

## 11.0 Groundwater

URS was commissioned to undertake an investigation of the groundwater impacts of the proposed open cut project at McArthur River Mine. The investigation included the drilling of two production bores and five groundwater monitoring bores during October and November 2004. The data obtained from this investigation, together with data from the network of groundwater production and monitoring bores installed since 1995, were used to develop a conceptual groundwater model for the site. This model has been used to describe the behaviour of groundwater aquifers at the site and to predict the potential groundwater impacts due to the proposed open cut mining.

Full details of the groundwater investigation undertaken for the EIS are given in Appendix C. This section summarises the results of that investigation.

### 11.1 Geology and Structure

#### 11.1.1 McArthur River Basin

The McArthur Basin comprises Carpentarian and Adelaidean rocks extending from the Alligator River in the Northern Territory to the Queensland border and includes a large part of Arnhem Land and the Gulf of Carpentaria drainage region.

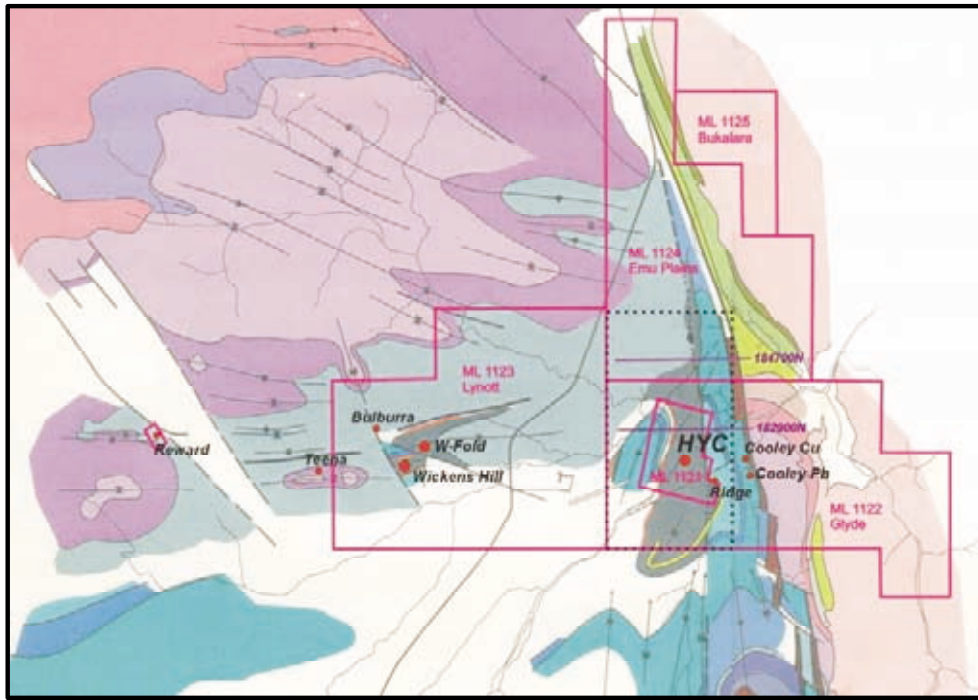
The dominant relief is low escarpments, plateaux and ridges. Limestone and dolomitic rocks of Palaeozoic age or older occur in the western part of the McArthur River catchment upstream of the project site. Sandstone and conglomeratic rocks occur in the eastern sub-catchments, including the Kilgour and Glyde Rivers (Figure 10.1).

#### 11.1.2 Open Cut Area

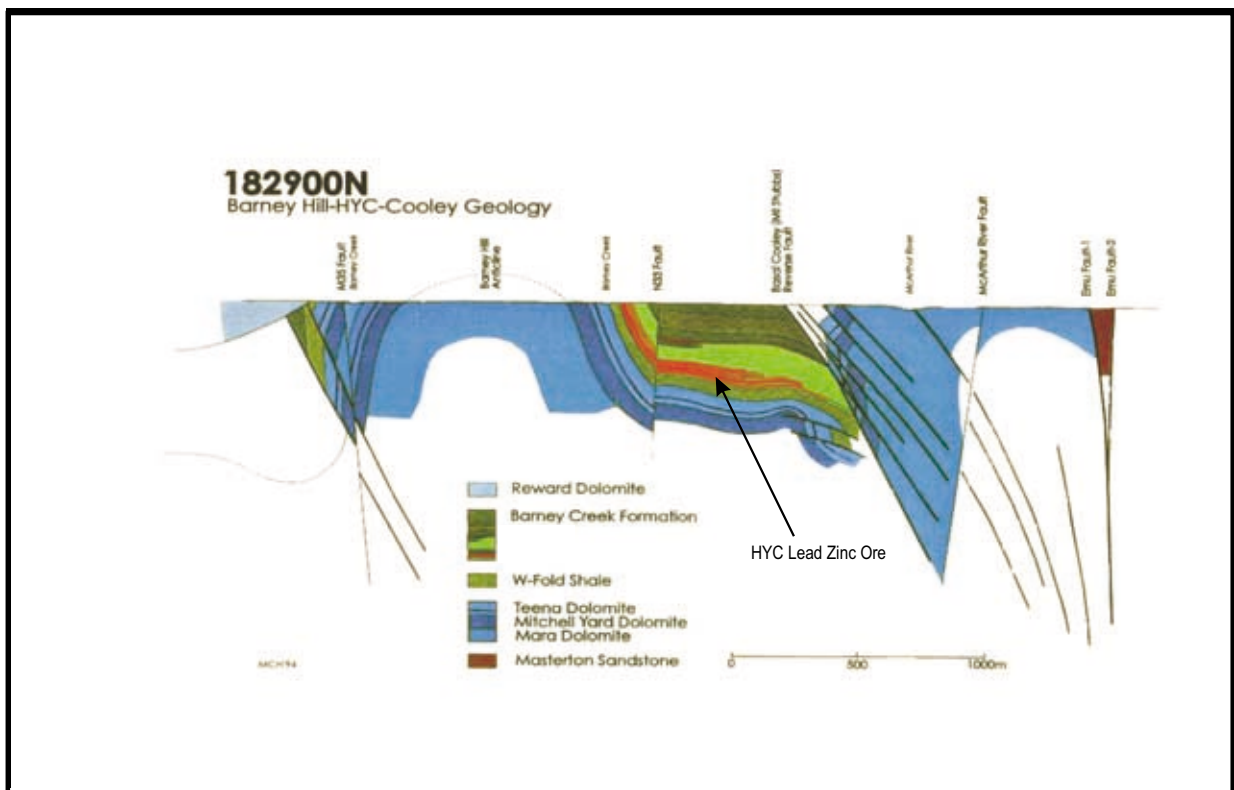
The sediment-hosted stratiform HYC deposit (Figure 11.1) has similarities with ore bodies at Mount Isa and Hilton in Queensland. It is about 1.5 km long and 1 km wide with an average thickness of 55 m.

The HYC deposit occurs near the base of the HYC pyritic shale member, within the Middle Proterozoic McArthur Group (Figure 11.1). The member comprises a sequence of inter-bedded pyritic bituminous dolomitic siltstones, sedimentary breccias and volcanic tuffs.

The HYC deposit has been folded and eroded along its western margin, which is covered with about 30 m of alluvium and soil. The western margin contains the Hinge ore zone, which is sub-vertical with a strike length of 1 km and vertical height of 200 m. The northern margins inter-finger with sedimentary breccias and the southern margin grades into thinned nodular barren pyritic siltstone. On the eastern margin, the ore body thickens and is folded to form the Fold Zone, which has a strike length of at least 600 m. The south-eastern corner is down faulted by about 110 m along the north-easterly trending Woyzbun Fault.





McARTHUR RIVER GEOLOGY - PLAN VIEW



McARTHUR RIVER GEOLOGY - SECTION VIEW

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 	<b>McARTHUR RIVER MINE OPEN CUT PROJECT ENVIRONMENTAL IMPACT STATEMENT</b>		<b>McARTHUR RIVER MINE GEOLOGY</b>	
	Drawn: VH Job No.: <b>42625552</b>	Approved: CMP File No. 42625552-g-063.cdr	Date: 15-02-05	Figure: <b>11.1</b>

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## 11.2 Groundwater Geology and Aquifer Occurrence

Aquifers in the mining area occur as a result of both intergranular and secondary permeability. There are two main aquifer types as follows:

- Alluvium – sand and gravel deposits in the major river channels and associated palaeochannels.
- Bedrock – secondary structures (such as faults, shear zones and joints) in the upper weathered bedrock and the lower fresh bedrock.

These aquifers are unconfined and are in hydraulic connection where large-scale permeable structures in the bedrock, such as faults, underlie major river channels.

### 11.2.1 Alluvium

Extensive aquifers with intergranular permeability in the mine area are rare and are generally limited to the alluvium that occurs in the drainage channels of the major rivers. However, only the basal few metres of the alluvium contain permeable sand and gravel deposits. The majority of the upper sediments are generally a heterogeneous mixture of silt, sand and gravel with only a moderate permeability.

The alluvium within the vicinity of the proposed open pit occurs predominantly in the McArthur River channel and associated floodplain. The alluvium consists of mainly a low permeability (2 m/day) mixture of silts, clays, and fine-grained sands. However, a higher permeability (50 m/day) basal section of coarse-grained sands, gravels and cobbles/boulders occur along the deepest portion of the channel.

The deepest part of the alluvium is offset to the east of the present day McArthur River channel and is represented by a palaeochannel of the former river location (Figure 11.2). The base of this palaeochannel is up to 34 m below ground surface (RL 5 m) and this represents the thickest known occurrence of the alluvium in the immediate mine area.

The palaeochannel is approximately 800 m wide across the southern perimeter of the proposed mine pit and could represent a significant source of groundwater inflow to the pit where it intersects the pit walls.

### 11.2.2 Weathered and Partially 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 has a low to moderate permeability.

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

Generally the base of weathered bedrock ranges between RL 5 m and RL 22 m (URS, 2003). The deepest zones of weathering are between RL 6 m and RL 8 m.



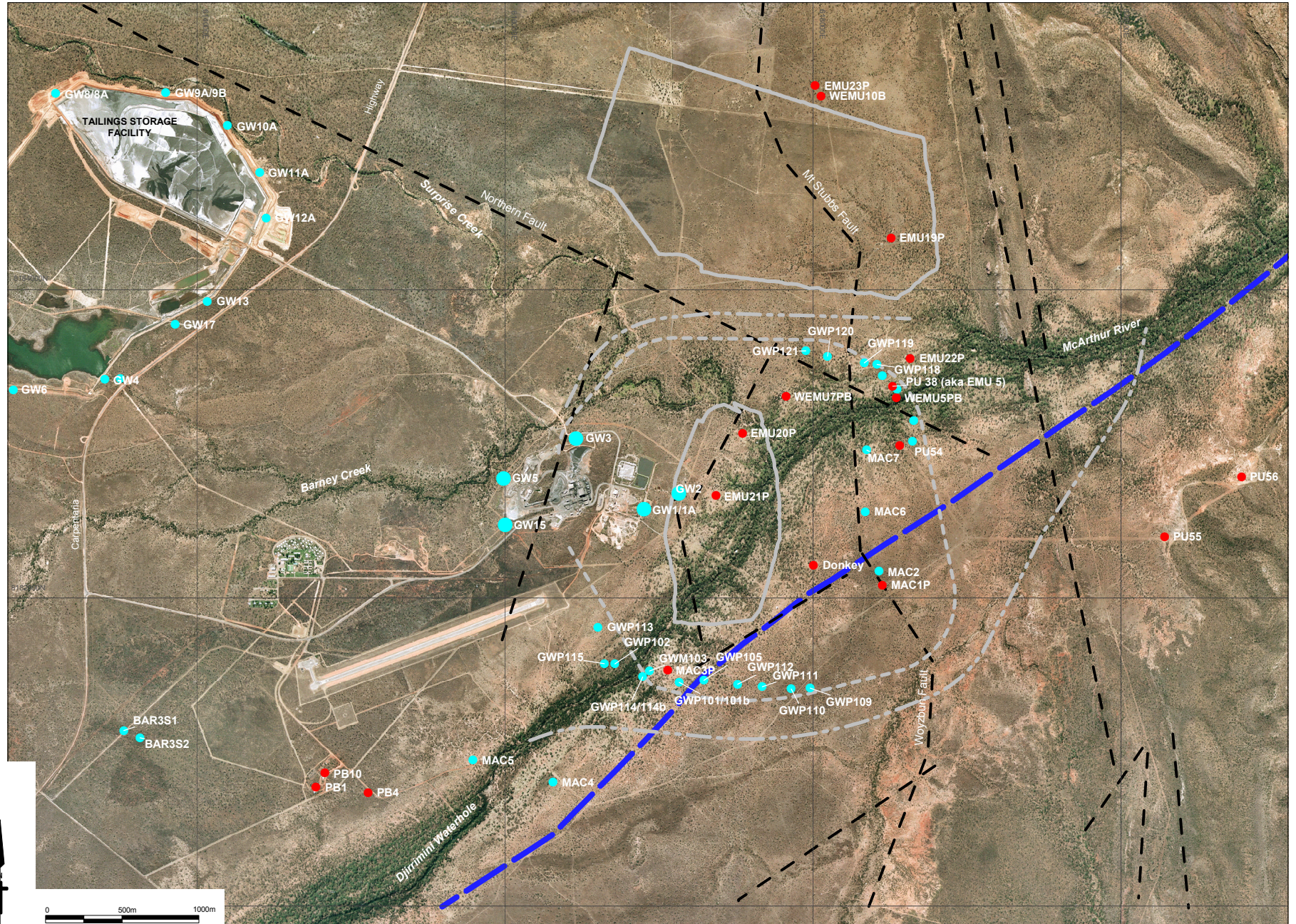
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 Approved: CMP  
 File No.: 42625552-g-059b wor  
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GROUNDWATER PRODUCTION  
 AND MONITORING BORES

Figure: 11.2

Rev: B  
 A4



0 500m 1000m  
 Scale 1:35 000 (A4)

Horizontal Datum: AGD84, Zone 53  
 Date of Aerial Photography, 2001

- Groundwater Production Bore
- Groundwater Monitoring Bore
- Realignment Channel
- Flood Levee
- Faults
- Paleochannel

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During heavy precipitation events, the main decline for the existing underground mine (approx 100 m from the portal) discharges water at a rate of 2,420 kL/day. This implies that permeable sections of the bedrock at shallow depths have a good connection with the overlying weathered bedrock.

### 11.2.3 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 (RL -270 m). These structures were predominantly in dolomite, located near the Mt Stubbs Fault north of the pit. In addition, production bore EMU 5 intersects vuggy dolomite at a depth of 65 m (about RL -35 m) and produced a yield of 864 kL/day. Similarly the recently constructed test production bore (MCA1P) yielded about 432 kL/day from vuggy dolomite along this fault trace.

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 and therefore transmit only minor amounts of groundwater. From the core viewed, these structures were apparent between depths of 10 m and 240 m (RL 20 m and RL -210 m). Open joints were most predominant above a depth of 100 m (RL -70 m).

### 11.2.4 Further Field Investigations

Based on the current information available, the exact location of the palaeochannel is not known within the area of the proposed open cut. While the general location of the channel is known, its thickness, width and location in relation to the proposed open cut has not yet been confirmed. As palaeochannels tend to meander, there is a possibility that it may intersect a larger, or smaller, proportion of the pit wall than is currently anticipated. Any change to the proportion of the palaeochannel aquifer intersecting the pit wall will influence the amount of groundwater that could flow into the open cut.

To provide greater accuracy to the modelling of groundwater inflow into the open cut, further hydrogeological drilling is being undertaken. Work commenced in the second half of July 2005 and will be completed by the end of August. The drilling program will include three drilling transects perpendicular to the river and one parallel to it, all within the area of the proposed open cut. It is proposed that one aquifer test production bore be installed and an aquifer test be completed to verify the permeability of palaeochannel aquifer. A monitoring bore will also be installed to assess the overlying alluvial aquifer.

An additional drilling transect is also being undertaken at Djirrinmini Waterhole which is a significant waterhole in the McArthur River approximately 1 km upstream of the beginning of the proposed river realignment. The purpose of this investigation is to confirm aquifer characteristics in the area.

The hydrogeological modelling undertaken to date (Section 11.8) and reported in this EIS has been based on the existing understanding of aquifer conditions as discussed above. Should the results of the drilling program indicate that there are areas where the accuracy of the assumed model can be improved, further modelling will be undertaken using the updated aquifer parameters.

### 11.3 Groundwater Inflows into the Underground Mine

The underground mine water balance indicates that the primary groundwater inflows to the underground mine are relatively small (2,420 kL/day or 28 L/sec). The sources of this measured inflow comprise the following faults and structures.

- Hinge Zone (bedrock aquifer) – 864 kL/day (10 L/sec)
- Eastern Vent Rise (alluvium aquifer) – 605 kL/day (7 L/sec)
- Northern Fault (bedrock aquifer)– 605 kL/day (7 L/sec)
- Other sources including joints and combined seepages – 346 kL/day (4 L/sec)

Mine groundwater inflows vary with rainfall events, however measurements of outflows from the mine are sporadic and no seasonal variations in flow have yet been established.

### 11.4 Groundwater Bores

#### 11.4.1 Production Bores

Groundwater has formed an important component of the mine process water supply, especially during the dry season. Since 1995, the following production borefields (Figure 11.2) have been established:

- Emu Borefield – north-east of mine site, commenced pumping June 1997, pumped for 6 months in 1997, and from January 2002 to January 2003: 7 production bores.
- Mimex Borefield - south of airstrip, commenced pumping June 1997, pumped for 6 months in 1997, and from January 2002 to present: 3 production bores.
- Donkey Borefield - east of mine site, near Glyde River, commenced pumping September 2002, pumped from September 2002 to present: 4 production bores.

#### 11.4.2 Monitoring Bores

In addition to the production bores, a network of groundwater monitoring bores has been established to monitor the impacts of the current mining operations on the groundwater resources of the area. Monitoring bores in a regional network are located both to the west and east of the mine area. A local monitoring network of bores is located in the plant area and around the tailings storage facility. The locations of these bores (GW1 – GW17) are shown on Figure 11.2.

### 11.4.3 2004 Drilling Program

During October and November 2004, two test production bores and five monitoring bores were installed.

The two production bores were MAC1P and MAC3P. MAC1P was 120 m deep in the dolomitic bedrock and yielded flows varying from 85 kL/day to 864 kL/day with a surge of up to 1,730 kL/day. MAC3P was 31.5 m deep in the alluvium and yielded 170 kL/day.

The five monitoring bores varied in depth from 18 m to 120 m.

The locations of these bores are given in Figure 11.2. Details of the drilling program, testing, and aquifer transmissivity and storativity characteristics are given in Appendix C.

## 11.5 Groundwater Levels and Flow

Groundwater levels across the mine site for the end of the dry season (August 2002) and wet season (March 2003) conditions are presented in Figures 11.3 and 11.4. In both cases, there is an easterly flow of groundwater from high elevations around the tailings dam (up to RL 42 m) to lower elevations near the McArthur River (down to RL 20 m). Based on groundwater elevations in the vicinity of the Donkey Borefield (PU55 and PU56), there is also groundwater flow into the McArthur River from the south-east. In general, regional groundwater flow in the mining area is easterly into the low topographic areas associated with the major river channels.

Superimposed on this regional pattern is a drawdown cone associated with abstraction from the bore EMU 5, where groundwater levels are depressed to an elevation of about RL 17 m, associated with groundwater abstraction from this production bore. There is no obvious drawdown pattern associated with groundwater abstraction from the existing underground mine.

Wet season groundwater levels are 5 to 6 m higher than dry season groundwater levels suggesting this is about the magnitude of seasonal groundwater level fluctuations.

## 11.6 Groundwater Chemistry

MRM routinely completes a monthly sampling program in the local groundwater monitoring bores around the plant site and the tailings storage facility (TSF). In addition, a recent program of groundwater sampling in monitoring bores near the proposed open pit and water supply production bores has been completed.

A summary of the monitoring results is given in Table 11.1.

The following discussion on groundwater chemistry is based on the results of all sampling programs and the associated analyses.



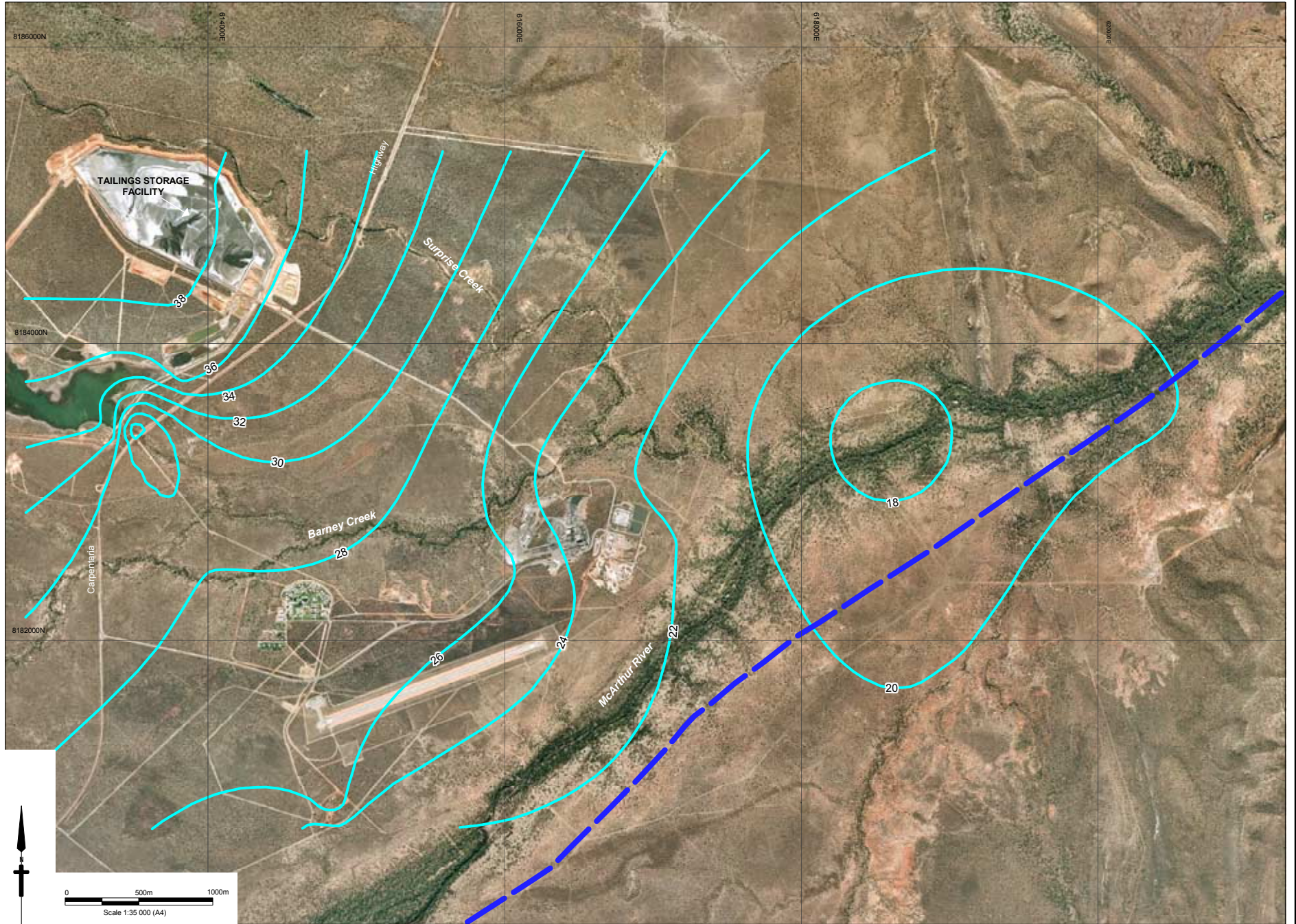
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 Job No: 42625552  
 Approved: CMP  
 File No: 42625552-g-064.wor  
 Date: 22-02-05

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Figure: 11.3

GROUNDWATER LEVELS  
 AUGUST 2002 (DRY SEASON)

Rev: A  
 A4



0 500m 1000m  
 Scale 1:35 000 (A4)

Horizontal Datum: AGD84, Zone 53  
 Date of Aerial Photography, 2001

— 20 — Groundwater Contour (mRL)      - - - - - Paeiochannel



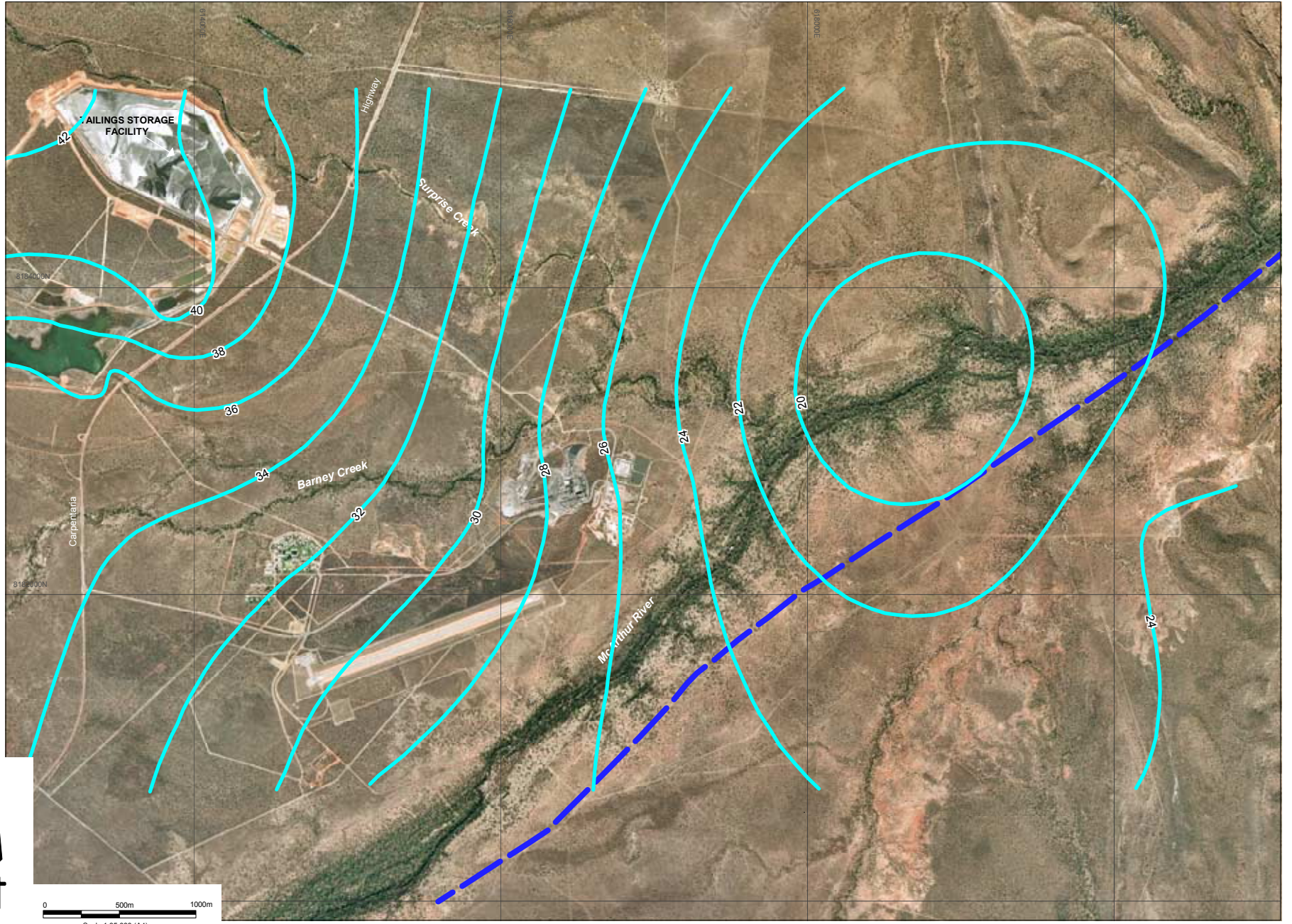
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Job No: 42625552 | File No: 42625552-g-065.wor

GROUNDWATER LEVELS  
MARCH 2003 (WET SEASON)

Figure: 11.4

Rev: A  
A4



0 500m 1000m  
Scale 1:35 000 (A4)

Horizontal Datum: AGD84, Zone 53  
Date of Aerial Photography, 2001

— 20 — Groundwater Contour (mRL)      - - - - - Paleochannel

**Table 11.1**  
**Summary of Monitoring Results**

Analysis	Unit	Alluvium (MAC1P)	Alluvium (MAC3P)	Alluvium (DONKEY)	Alluvium (EMU5)	Alluvium?/ Bedrock (Eastern Vent Rise)	Underground - Bedrock (4J1)	Underground - Bedrock (2KN/6)	Shallow Bedrock (GW1A)	Shallow Bedrock (GW2)
Date			21/11/2004	17/04/2003	23/04/2003	17/04/2003	17/04/2003	17/04/2003	17/04/2003	17/04/2003
pH		7.1	7.1	-	-	-	-	-	-	-
Conductivity $\mu\text{S/cm}$	$\mu\text{S/cm}$	2030	1220	-	-	-	-	-	-	-
TDS	mg/L	1130	720	-	-	-	-	-	-	-
Calcium (Filtered)	mg/L	138	102	19.9	24.9	26.2	122	108	195	216
Magnesium (Filtered)	mg/L	146	91.5	23.7	15.5	134	102	108	156	178
Sodium (Filtered)	mg/L	63.8	34.5	24.2	7.7	84.2	101	117	153	158
Potassium (Filtered)	mg/L	10.3	9.5	4.7	7.5	12.6	10.7	13.9	7.3	9.5
Sulphate (Filtered)	mg/L	80	86.4	85.8	0.1	217	262	254	622	888
Chloride	mg/L	382	72.9	23.9	10.4	163	126	173	175	73.8
Fluoride (Filtered)	mg/L	-	-	0.1	-	0.4	0.5	0.6	0.7	0.5
Nitrite	mg/L	<0.005	<0.005	0.01	-	<0.005	<0.005	<0.005	<0.005	0.01
Nitrate	mg/L	0.215	0.305	1.3	0.02	3.76	0.025	0.055	1.15	0.03
Manganese (Filtered)	mg/L	15.3	597	-	-	-	-	-	-	-
Carbonate	mg/L	-	-	<1	-	<1	<1	<1	<1	<1
Bicarbonate	mg/L	535	533	48	-	260	392	443	418	462
Hardness	mg/L	946	632	-	-	-	-	-	-	-
Arsenic (Filtered)	$\mu\text{g/L}$	-	-	2.95	-	18.5	65	40	4.7	6.25
Barium (Filtered)	$\mu\text{g/L}$	-	-	62	-	30	38	36	58	104
Cadmium (Filtered)	$\mu\text{g/L}$	0.06	0.06	2.6	-	4.72	1.8	0.28	0.08	<0.04
Cadmium (Total)	$\mu\text{g/L}$	0.1	0.1	-	0.02	-	-	-	-	-
Copper (Filtered)	$\mu\text{g/L}$	2.15	0.68	9.4	-	3.1	3.65	2.95	3.08	2.78
Copper (Total)	$\mu\text{g/L}$	6.26	2.77	-	0.37	-	-	-	-	-
Iron (Filtered)	$\mu\text{g/L}$	-	-	100	2.55	<40	200	<40	100	100
Lead (Filtered)	$\mu\text{g/L}$	2.48	10.4	32.2	-	160	15.7	2.25	0.47	0.34
Lead (Total)	$\mu\text{g/L}$	13	15.4	-	0.37	-	-	-	-	-
Silver (Filtered)	$\mu\text{g/L}$	-	-	<0.05	-	<0.1	<0.1	<0.1	<0.1	<0.1
Thallium (Filtered)	$\mu\text{g/L}$	-	-	1.3	0.02	12.6	3.96	1.02	0.22	0.02
Zinc (Filtered)	$\mu\text{g/L}$	151	105	888	-	308	546	82.6	30.9	3.1
Zinc (Total)	$\mu\text{g/L}$	181	139	-	20.6	-	-	-	-	-

### 11.6.1 Mining Area

The groundwater in the upper weathered rock profile in the mining area is relatively saline with total dissolved solids (TDS) contents of 2,000 to 4,000 mg/L with a neutral pH. This groundwater has a high hardness (derived from carbonate bedrock such as dolomite) and is a (Na-Ca-Mg)-Cl type with significant concentrations of  $\text{HCO}_3$  and  $\text{SO}_4$ . The large concentrations of  $\text{SO}_4$  are probably derived from the bedrock because of the common occurrence of sulphide minerals in the area.

Groundwater from the underground mine and vent raise is significantly fresher than the weathered rock aquifer, having TDS contents ranging from 700 to 1,100 mg/L. This may be the result of dilution by both runoff down the decline and from infiltrating rainfall recharge into the weathered zone moving down the vent raise and into the underground mine. As for the weathered zone groundwater in the mining area, the groundwater being discharged from the underground mine is a (Na-Ca-Mg)-Cl type with significant concentrations of  $\text{HCO}_3$  and  $\text{SO}_4$ .

Groundwater in the alluvium is generally of better quality than the bedrock/weathered zone groundwater. With a TDS content less than 1,000 mg/L, the alluvial groundwater can be classified as fresh to brackish and generally has a neutral pH. As with the bedrock, alluvial groundwater is hard and sodium, chloride and sulphate are the dominant ions. The largest amount of the groundwater in the alluvium is derived from infiltrating surface runoff associated with wet season flows in surface drainages.

In both the bedrock and alluvial groundwaters, lead and zinc are elevated and these metals are probably derived from sulphides in the bedrock.

### 11.6.2 Tailings Storage Facility Area

Based on monitoring results since 1995, the groundwater (mainly in shallow weathered bedrock) around and under the TSF is hard and is a (Na-Mg-Ca)-(SO<sub>4</sub>-Cl) type with a TDS content of 2,000 to 3,000 mg/L. Groundwater quality in other monitoring bores around the TSF is similar although the combination of cations and anions varies and the TDS content shows a considerable variation. Since 1995, EC and SO<sub>4</sub> content have both increased.

### 11.6.3 Borefields

The groundwater from the Emu borefield is of good quality with TDS in the range 300 to 500 mg/L and is derived from permeable shallow (< 100 m) bedrock. The groundwater is hard and is a (Ca-Mg)  $\text{HCO}_3$  type with only minor Na and Cl. Most groundwater pumped from these bores is derived from the Emu Fault in vuggy permeable sections of the dolomitic bedrock. The low TDS content of this groundwater suggests that rapid recharge of infiltrating rainfall occurs into permeable zones within the Emu Fault and surrounding bedrock, especially in areas where such structures underlie major drainage channels.

The groundwater from Donkey Bore is a (Na-Ca-Mg) (Cl- $\text{HCO}_3$ ) type with significant SO<sub>4</sub> content. This chemistry is a result of sulphide minerals present in the rocks in the area of the proposed open pit where the bore is located.

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## 11.7 Stream Flows

An assessment has been undertaken on the groundwater/surface water relationship of the pools and channel flow within the McArthur River in the areas upstream and downstream of the mine site. Anecdotal evidence is that seepage from aquifers upstream supports the river pools during the dry season (typically May to October). To verify this, a stream gauging study was undertaken to measure stream flows in June 2005 to characterise stream flows arising from groundwater and the dependence of river pools near the mine on groundwater inflows during the dry season. Details of the study are given in Appendix C.

Work involved measuring stream flow and water quality (electrical conductivity and pH) at 11 sites along a 14 km length of the McArthur River, extending from 6 km upstream of Djirrimini Waterhole to approximately 4 km downstream of the proposed open cut just above the confluence with the Glyde River. The upstream reach included Djirrimini Waterhole and, at the time of sampling, there was another pool upstream of that. The two pools were separated by a dry stretch of river.

A simple water balance for each river reach between the sampling sites was used to account for evaporation losses and groundwater inflows. Evaporation losses were calculated by multiplying the evaporation rate by the water surface area. Groundwater inflow/outflow in the reach was then calculated by adding the evaporation loss to the change in measured stream flow between the top and bottom of each reach.

The water balance showed that groundwater inflow to the river occurs above and below the proposed open cut area but there was little net inflow or outflow through the open cut area itself. However, there is a reach with net outflow to groundwater just inside the western edge of the open cut area. The remainder of the river through the open cut area has no or little net groundwater inflow or outflow. Groundwater inflow increases downstream of the open cut area. Accordingly, loss of this section of the river to the open cut is likely to have little impact on dry season stream flows immediately downstream of the pit.

Observations of stream flow and salinity show that the pools upstream of the open cut area are fed by groundwater to varying degrees. Generally, groundwater inflows were greater than evaporation (between 2.3 and 4.9 L/s) and probably in the order of 10 L/s.

The pond upstream of Djirrimini Waterhole had a high electrical conductivity (2,660  $\mu\text{S}/\text{cm}$ ) suggesting that groundwater inflow was less than evaporation. Salinity was about 6 times the salinity at nearby sections, indicating considerable concentration since the end of the previous wet season.

Between that pond and Djirrimini Waterhole the stream bed was dry but the groundwater level in the dry bed was close to the surface. This groundwater is likely to flow from the upstream pond into Djirrimini Waterhole.

In Djirrimini Waterhole there was likely to be enough groundwater inflow (in June) to maintain water levels and there appeared to be enough outflow to minimise salt build up as a result of evaporation. The electrical conductivity in the waterhole varied from 737 to 837  $\mu\text{S}/\text{cm}$  and the outflow measured at the downstream end was 8.6 L/sec.

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## 11.8 Groundwater Models

To assess the potential impacts of the open cut mine on the groundwater system, a numerical model has been developed. Initially a conceptual model was developed based on interpreted geology and this was then used to develop a quantitative groundwater flow model. Details of the model development are given in Appendix C.

### 11.8.1 Conceptual Model

The conceptual hydrogeological model of the area is complex and comprises the following features:

- The general groundwater flow direction is towards the south-east, from the higher topography near the TSF into the lower topography associated with major river drainages on the eastern and southern sides of the mining area.
- Groundwater levels are generally shallow and are within 15 m of ground surface.
- Surface runoff in the McArthur River channel is assumed to be in direct hydraulic connection with groundwater in the underlying alluvium and major permeable structures in the bedrock.
- Away from the river channel, the surficial cover is generally thin and does not contain significant aquifer zones.
- A previous river bed (palaeochannel) runs parallel to and south of the existing McArthur River location (Figure 11.2). Here the alluvium is 3 to 34 m thick with a very permeable basal sand and gravel layer.
- The bedrock in the mining area comprises steeply-dipping Barney Creek Formation (shale, breccia, lead-zinc orebody) and dolomite. These rocks have little intergranular permeability and are only permeable locally where faults, shear zones or fractures occur. In general, the permeability of the bedrock is enhanced in the weathered zone.
- The site is dominated by north and north-west trending faults. These structures cause the bedrock to be more permeable along than across strike, thus creating horizontal permeability anisotropy. This anisotropy will generally redirect groundwater flow along the least resistant flow path and this results in preferential flow along the strike in these structures.
- Seepage from the TSF is small and generally occurs through small permeable structures in the weathered bedrock.

### 11.8.2 Groundwater Flow Model

The model used was MODFLOW which is a three dimensional block-centred finite difference model commonly used to simulate groundwater flow in the saturated subsurface. The model was built on the basis of the conceptual model described above. Details of the model are given in Appendix C.

The model was calibrated to ensure that it could reproduce measured groundwater levels and flows, both regionally and during aquifer tests, i.e. the model can reasonably represent the conceptual hydrogeological model of the deposit and environs. Both a steady state and transient calibration was undertaken and the results demonstrated an acceptable correlation of modelled versus measured conditions.

Table 11.2 summarises the hydraulic parameters derived from the calibrated model that broadly correspond with the values derived from the aquifer tests.

**Table 11.2**  
**Hydraulic Parameters Derived from the Calibrated Model**

Descriptions	Hydraulic Conductivity (Permeability)			Specific Storage (m <sup>-1</sup> )	Specific Yield
	Kx <sup>1</sup> (m/d)	Ky <sup>1</sup> (m/d)	Kz <sup>1</sup> (m/d)		
Palaeochannel Clay	1.00E-04	1.00E-04	1.00E-05	1.00E-06	0.001
Alluvial Sand/Silt/Clay	2.0	2.0	0.5	1.00E-04	0.05
Palaeochannel Sand/Gravel	50	50	10	1.00E-04	0.10
Fresh Bedrock (Dolomite)	0.0001	0.0001	0.0001	5.00E-06	1.00E-03
Fresh Bedrock (Sandstone)	0.0001	0.0001	0.0001	5.00E-06	1.00E-03
North-South Bedrock Faults	2.0	2.0	0.1	5.00E-04	0.10
Weathered Bedrock (Teena Dolomite)	1.5	1.5	0.5	1.00E-05	5.00E-03
Weathered Bedrock	0.10	0.10	0.10	3.00E-04	5.00E-03
East-West Bedrock Faults	2.0	2.0	0.1	5.00E-04	0.10

<sup>1</sup> Kx and Ky show horizontal permeability, Kz shows vertical permeability

The model assumed groundwater recharge occurred from both direct rainfall and river flows. Rainfall recharge was assumed to be at a rate of 10 or 20 mm/year depending on surface geology. River recharge rates also varied with geological conditions with a conductance equal to the vertical permeability of the river bed materials. A good hydraulic connection between surface water and groundwater in major drainages was assumed.

The model has some limitations due to the generalisations, interpretations and assumptions made in simulating the hydrogeology. These limitations include:

- The model is a fully saturated groundwater flow model code, which can lead to an overestimation of the dewatered areas.
- The use of the vertical permeability of the nearest rock unit for the drain conductance was arbitrarily selected to allow ease of flow into the pit.

- The area is largely underlain by a fractured rock environment where the only major aquifers in the bedrock are secondary structures such as faults and karst development in the weathered zones of dolomites.
- There are large tracts of saturated alluvium along the current McArthur River valley in hydraulic connection with stream flow. A palaeochannel of the river also occurs in the valley. The geometry and extent of these alluvial deposits is not well known.

## 11.9 Predicted Pit Dewatering Requirements

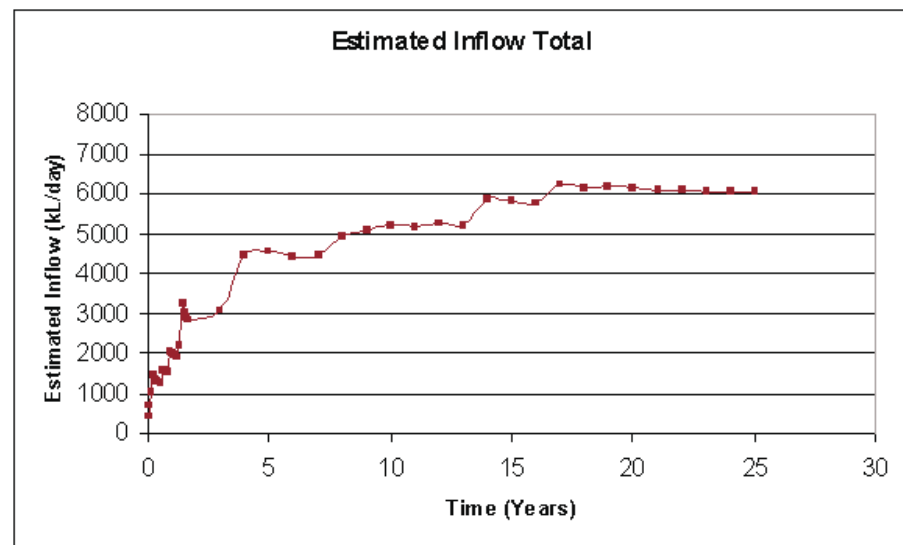
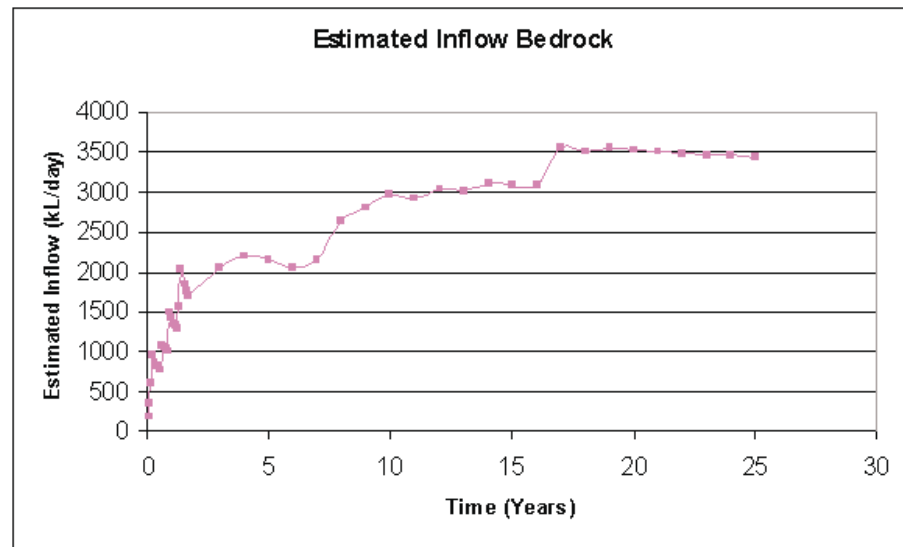
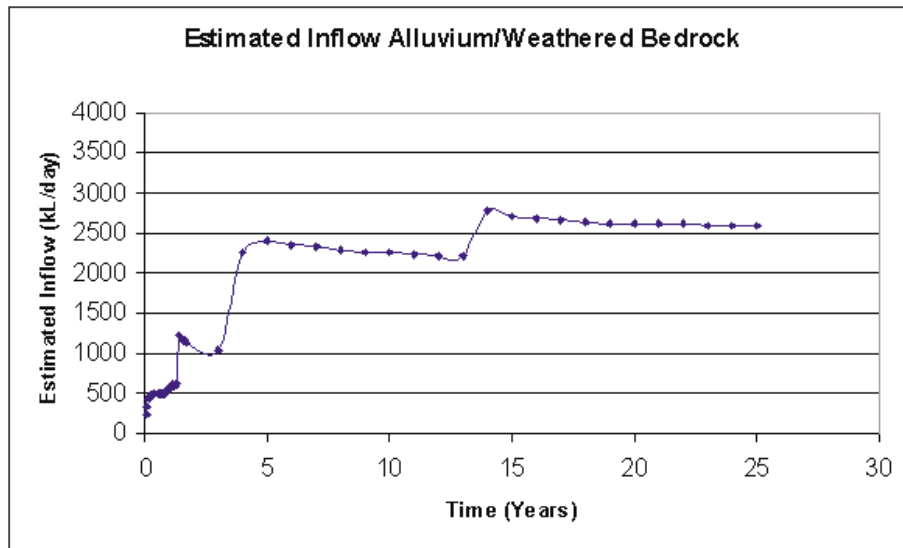
### 11.9.1 Pit Dewatering Rates

To ensure dry working conditions in the open pit, it will be necessary to install a network of interception bores around the pit to remove groundwater that would otherwise flow into the pit threatening the stability of the pit walls and hampering mining operations.

The groundwater model has been used to estimate the extent of the mine dewatering requirements. The proposed pit excavation schedule of 5 stages over the 25 year mine life (Section 4.2.2) has been included in the model to simulate development of the open pit and groundwater abstraction from the dewatering system.

The rate of groundwater abstraction has been estimated from the alluvium and associated palaeochannel, weathered bedrock and bedrock. Figure 11.5 shows the predicted abstraction rates for up to 25 years. The estimated total rate is low in the first 6 months of mining at 1,270 kL/day, increasing to 1,990 kL/day after 1 year. After year 4 of mining as the depth of the pit increases, estimated rate increases to 4,450 kL/day. It progressively increases to about 6,330 kL/day at year 17 and slightly decreases to 6,035 kL/day at year 25. Generally the necessary abstraction rates from the alluvium and weathered bedrock are smaller than from the bedrock. At year 17 when the rate of groundwater abstraction is at a maximum, abstraction from alluvium and weathered bedrock is about 2,770 kL/day and 3,560 kL/day from bedrock.

As discussed in Section 11.2.1, the palaeochannel is approximately 800 m wide across the southern perimeter of the proposed mine pit and could represent a significant source of groundwater inflow to the pit where it intersects the pit walls. Because of the concern, consideration was given to installing a cut-off trench underneath the flood protection bund on the southern side of the pit where the palaeochannel is intersected. This would have the effect of placing an impermeable barrier between the realigned river channel and the open pit so as to reduce the rate of groundwater inflow. However the modelling undertaken in Appendix C shows that a cut-off trench would not significantly reduce inflows to the pit. The effectiveness of the cut-off trench would be limited by the permeability of the weathered bedrock underneath the palaeochannel and also by the groundwater inflow from the northern area of the pit drawing groundwater from the downstream portion of the palaeochannel. Consequently the option of installing a cut-off trench has not been considered further.



McARTHUR RIVER MINE  
OPEN CUT PROJECT  
ENVIRONMENTAL IMPACT STATEMENT

**ESTIMATED PIT DEWATERING  
REQUIREMENT**

Drawn: VH	Approved: CMP	Date: 04-05-05
Job No.: 42625552	File No. 42625552-g-072.cdr	

Figure: **11.5**

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### 11.9.2 Effects of Flood Events

Modelling of a 1 in 50 year and a 1 in 500 year flood event was undertaken to determine if flooding had any significant effect on dewatering requirements. Recharge plots for both of these events are given in Appendix C.

#### ***1 in 50 Year Event***

The extent and stage height of the 1 in 50 year event was modelled over the extent of the flooded area in 6-hour intervals. After the peak flood event, the flooded area gradually reduces over 30 days back to the original river flow conditions. The flooding scenario assumed that mining and dewatering had been occurring for 6 years (at which time the pit extends considerably into the alluvium) and dewatering continues throughout the flood event.

The model showed a minor increase in groundwater levels (less than 0.5 m) at the dewatering bores between days 5 to 15. Groundwater inflows into the pit showed a delayed response after the initial flood peak (after 4.5 days), with inflows increasing after 5 days within the alluvium and weathered bedrock. Inflows from the alluvium and weathered bedrock increased by about 80 kL/day during this event. Following this, groundwater inflow rates gradually declined up until day 20 when pre-flood conditions were restored.

#### ***1 in 500 Year Event***

The extent and stage height of the 1 in 500 year event was modelled over the extent of the flooded area in 6-hour intervals. After the peak flood event, floodwaters gradually recedes over a 30 day period. The flooding scenario assumed that mining and dewatering had been occurring for 6 years (at which time the pit extends considerably into the alluvium) and dewatering continues throughout the flood event.

The model showed a moderate increase in groundwater levels (up to 6 m) at the dewatering bores between days 5 to 15. Groundwater inflows into the pit showed a delayed response after the initial flood peak with inflows increasing after 3 days within the alluvium and weathered bedrock. Groundwater inflows from the alluvium and weathered bedrock increased by about 550 kL/day during this event.

### 11.9.3 Chemistry of Groundwater from Dewatering Bores

The quality of the groundwater from the dewatering bores cannot be accurately predicted but it will probably be a “blend” of the different bedrock and alluvial groundwaters. It is likely to have the following characteristics:

- be moderately saline with a TDS content of 1,000 to 4,000 mg/L and a neutral pH;
- have a very high hardness (derived from carbonate bedrock such as dolomite);
- be a (Na-Ca-Mg)-Cl type with significant concentrations of HCO<sub>3</sub> and SO<sub>4</sub>; and
- have a significant metal content.

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Water of the above quality is likely to be unsuitable for discharge to the environment. Consequently it will be pumped to the voids in the decommissioned underground mine for subsequent reuse as process water in the concentrator (Section 12.9.1).

## 11.10 Effect of Water Storage in the Underground Mine Voids

As the open cut is developed, various shafts and voids associated with the decommissioned underground mine will be exposed. Rainfall and seepage entering the open cut will flow into the underground voids which will also be used to receive water from the open cut dewatering bores. As discussed in Section 12.9, the underground mine voids will be used to store water as part of the site's overall water management system. Because of this, the volume of water in the underground voids at any given time will fluctuate due to the varying groundwater and surface water inflows, the addition of water from the open cut de-watering system, and the extraction of water for use in the processing plant.

During open-cut mining, the water level in the underground void will be maintained below the active pit floor. Therefore, the underground void will act as a groundwater 'sink' effectively drawing groundwater towards it from the surrounding fresh bedrock aquifer. Groundwater inflows into the current underground workings are small at approximately 2,240 kL/day. Based on an estimated hydraulic gradient of 0.006 m/m for the bedrock aquifer, a groundwater flux (velocity) of 2.2 m/year is likely through the faults. Regionally, through-flow is likely to be lower at approximately 0.4 m/year.

Because of the fluctuating water levels and the consequent exposure of the underground voids to oxygen, there is potential for oxidised sulfides remaining in the walls of the underground voids to generate acid and possibly release elevated concentrations of metals into the in-flowing groundwater. However, water in the underground voids will be pumped to the surface for reuse in the processing plant resulting in groundwater flowing into the voids rather than out from them. Hence the water quality of the bedrock aquifer is not expected to be impacted. If the water pumped from the underground is slightly acidic or metalliferous, it will be treated (at the surface) if necessary prior to reuse.

Once mining ceases, it is proposed to remove part of the flood protection bund surrounding the open cut (Section 20.3.7). Consequently the underground voids will fill relatively quickly (most likely within a year). Once the underground voids are full, the potentially acid forming material in the walls of the underground voids will be submerged, oxidation will cease, acid generation will cease, and metals are less likely to become soluble. Furthermore, should any contamination of underground void water occur, it will be contained within the slow moving (2.2 m/year) fresh bedrock aquifer at depths of greater than 200 m. Consequently, the long-term effects on the quality of the bedrock aquifer will be minimal.

## 11.11 Groundwater Drawdown Impacts

### 11.11.1 Magnitude of Groundwater Drawdown

The mining schedule has been included in the groundwater model to indicate how the cone of depression of groundwater levels develops in surrounding areas (caused by the dewatering bores) as the open pit

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expands. The simulation shows that the groundwater drawdown is initially localised but gradually expands with time.

Bedrock groundwater levels will be lowered significantly in the immediate area of the open cut because of the groundwater abstraction required for mine dewatering. Most of this abstraction will occur from: (i) faults in both the fresh and weathered bedrock; and (ii) the permeable sections of the weathered bedrock (i.e. karst development in weathered dolomite).

Figures 11.6 and 11.7 show the groundwater level drawdown that occurs in the alluvial and weathered bedrock aquifers at years 10 and 25 over the life of the mine. Groundwater levels will be lowered significantly in the immediate area of the open pit but the depth of lowering reduces significantly as the distance from the open pit increases.

By the end of mining, the depth to groundwater will be approximately 230 - 240 m in the bedrock at the open cut – slightly deeper than the open cut (ultimate depth 215 m) due to the required depth of dewatering bores. This will result in a total drawdown of about 210 to 220 m below the initial static groundwater level. However, because of the generally low permeability of the bedrock surrounding the open cut, the drawdown cone will only migrate significant distances along the more permeable structures that intersect the pit, such as faults.

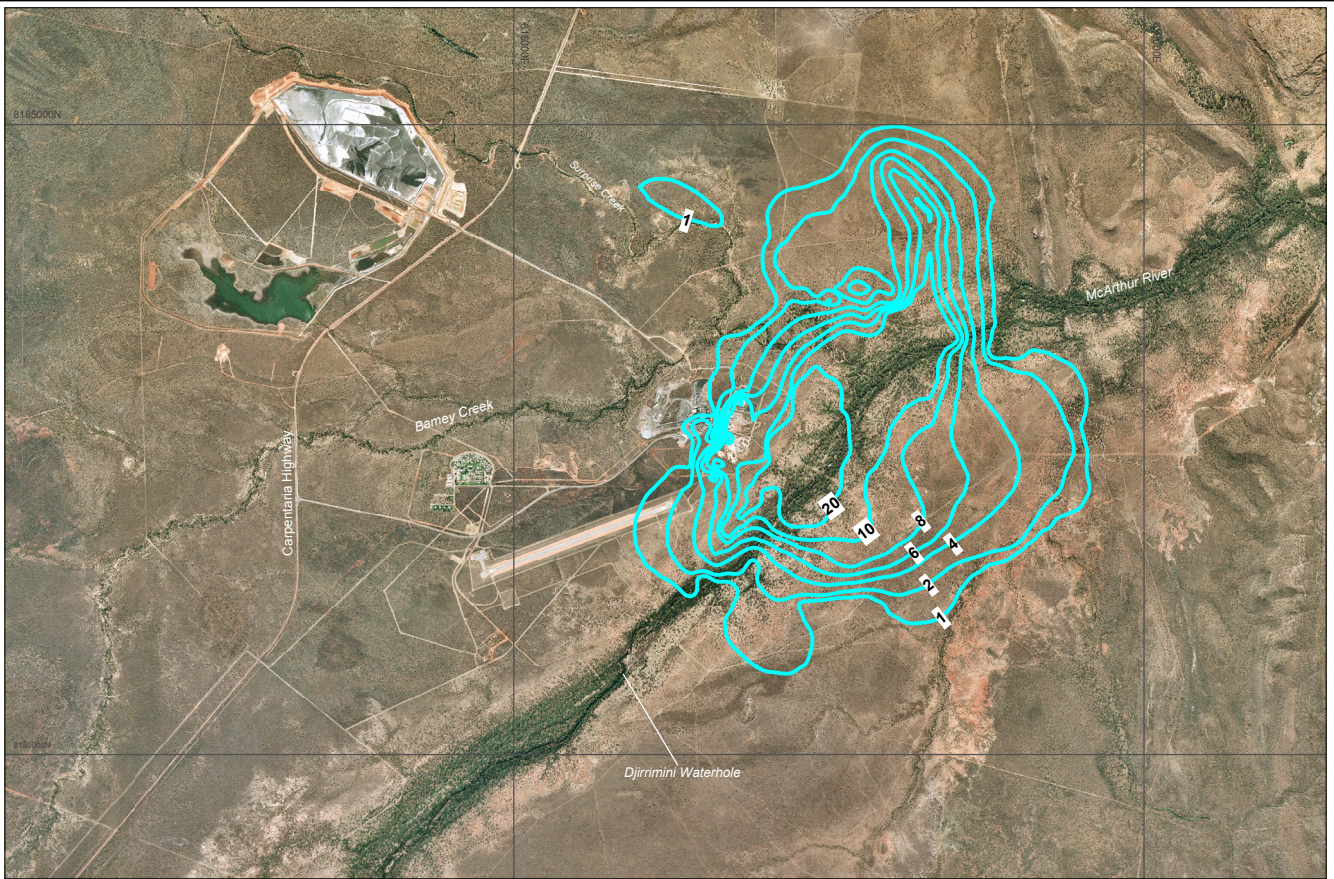
The unstructured fresh bedrock between the faults has a very low permeability and probably contains very little recoverable groundwater. Any groundwater in the unstructured fresh bedrock will drain slowly towards the faults, which will have lowered groundwater levels due to pumping. Therefore, there could be large areas of fresh bedrock in which groundwater levels are highly variable with very little drawdown and steep vertical hydraulic gradients. In-pit horizontal drains may be required to reduce pore pressures associated with slow-draining fresh bedrock.

Due to the resulting steep vertical hydraulic gradients in the fresh bedrock, the very large drawdown that occurs around the open cut will reduce vertically upwards, resulting in less drawdown in the upper sections of the fresh bedrock, the weathered bedrock and the alluvial sediments. Where the weathered bedrock is permeable and intersected by the faults, it will contribute groundwater flows to the underlying faults during dewatering and groundwater levels will potentially decline. However, in any areas where faults and weathered bedrock extend below major river channels they probably receive recharge from wet season streamflow, which will tend to limit the drawdown in these features.

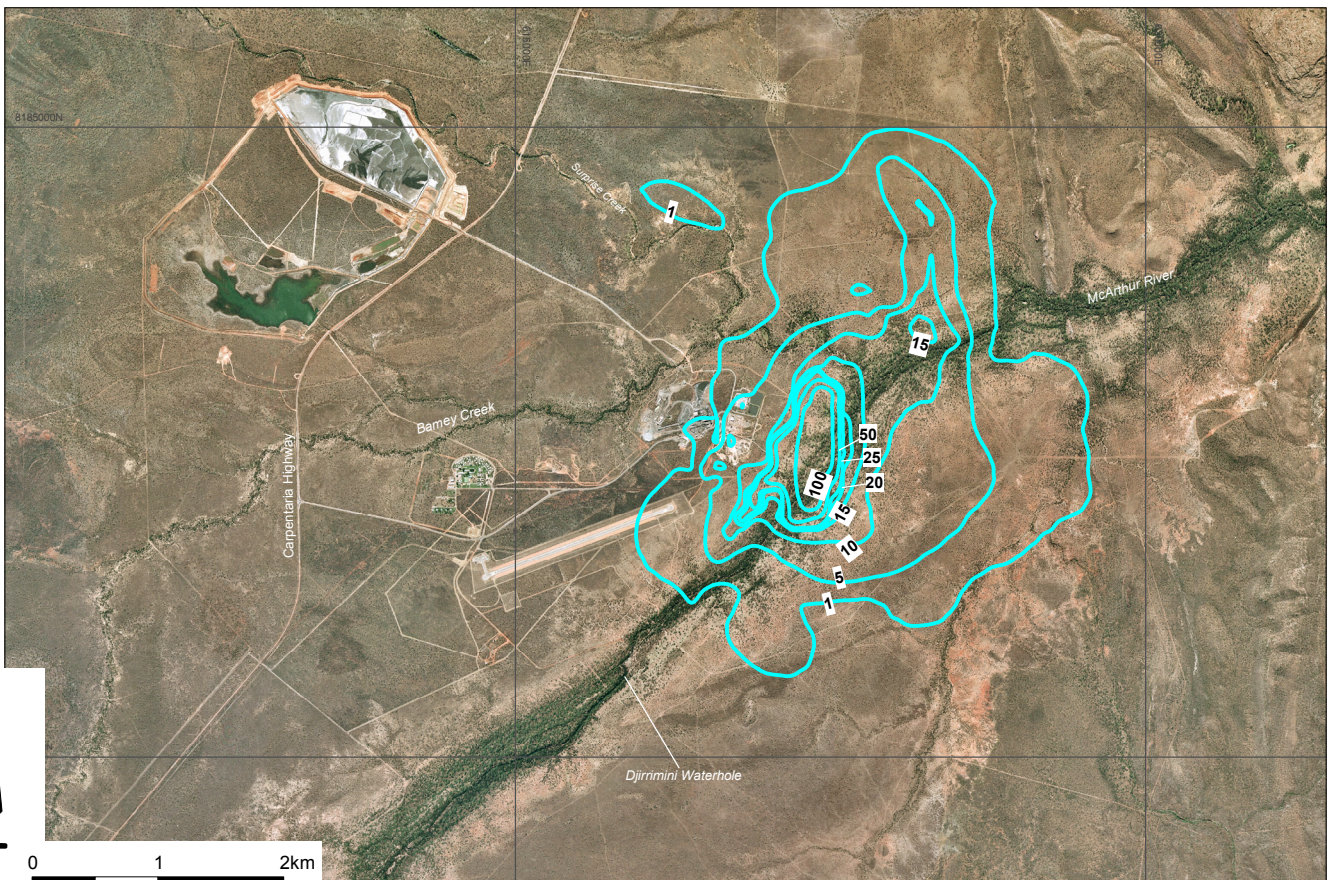
The modelling results indicate that the cone of depression migrates along the major fault systems in the bedrock during mining and model calibration suggests that the hydraulic parameters of the river alluvium (especially a large vertical permeability) have a significant effect in reducing drawdown in the upper weathered bedrock because of vertical leakage and the resulting recharge.

### **11.11.2 Impacts on Other Groundwater Users**

The lowering of groundwater levels due to mine dewatering can affect groundwater supply bores (stock wells, private domestic supply bores and industrial supply bores) if they are located within the cone of depression. Such drawdown can increase pumping heads, reduce available drawdown, and reduce pumping rates from bores.



**ALLUVIUM (LAYER 3)**



**WEATHERED BEDROCK (LAYER 4)**

— 1 — Groundwater Drawdown Contour (m)

0 1 2km  
 Scale 1:60 000 (A3)  
 Horizontal Datum: AGD84, Zone 53

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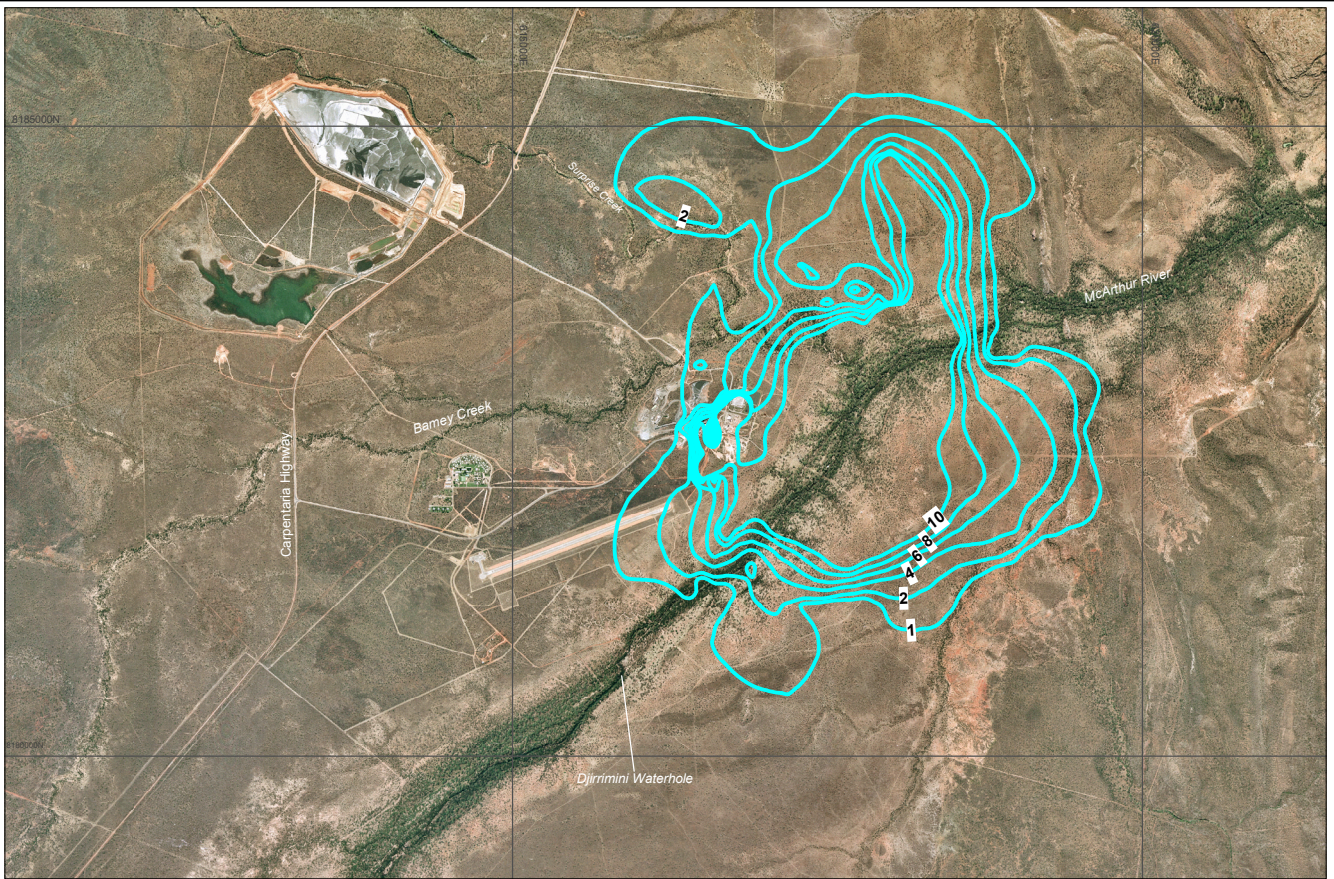
McARTHUR RIVER MINE  
 OPEN CUT PROJECT  
 ENVIRONMENTAL IMPACT STATEMENT

**SIMULATED GROUNDWATER  
 DRAWDOWN YEAR 10**

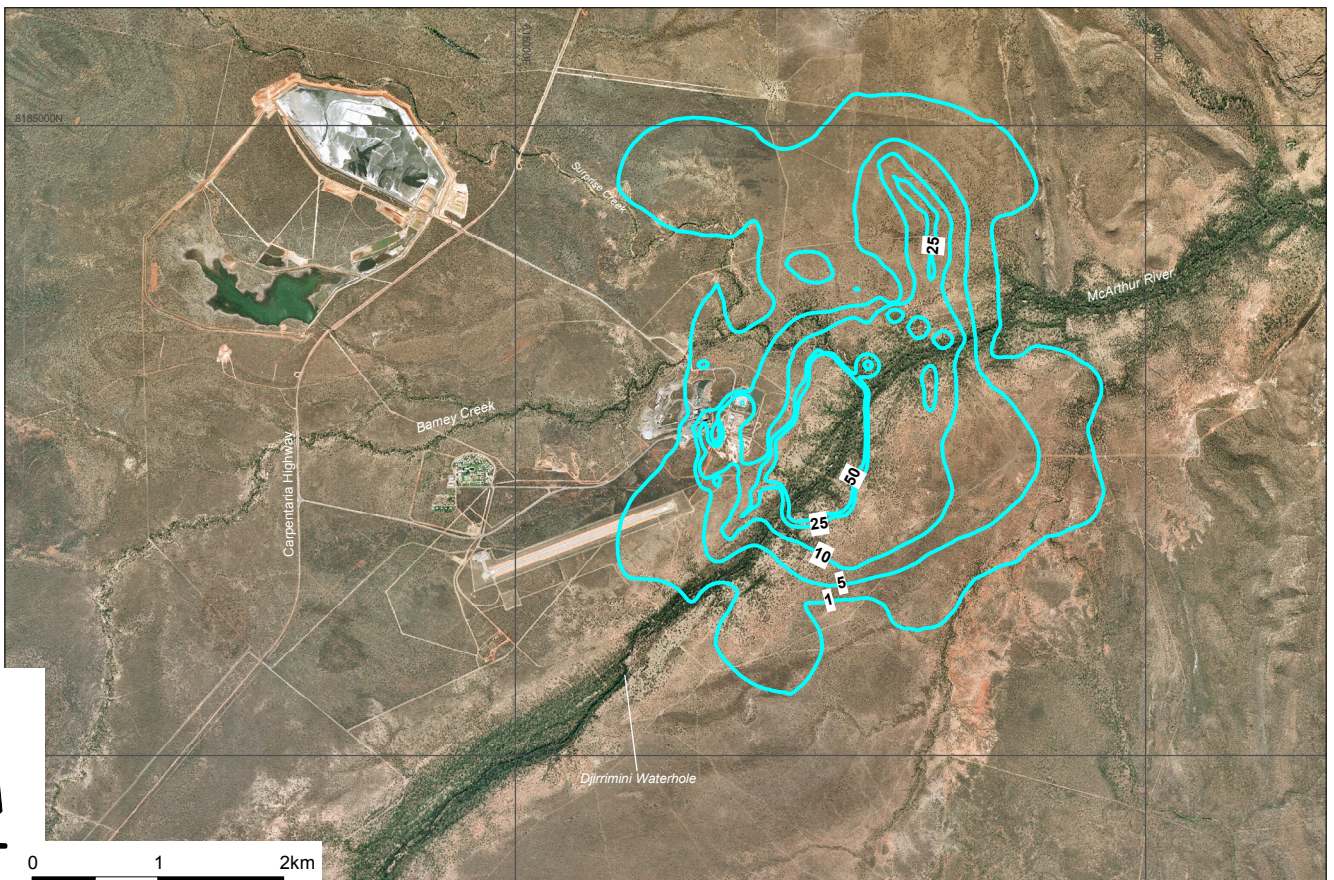
Drawn: VH	Approved: CMP	Date: 25-05-05
Job No: 42625552	File No: 42625552-g-073b.wor	

Figure: 11.6

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**ALLUVIUM (LAYER 3)**



**BEDROCK (LAYER 4)**

— 1 — Groundwater Drawdown Contour (m)



0 1 2km

Scale 1:60 000 (A3)

Horizontal Datum: AGD84, Zone 53

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McARTHUR RIVER MINE  
OPEN CUT PROJECT  
ENVIRONMENTAL IMPACT STATEMENT

**SIMULATED GROUNDWATER  
DRAWDOWN YEAR 25**

Drawn: VH	Approved: CMP	Date: 25-05-05
Job No: 42625552	File No: 42625552-g-074b.wor	

Figure: 11.7

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Based on current knowledge and a NT Government database search, there are no groundwater bores in the mining area that do not belong to MRM. Thus no groundwater users other than MRM will be affected by the groundwater drawdown. MRM will monitor its water supply bores and adjust them accordingly if drawdown effects become evident.

While there are no beneficial groundwater uses declared for the area, the groundwater is beneficially used for mining purposes. Due to the presence of the deposit, the metal concentrations in the groundwater in the vicinity of the mine are generally unsuitable for other beneficial uses such as stock watering.

### **11.11.3 Impacts on Surrounding Vegetation**

Drawdown caused by dewatering has the potential to lower groundwater levels in the superficial sediments around the pit and in the alluvium associated with both the current McArthur River channel and the palaeochannel sediments. Groundwater levels in the superficial sediments over most of the area (away from the major drainages) are already reasonably deep (10 to 15 m below ground surface) and in some areas, these sediments are largely unsaturated. Lowering of groundwater levels in these sediments, therefore, cannot have a significant environmental impact as most flora in the area are likely to rely on soil moisture (rather than the water table) for survival.

### **11.11.4 Potential McArthur River Impacts**

#### ***River Flows***

The first 1.5 km of the realigned river channel will be in alluvial material while most of the remainder of the realigned channel will be located in weathered bedrock. It is likely that this section the channel will be in hydraulic connection with groundwater. In this area the annual stream flow could potentially reduce if groundwater levels under channel are significantly lowered. Obviously during peak flooding periods in the wet season, this is not an issue. However at low-flow times during the dry season, significant loss to groundwater recharge could alter flow amounts or extend the duration of no-flow periods.

The groundwater model can calculate such flow losses from the channel to the groundwater system. Based on the modelling results, the initial loss in the first year of dewatering to the alluvium underlying the channel will be 60 kL/day. By the end of mining, the drawdown in the bedrock in the same area will have caused an increase of vertical leakage to 170 kL/day.

The increase in leakage (170 kL/day) to aquifers underlying the river is insignificant during the wet season when flows in the McArthur River at the mine site average 4,750,000 kL/day. Even at the end of the dry season (September) when average flows have declined to about 23,000 kL/day, the increase in vertical leakage is less than 1 % of river flows. During dry years when river flows cease, the predicted vertical leakage will not significantly extend the no-flow period.

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### **Permanent Pools**

As discussed in Section 13.5.3, there are two permanent pools in the McArthur River upstream of the mine. The major pool is Eight Mile Waterhole, about 8 km upstream of the mine site. It is some 5 km in length, up to about 200 m wide, and has a depth likely to be in excess of 5 m. The second and smaller pool is Djirrinmini (Jirinmini) Waterhole which is about 1 km upstream of the proposed river realignment.

At a distance of 8 km, the Eight Mile Waterhole will not be affected by mine induced drawdown of the water table. However, Djirrinmini Waterhole is much closer to the mine and within the area influenced by groundwater drawdown.

While Djirrinmini Waterhole is filled by stream flow on a seasonal basis each wet season, during the dry season when the stream flow reduces, groundwater inflow from the surrounding aquifers plays an important role in maintaining water levels.

The downstream end of Djirrinmini Waterhole is located in low permeability weathered bedrock. Further upstream, while the bed of the waterhole remains in weathered bedrock, its sides are partially in the alluvial aquifer. It appears that that dry season water levels of the waterhole are maintained with the assistance of recharge from the weathered bedrock aquifer as well as lateral discharge from the alluvial aquifer.

Modelling results have predicted that after 25 years of mining the drawdown at Djirrinmini Waterhole will be approximately 0.5 m in both the weathered bedrock and the alluvial aquifers (Figures 11.6 and 11.7).

As shown in Figure 11.2, bores MAC4 and MAC5 are located near Djirrinmini Waterhole. At the end of the dry season in 2004, the bed level in the waterhole was measured at RL 18.35 m with the water surface at RL 19.85 m (1.5 m deep). Groundwater elevations at MAC4 and MAC5 (both of which are located in the weathered bedrock aquifer) were slightly higher at RL 22.23 m and RL 23.27 m, respectively. This distribution of surface water and groundwater elevations suggests that groundwater is discharging laterally into both the river and the waterhole. Further upstream, the banks of the waterhole receive lateral seepage from the alluvial aquifer.

A reduction in groundwater level of 0.5 m in both the weathered bedrock and alluvial aquifers can be expected to result in a reduced lateral flow into the waterhole. This may result in a decrease in the depth and extent of the waterhole at the end of the dry season prior to it being replenished in the following wet season.

It should be noted that the predicted drawdown of 0.5 m is a maximum which will not occur until after 25 years of mining. Prior to that, the drawdown will be less. During the initial years of mining, a program for monitoring groundwater levels in both the weathered bedrock and the alluvial aquifers at the waterhole will be implemented to confirm the accuracy of the predicted effects. In the event that the monitoring program indicates that drawdown levels are significantly greater than expected, mitigation measures such as sustaining upstream river flows from suitable existing bores will be considered.

At mine closure, the dewatering will cease and the groundwater levels will rise to their pre-mine levels. It is expected that at the waterhole pre-mining groundwater levels would be obtained within less than 5 years.

### **11.11.5 Seepage from Tailings Storage Facility**

The modelling results indicate that the drawdown from the open pit dewatering does not extend as far as the tailings storage facility (TSF). Based on this result, the drawdown resulting from the pit dewatering will not increase the seepage of tailings dam water through the base of the TSF because the depth to groundwater below the TSF will not increase.

Details of seepage management from the TSF are given in Section 7.4.

### **11.11.6 Seepage from the Overburden Emplacement Facility**

The overburden emplacement facility (OEF) has been designed with a “multiple lines of defence” strategy to minimise the generation of contaminated seepage into the underlying groundwater. This strategy includes measures such as:

- Compacting and sloping the OEF base prior to emplacement to diver seepage to the perimeter.
- Providing low permeability layers throughout the OEF to divert seepage to the perimeter.
- Encapsulating PAF material with clay to prevent seepage being contaminated.
- Providing a pond to collect any seepage for reuse in the processing plant.

Details of the OEF seepage management strategy are provided in Section 7.2.4.

## **11.12 Management and Monitoring**

The current groundwater monitoring network will be expanded to meet environmental requirements of the open pit project.

Additional requirements for groundwater monitoring will include:

- Incorporation of any stock wells within the area of mine influence into the monitoring network.
- Monitoring fluctuations in groundwater levels adjacent to Djirrinmini Waterhole.
- Monitoring drawdown effects around the open cut to assess the efficiency of the dewatering system.

Details of the groundwater environmental management plan are given in Section 22.4.