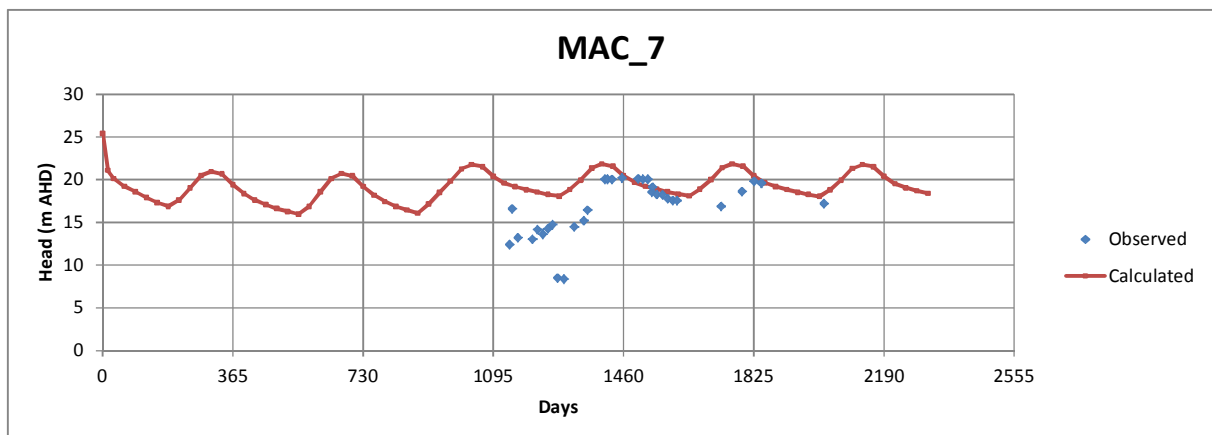
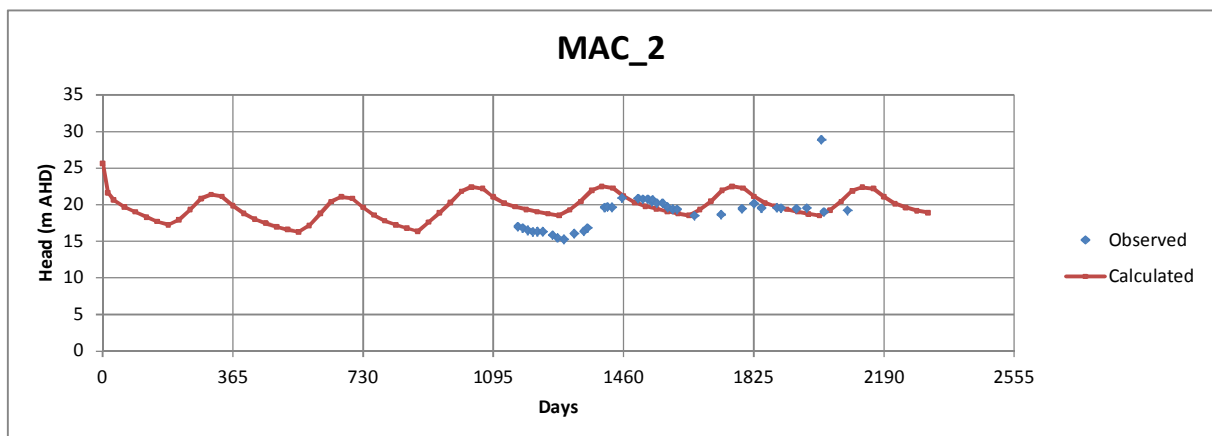
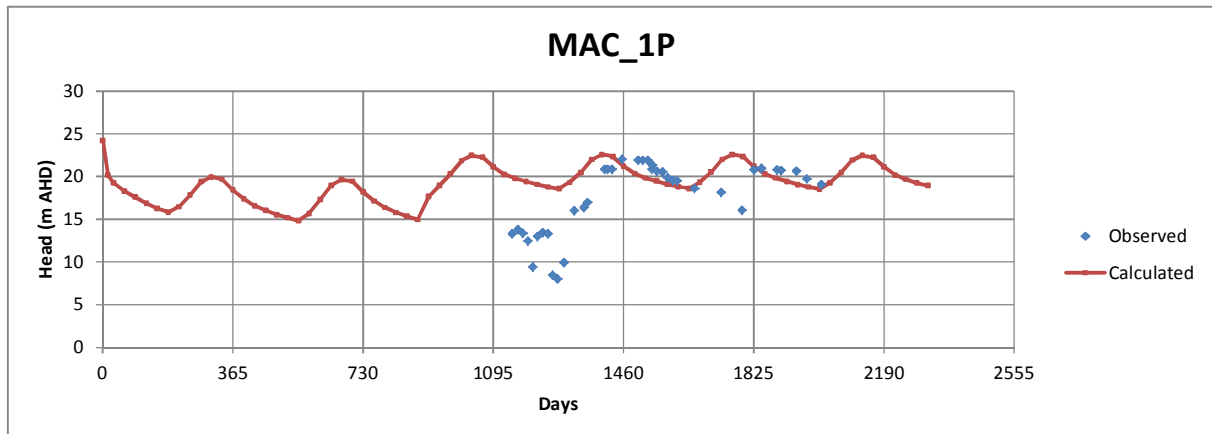




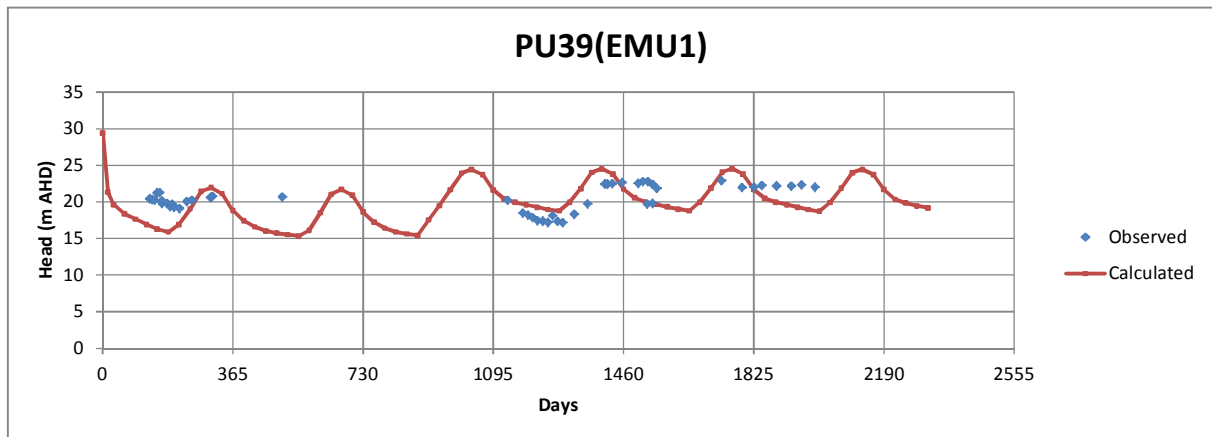
Appendix C

Hydrographs from Bedrock

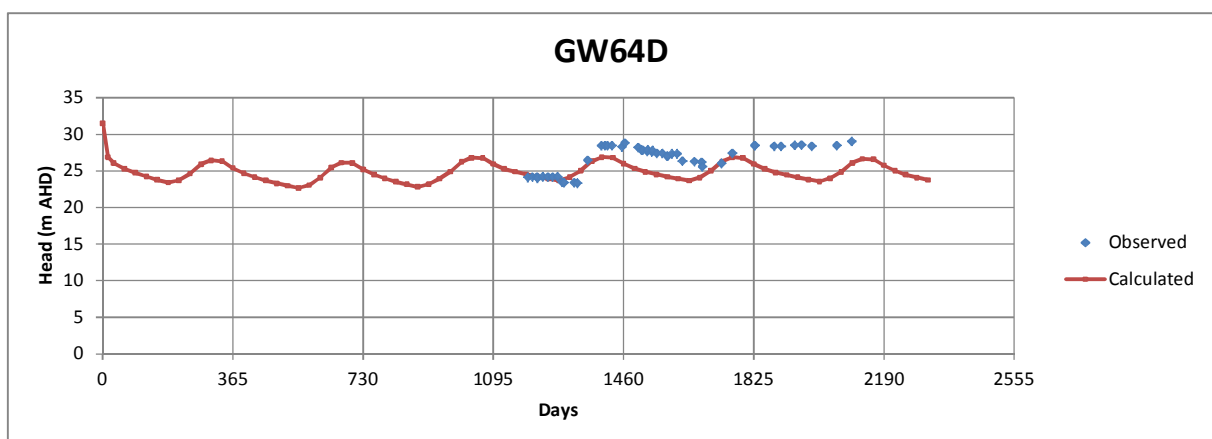
Model Layer 4



Model Layer 5



Model Layer 10



Appendix D Predictive Simulation Results



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MRM PHASE 3 DEVELOPMENT PROJECT EIS - GROUNDWATER

Legend

Groundwater Contour

DRAWDOWN IN PALAEOCHANNEL (LAYER 2) AT END OF 2016 DRY SEASON

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Figure: **D1**

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MRM PHASE 3 DEVELOPMENT PROJECT EIS - GROUNDWATER

Legend

Groundwater Contour

DRAWDOWN IN PALAEOCHANNEL (LAYER 2) AT END OF 2026 DRY SEASON

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Figure: **D2**

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MRM PHASE 3 DEVELOPMENT PROJECT EIS - GROUNDWATER

Legend

Groundwater Contour

DRAWDOWN IN PALAEOCHANNEL (LAYER 2) AT END OF 2036 DRY SEASON

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Date: 15-11-2011

Figure: **D3**

Rev. A A4



Appendix E Model Audit Report (Dr F Kalf, Kalf and Associates Pty Ltd)

Background

Dr Frans Kalf (Kalf and Associates Pty Ltd - KA) was requested to conduct a review and audit of the URS groundwater model by Mr Brett Harwood of METSERVE commencing on the 7 October 2011. The assignment involved discussions with URS staff in the Darwin office, and subsequently led to the same version of the model being run and audited in the Kalf and Associates' office in Sydney. The reason for the audit was to check the model set-up, parameters, boundary conditions and assumptions and determine whether model predictions were reasonable.

This work in collaboration with URS staff was conducted at various stages during the period from early October through to the early weeks of December. The agreement was that any changes suggested by Dr Kalf be agreed to by URS and incorporated into their model for subsequent analysis. However, not all steps that were part of this audit are recorded in this report. Only the key elements and issues are referred to herein.

URS Model Review and Audit

The URS model is as described in this URS report. It is being used primarily for predicting inflow rates into the proposed expanded pit for water balance purposes.

Although there are a number of bore hydrographs available these are confined to shallow depths within the paleochannel. Some of these bores could be considered more reliable than others given the limited time periods available for model comparison. However, it has to be kept in mind also that the method of completion and partial penetration of the screened intervals in an essentially unconfined to semi-unconfined aquifer system will tend to yield variable results in attempting any calibration using these bore water levels and the model generated water levels. Therefore they provide only a poor to reasonable data set to calibrate against.

There are no deep bores that penetrate the dolomite to the final depth of the proposed mine pit and therefore no specific hydraulic parameters are available for these strata, or for the surrounding fault zones. However unlike virgin sites, mining has already been active with an open pit floor at about 70m in depth together with a connected deeper underground ore zone (from the floor of the existing pit) that has already been extensively mined. Inflow estimates are available for both of these mining zones. Thus calibration, while not possible for a deeper set of boreholes, is available at shallow depth from existing boreholes and from inflows recorded from the existing open pit and underground workings.

While not an ideal data set, it does provide data to calibrate against, with the understanding that results will contain an inevitable degree of uncertainty, as do most mine predictions of inflow. Because of unknown surface inflow contribution to the estimated inflows during the Wet it was decided during this audit to calibrate against dry weather pit and underground inflows for which there is a more reliable data set available. This calibration has proved quite reasonable and in agreement with the inflows estimated.

During the audit various changes were made to the model that included the introduction of evapotranspiration; decreasing the dolomite permeability and increasing the specific yield of shallow weathered and alluvial sediments. A check was also made whether the western boundary constant head would affect results, and it was found that its removal did not alter the results appreciably. Increasing the vertical permeability of the river bed and diversion also yielded unacceptable results. In addition several utility programs developed by KA for assisting with delivering output suitable for extracting mass balance results was also supplied to URS during this period. Modifications to the solution algorithm parameters were also made to reduce model run times.

Additional results were generated by the URS modeler and these have been found to be satisfactory. Suggestions and corrections to the modelling report have also been provided.

Appendix E

Conclusion

The model as it currently stands is considered the best that can be achieved given the data set available. Clearly results have a degree of uncertainty attached to them, particularly given the quite variable dolomite permeability distribution, and it will be necessary in time to review and compare inflows with those obtained in the pit and those predicted. If the inflow range during a given year, during the early stages of mining, differ substantially from those predicted the model should be reviewed and updated as necessary.

Additional hydraulically tested monitoring bores at medium and deeper depths and multi-piezometers adjacent to the diversion channel for monitoring heads during the wet and dry periods should be included in any future drilling programme including hydraulic testing of the fault zones.



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