1.1 Background

The McArthur River Mine is located 45 km south west of the township of Borroloola in the Gulf Region of the Northern Territory, approximately midway between Darwin and Mount Isa. The McArthur River Mine is accessible by sealed road from Daly Waters to the west and from the Barkly Highway 350 km to the south. The underground mine is located adjacent to the McArthur River (Figure 1), in the middle reaches of the river catchment between the confluences of the Kilgour and Glyde Rivers.

A mine expansion study has being undertaken at McArthur River Mining Pty Ltd (MRM) by Xstrata Plc (Xstrata) to develop an open pit mine and increase mill feed rates from 1.4 Mtpa (million tonnes per annum) to 1.8 Mtpa and ship the resulting concentrate to the Gladstone Refinery for processing. URS Australia Pty Ltd (URS) was engaged by Xstrata to conduct groundwater drilling investigations prior to the wet season 2004 and construct a groundwater model and complete predictive simulations to assess dewatering and environmental impacts.

Results from the predictive simulations indicate the potential for lowering of groundwater levels near river pools (the nearest being the Djirrinmini Billabong). This may cause the river pools to reduce in size during the dry season. The Northern Territory regulatory authorities indicated that the groundwater/surface water relationship of these pools needs to be refined in order to define the permanence and groundwater dependence of these pools. It is thought that river flow (baseflow from aquifers upstream of the pools) support such pools during the dry season, however this is anecdotal and not defendable without further investigation.

1.2 Previous Work

Previous drilling investigations conducted by URS targeted bedrock and alluvial aquifers within the proposed open-cut pit. Information was also gathered near the Djirrinmini Billabong.

Permeability testing, directed by URS, was undertaken on two test production bores to obtain the permeability of alluvial and bedrock aquifers. The assumed geometry of alluvium and palaeochannel aquifers was based largely on data collected from a geotechnical drilling programme.

Previous mineral exploration drilling (RAB/core) programmes by Xstrata have been useful for the approximate location and depth of weathering, however the logs generally contain little or no data on the alluvial aquifer thickness, material type and location of palaeochannel sediments.

1.3 Investigation Programme

Xstrata asked URS to quantitatively assess the groundwater/surface water relationship supporting the Djirrinmini Billabong and to locate the McArthur River palaeochannel near the proposed open pit as detailed in Proposal 3021750/589-A1002.0, dated 15 June 2005.

The scope of work for this project was outlined in URS proposal 3021750 and is summarised below.

2.1 Investigation Planning

Preparation time was required to adequately plan the investigations and this comprised;

- Preparation of URS site health, safety and environmental plans,
- Preparation of drilling schedules for drilling contractor budget, and
- Liaison with on-site Xstrata personnel to commence site works.

2.2 Field Investigations

The field investigations comprised three components:

- To determine the baseflow component of the McArthur River.
- To determine the precise location of the McArthur River palaeochannel within the vicinity of the proposed open pit; and
- Determine the local hydrogeology of the Djirrinmini Billabong.

2.2.1 McArthur River Baseflow Determination

Baseflow determination (spot river gauging) was required to locate areas along the McArthur River where groundwater discharge is contributing significantly to river baseflow during the dry season. This was used to determine places along the river where there is interaction with aquifers and thereby attempt to determine the proportion of groundwater discharge in the baseflow. This involved gauging of the McArthur River at a number of different locations and the determination of flow at these locations.

2.2.2 Hydrogeological Site Investigations

The hydrogeological site investigations had two main objectives:

- To assist in locating the McArthur River palaeochannel in the vicinity of the proposed open pit.
- To assess the hydraulic connection between the Djirrinmini Billabong and the McArthur River palaeochannel.

2.3 Reporting

All results from the field program and subsequent analysis were collated and presented in a report detailing the findings. The current report therefore includes:

- An assessment of the surface water/groundwater interaction at Djirrinmini Billabong.
- A more accurate position for the palaeochannel.
- Lithological descriptions of the stratigraphy encountered during drilling and bore construction diagrams.
- Results of the aquifer testing and the quality of the groundwater that was pumped.
- Hydrogeological cross sections along the drilling transects.
- An interpretation of the hydrostratigraphy along the river reach investigated.
- An analysis to determine the amount of groundwater that is contributing to river baseflow, especially in the area of the Djirrinmini Billabong.
- Hydrogeological interpretation of the McArthur River palaeochannel in the vicinity of the open pit.
- Revision of the previous groundwater model to include the newly acquired data and re-run the predictive simulations. (This task was not included the original scope of work, however was incorporated into the supplemental reporting component of the EIS).

3.1 Field Investigations

The field investigations involved measuring stream flow and water quality (electrical conductivity and pH) at a number of sites along the McArthur River (Figure 2). The gauging was undertaken between 29 and 30 June 2005 by URS and Xstrata staff. Gaugings were taken along approximately a 14 km length of the River, extending from south west of the proposed open pit to just above the confluence with the Glyde River.

Stream flow was calculated from measurements of flow velocity and the water cross-sectional area. Flow velocity was measured at intervals across the flow section using a Global FP101 water velocity meter. Water depth was measured at regular intervals across the section and flow area calculated for each velocity measurement. Flow was then calculated by multiplying velocity by area and summing for the section.

Stream flow could not be measured in pools as the water velocity was lower than the effective resolution of the water meter.

Water quality was measured *in situ*. Electrical conductivity (a measure of salinity) was measured using a hand-held Cond315i meter and pH was measured using a pHScan1 meter. The reported electrical conductivity is temperature compensated to 25 ^{o}C.

3.2 Water Balance

A simple water balance for each river reach between cross-sections was used to account for evaporation losses. An average water width was assumed based on field observations – 20 m for "ponded" reaches of the river and 10 m for "flowing" reaches. The river upstream of the main McArthur River crossing (Gauging Location 7), opposite the airstrip, was considered to be continuously ponded. Downstream of this point the river was considered to be continuously flowing. Water surface area was calculated as the water width multiplied by the reach length.

An evaporation rate for the gauging period (29 to 30 June) of 5.9 mm/day multiplied by an evaporation factor of 0.9 was used (BOM 2005, Station 014714 McArthur River Mine), with evaporation assumed to occur over 12 hours. Evaporation was calculated for each reach by multiplying the evaporation rate by the water surface area. Groundwater inflow/outflow in the reach was calculated by adding the evaporation loss to the change in stream flow.

3.3 Results and Discussion

Observed stream flow and water quality and calculated groundwater inflow are shown in Figure 3 and Table 1.

Groundwater inflow to the river occurs above and below the proposed open pit area, but there was little net inflow or outflow through the immediate open pit area. There is a reach with net outflow to groundwater just inside the western edge of the levee, between Sections 7a and 7c. The remainder of the river within the levee area has little to no net groundwater inflow or outflow. Groundwater inflow increases downstream of the levee area.

Accordingly, loss of water flow from this section of the river to the open pit (during dewatering) is likely to have little impact on dry season stream flows immediately downstream of the open pit.

Observations of stream flow salinity show that pools south west of the proposed open pit are fed by groundwater to varying degrees. Salinity and flows through gauging locations 1 to 6 indicate that, with the exception of gauging locations 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.

The pool at location 2 had significantly higher salinity than the other pool, suggesting that groundwater inflow was less than evaporation (3.7 L/s). Salinity here was about 6 times the salinity at nearby gauging locations, indicating considerable concentration since the end of the previous wet season.

At gauging location 3, the stream bed was dry between two pools, however the water level in the dry bed was close to the surface. Electrical conductivity of groundwater in the stream bed (measured in an excavated hole) was 314 µS/cm, less than flowing water at gauging location 1 (475 µS/cm). Electrical conductivity in a nearby pool was 950 µS/cm. It is possible that there is groundwater inflow to this pool from the base (despite the nearby dry stream bed), but the inflow rate is likely to be less than evaporation, or less than about 5 L/s.

In the sections with pools with low salinity (Sections 1, 4, 5 and 6), there is likely to be enough groundwater inflow (in June) to maintain constant water levels and there is probably enough outflow from the pools to minimise salt build up resulting from evaporation. Pools with higher salinity (particularly at gauging location 3) probably also have groundwater inflow, but at lower rates.

Any impact of dewatering on groundwater inflow rates to these pools is likely to have an effect on pool water levels and salinities during the dry season.

The salinity of non-ponded water in gauging locations 1 and 3 (300-500 µS/cm) was lower than in the remaining downstream sections (800-900 µS/cm), indicating that groundwater here is derived from a different aquifer.

Observed pH was variable along the river, ranging around a value of 8. There appeared to be a general upward trend in pH with distance downstream.

Stream flows and groundwater inflows may vary during the remainder of the dry season and from year to year in response to varying groundwater levels and seasonal conditions. The stream gaugings were completed as a single sampling event in June 2005, after a relatively dry prior wet season. June also corresponds approximately to the seasonal low in local groundwater levels. Accordingly, the observed stream flows probably represent a value towards the lower end of the range for June. Flows may vary (probably decrease) during the remainder of the 2005 dry season and may vary from year to year.

Table 1

Stream Flow, Groundwater Inflow and Water Quality

Section	Location*		River Length, Downstream From Section 1 (km)	River Reach Length (m)	Adopted Reach Width (m)	Observed pH	Observed Electrical Conductivity (µS/cm)	Observed Stream Flow (L/s)	Calculated Evaporation (L/s)	Calculated Groundwater Inflow (L/s)	Comments
	(m E)	(m N)									
1	611466	8175057	0.0			8.5	475	8.0	0		
2	612097	8176256	1.6	1.6	20	8.6	2,660		3.3		Ponded, no stream flow observation possible.
3	613229	8177657	3.5	1.8	20	7.4	950	0.0	4.4		Stream bed dry between pools; moist sand in lower parts of the dry bed. Electrical conductivity of water in sand 314 µS/cm.
4	613653	8178497	4.4	0.9	20	8.3	737		2.3		Ponded, no stream flow observation possible.
5	614584	8179708	5.9	1.6	20	7.9	780		3.8		Ponded, no stream flow observation possible.
6	615323	8180083	6.7	0.8	20	8.3	837	8.6	2.0		Ponded, no stream flow observation possible.
7	616161	8181072	8.0	1.3	20	7.8	920	21.5	3.2	16.1	Main McArthur River crossing.
7a	616917	8181658	9.0	1.0	10	7.9	950	33.4	1.2	13.1	Western pit edge.
7c	617398	8182168	9.7	0.7	10	8.2	910	26.0	0.9	-6.5	
8	617460	8182230	9.8	0.1	10	8.2	970	26.5	0.1	0.6	Power line crossing.
9	618112	8183165	11.0	1.2	10	8.1	880	25.1	1.4	0.0	Eastern pit edge.
10	619151	8183720	12.2	1.3	10	8.2	810	35.5	1.4	11.8	
11	621206	8184382	14.5	2.3	10	8.3	800	36.8	2.7	4.0	Above confluence with the Glyde River

* AMG 84 grid 53, based on GPS UTM projection of AGD 84

4.1 Groundwater Drilling

One test production bore and 23 groundwater monitoring bores were installed at the McArthur River mine (T series bores, Figure 4) during September and October 2005. Drilling was completed by H2O Drilling and Rehabilitation contractors with a truck-mounted drilling rig using air-hammer and mud rotary methods.

A 203 mm diameter pilot hole was drilled at each site location. All holes were lithologically logged and sampled. An alluvial test production bore (T3-1P) was constructed to determine the hydraulic parameters of the palaoechannel in proximity of the proposed open-pit.

Bore construction details are summarised in Table 2 and discussed below.

Table 2
Groundwater Bores - Construction Details

Bore Number	Collar Co-ordinates			Total Depth (mbgl)	Screened Interval (mbgl)	Screened Interval Lithology	Groundwater Depth (mbtoc)
	Easting	Northing	m AHD				
T2-1	617,496.42	8,183,141.88	28.76	15	3-15	Clay/Dolomitic Breccia	Dry
T3-1	617,572.14	8,181,814.78	31.77	23	12-19	Gravel	11.59
T3-2	617,692.23	8,181,719.47	31.52	10	5-10	Sand	Dry
T3-3	617,830.01	8,181,518.21	37.29	26	17.5-25.5	Gravel	16.50
T4-1s	615,715.02	8,180,562.44	32.00	13.4	7.4-13.4	Clay/Sand/Gravel	8.00
T4-1d	615,719.14	8,180,565.51	31.96	24	16.6-22.6	Dolomite	9.11
T4-2s	615,641.06	8,180,676.22	31.43	11.9	5.2-11.2	Clay/Sand/Gravel	6.80
T4-2d	615,643.75	8,180,678.13	31.55	27	14.4-26.4	Fractured Dolomite	6.79
T4-3s	615,786.46	8,180,472.21	32.30	20.7	13.8-19.8	Gravel/Sand/Clay	9.10
T4-3d	615,784.84	8,180,470.97	32.22	37	25-36.4	Dolomite	8.76
T4-4s	615,848.01	8,180,407.09	32.98	15.1	9.1-15.1	Clay/Sand/Gravel	8.96
T4-4d	615,847.02	8,180,405.89	33.02	31	18.5-30.5	Dolomite	8.98
T5-1	617,780.34	8,182,657.13	31.41	22.4	13-21	Clay/Sand	14.15
T5-2	617,797.27	8,182,539.31	31.30	22	10.5-16.5	Clay/Sand/Gravel	13.45
T5-3	617,788.28	8,182,391.17	30.23	22	8-18.9	Silt/Sand/Clay/Gravel	13.00
T5-4	617,730.22	8,182,259.34	31.23	25	12.1-22.1	Gravel	13.97
T5-5	617,695.42	8,182,121.93	29.89	19	12-18	Clay/Sand	12.61
T5-6	617,675.65	8,181,984.16	28.62	17.5	8.5-16.5	Clay/Sand	9.68
T5-7	617,562.25	8,181,866.31	30.65	22	7.5-17.5	Gravel/Sand	10.45
T5-8	617,401.10	8,181,832.33	30.40	21	10-20	Gravel	10.13
T5-9	617,211.27	8,181,866.35	32.42	19	7-19	Clay	13.99
T6-1	616,244.03	8,180,913.53	32.75	10	2-10	Clay	Dry
T6-2	616,536.28	8,180,641.50	37.68	28	15-27	Clay/Gravel	15.07
GW24	617,603.94	8,182,777.20	32.52	21	15-21	Sand/Gravel/Clay	16.60
GW25	617,603.10	8,182,767.68	32.63	42	36-42	Shale	16.41
T3-1P	617,588.11	8,181,831.51	31.44	20	11.5-17.5	Gravel	11.21

Notes: mbgl = metres below ground level
mbtoc = metres below top of collar

Bore logs, showing descriptions of strata and graphical well construction details, are presented in Appendix A.

4.1.1 Test Production Bore

One test production bores (T3-1P) were constructed and cased with 203 mm internal diameter casing using wire-wound stainless steel screens with 0.8 mm aperture slots.

The bore was drilled using mud-rotary techniques and encountered unconsolidated silt, clay, sand and gravel. The basal gravel was intersected between 11 and 18.5 metres.

Bore development was by air-lifting and surging, using compressed air to force groundwater into and out of the screened section, and discharge groundwater from the bore.

The bore was developed by this method until silt-free groundwater returns were obtained.

4.1.2 Groundwater Monitoring Bores

Twenty three groundwater monitoring bores were drilled and constructed using 50 mm nominal diameter uPVC casing. Machine-slotted uPVC casing (1 mm aperture slots) was used for the screened section, which was gravel packed with washed filter gravel. Bentonite seals were placed above the gravel pack and the bore annulus cement grouted to ground surface.

Djirrinmini Billabong

T4 series monitoring bores were installed adjacent to the Djirrinmini Billabong to determine the hydrogeology near the river pool. A hydrogeological cross section through the pool is presented in Figure 5. The bores intersected fine to medium grained sand, clay with interbeds of fine to coarse grained sand, gravel, pebbles and dolomite.

Shallow and deep groundwater monitoring bores were installed at each location, one screened within sand, sandy clay and gravel (shallow), and the others within bedrock (deep).

Eastern Pit Extent

T5 and T2 series groundwater monitoring bores are located on the eastern edge of the maximum pit perimeter to determine the hydrogeology in this area. A hydrogeological cross section is presented in Figure 6. The bores intersected fine to medium grained sand, clay with interbeds of fine to coarse grained sand, sand and silt, clay and silt, gravel, pebbles dolomite and shale.

All bores were screen within alluvial or palaeochannel sediments.

Southern Pit Extent

T3 series groundwater monitoring bores were located on the southern edge of the maximum pit perimeter to determine the hydrogeology in this area. A hydrogeological cross section is presented in Figure 7. The bores intersected fine to medium grained sand, clay with interbeds of fine to coarse grained sand, sand and silt, clay and silt, gravel, pebbles dolomite and shale.

All bores were screen within alluvial or palaeochannel sediments.

Palaeochannel Infill

Two bores were drilled to determine the location of the palaochannel between the Djirrinmini Billabong and the proposed open pit (T6 series bores). Bore T6-1 intersected shallow bedrock at 4 metres. Bore T6-2 intersected silty and sandy clay, clay, and gravelly clay. The gravelly clay at the base of the bore indicates that the bore is located in close proximity to the palaeochannel.

4.2 Bore and Aquifer Testing

Bore and aquifer tests were completed on aquifer test bore T3-1P. They comprised step-drawdown tests, constant-rate tests and recovery tests.

4.2.1 Step Drawdown Tests

The step-drawdown tests were used to determine bore pumping characteristics and estimate a pumping rate suitable for the constant-rate test. These tests comprised pumping the bore at rates that were increased incrementally ("steps"). The steps were generally of 30 minutes duration. Analyses of these results were used to determine well and formation loss factors and to select a suitable rate for the constant -rate test.

Groundwater level drawdown in a pumping bore has two components, formation loss and well loss. Formation loss is dependent on the hydraulic characteristics of the aquifer in the vicinity of the bore and is directly proportional to the pumping rate. Well loss is caused by turbulent flow and friction head loss through casing slots and around the pump, and thus depends on bore construction and development. It is generally considered proportional to the square of the pumping rate.

Therefore, drawdown in a pumping bore can be expressed by the formula:

$$Sw = BQ + CQ^2$$

where: $Sw =$ Groundwater level drawdown (m)

$Q =$ Pumping rate (kL/day)

$B =$ Formation loss factor (day/m^2)

$C =$ Well loss factor (day^2/m^5)

$$WellEfficiency = \left(\frac{BQ}{BQ + CQ^2} \right) \times 100$$

The step-drawdown test results have been analysed by the Bierschenk and Wilson method, whereby Sw/Q is plotted against Q, giving a line with a y-intercept of B and slope C (Table 3, Figure 8).

Table 3
Step-Drawdown Test Results (T3-1P)

Step	Pumping Rate (kL/day)	Drawdown (m)	Formation Loss BQ (m)	Well Loss, CQ^2 (m)	Well Efficiency (%)
1	43	0.78	0.67	0.06	91
2	86	1.82	1.34	0.27	83
3	173	3.93	2.68	1.08	71
4	216	-	-	-	-

Well efficiency generally decreases as pumping rate increases, due to the higher proportion of well loss (CQ^2) contributing to total drawdown ($BQ + CQ^2$) in the well. At higher pumping rates, the higher velocity of groundwater entering the well causes a higher proportion of well loss resulting in lower bore efficiency.

4.2.2 Constant Rate and Recovery Tests

The constant-rate test in each production bore was commenced following the step-drawdown test and after groundwater levels had recovered to initial static levels. Upon completion of each constant-rate test, recovering groundwater levels were also measured and analysed.

The test pumping was undertaken by the drilling contractors using electric submersible pumps. Pumping rates were measured through an orifice weir. Electric contact meters (dip meters) were used to measure groundwater levels in both the pumped bore and suitable observation bores.

The constant-rate test results enable the hydraulic characteristics of the aquifers intersected by each test production bore to be determined. These parameters quantify the storage and transmission of groundwater in the aquifer.

The results of the constant-rate tests and the calculated hydraulic parameters are shown on Table 4, with drawdown plots presented in Figure 9.

Table 4
Constant-Discharge Test Results

Pumping Bore	Date of Test	Pumping Rate (kL/day)	Final Drawdown (m)	Observation Bores		Transmissivity (m^2/day)		Storativity
				Bore No.	Distance (m)	Theis Method	Cooper – Jacob	
T3-1P	22/10/2005	173	3.12	-	-	-	-	-
				T3-1	23.1	183	281	-
				T5-7	43.4	-	431	-

5.1 Geological Setting

The geological setting of the area has been described previously (URS, 2005). A short summary is provided below.

5.1.1 Regional Setting

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.

5.1.2 Geology of the Open Pit

The sediment-hosted stratiform HYC deposit has similarities with ore-bodies at Mount Isa and Hilton in Queensland. It is about 1.5 km long and 1.0 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. 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 1.0 km and vertical height of 200 m. The northern margins inter-finger with sedimentary breccias and the southern margin grades into thin 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 southeastern corner is down faulted by about 110 m, along the northeasterly trending Woyzbun Fault.

5.2 Hydrogeology

The detailed hydrogeology of the area has been described previously (URS, 2005) and is summarised below.

5.2.1 Groundwater Geology and Aquifer Occurrence

Aquifers in the mining area occur locally in both the surficial deposits and the bedrock. These aquifers are a result of both intergranular and secondary permeability.

The alluvium near the proposed open pit occurs predominantly in the McArthur River channel and associated floodplain. The alluvium comprises mainly a low permeability mixture of silts, clays, and fine-grained sands. However, a higher permeability basal section of coarse-grained sands, gravels and cobbles/boulders occurs along the deepest portion of the channel.

Aquifers occur locally in both 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, dolomitic siltstones, shale and dolomite (Teena Dolomite). The most significant aquifer occurs within the weathered dolomite, which appears to have a low to moderate permeability.

Faults that intersect the weathered and partially weathered zones are probably transmissive. These will contribute groundwater flows to the proposed open pit, where they intersect the wall.

Groundwater can occur in open vugs or solution channels (collectively referred to as karst and weathered/vuggy dolomite), fractures, joints and faults within the fresh bedrock. The underground mine water balance provided by MRM in May 2003 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 faults and structures.

5.2.2 Groundwater Levels and Flow

Since 1995, a network (including both regional and local locations) of groundwater monitoring bores has been established by MRM to monitor any potential impacts of the current mining operations on the groundwater resources of the area.

Groundwater levels across the mining area, for the end of dry season 2005 are presented in Figure 10. The regional groundwater flow in the mining area is towards the low topography associated with McArthur River.

6.1 Conceptual Hydrogeology Model

Based on the interpreted geology and the additional information from the most recent groundwater investigation programme, the conceptual hydrogeological model of the area has been slightly revised. Summarised below are changes from the conceptual hydrogeology model outlined in our previous report (URS, 2005).

A palaeochannel (sub-parallel to the McArthur River) drains to the north-east and occurs on the south-eastern side of the current McArthur River channel. The thickness and width of the palaoechannel are similar to that previously interpreted, however the channel bifurcates south of the proposed open cut, separated by an area of shallow bedrock (Figures 7 and 10). Aquifer testing of the palaoechannel near the proposed open pit has confirmed the previously calculated hydraulic conductivities of the palaeochannel gravel.

The current location of the palaeochannel is closer to the McArthur River than that of the previous conceptual model. The recent drilling investigation has identified the location of the palaeochannel near the vicinity of the proposed open pit and near the vicinity of the Djirrinmini Billabong (Figure 10) and clarified the hydrogeology near this pool.

6.2 Groundwater Flow Model Details

The groundwater model code and model domain, boundary conditions, distribution of hydraulic properties and layering have remained similar to that described previously. The geometry of layer three, however, is refined to reflect the slight change in the location of the palaeochannel. Modelling assumptions and limitations are also comparable with that detailed in the previous report.

6.3 Groundwater Model Calibration

Previous calibration of the groundwater model was undertaken using aquifer tests conducted on bores screened within palaeochannel and bedrock aquifers (MAC1P and MAC3P). Due to the limited drawdown in observation bores during the aquifer testing of T3-1P, the previous aquifer test results were used to re-calibrate the model.

Steady state calibration is presented in Figure 11 and shows comparable groundwater levels to that measured (Figure 10).

Figure 12 shows the simulated drawdown in MAC2 and GWM103 from the model. The observed drawdown and final simulated drawdown are presented in Table 5. Actual drawdown in the test production bores was not compared to the simulated drawdown because the model does not account for bore efficiency and the modelled cell size is much larger than the test production bore.

Table 5
Final Drawdown in MAC2 and GWM103 (MAC1P & MAC3P)

Observation Bore	Observed Drawdown (m)	Simulated Drawdown (m)
MAC2	0.57	0.59
GWM103	0.76	0.77

6.4 Derived Hydraulic Parameters

Nine transient calibration runs were completed in order to match simulated aquifer test drawdown to that observed during the tests and this produced a satisfactory model calibration. Table 6 summarises the hydraulic parameters derived from the calibrated model that broadly correspond with the values derived from the aquifer tests.

Table 6
Hydraulic Parameters Derived from the Calibrated Model

Material Type	Model Layer	Descriptions	Hydraulic Conductivity (Permeability)			Specific Storage	Specific Yield
			Kx	Ky	Kz		
			(m/d)	(m/d)	(m/d)	(1/m)	(-)
2	1	Palaeochannel Clay	1.00E-04	1.00E-04	1.00E-05	1.00E-06	0.001
3	2	Alluvial Sand/Silt/Clay	2.0	2.0	0.5	1.00E-04	0.05
4	3	Palaeochannel Sand/Gravel	50	50	10	1.00E-04	0.10
5	5	Fresh Bedrock (Dolomite)	0.0001	0.0001	0.0001	5.00E-06	1.00E-03
6	5	Fresh Bedrock (Sandstone)	0.0001	0.0001	0.0001	5.00E-06	1.00E-03
7	4,5	North-South Bedrock Faults	2.0	2.0	0.1	5.00E-04	0.10
8	4	Weathered Bedrock (Teena Dolomite)	1.5	1.5	0.5	1.00E-05	5.00E-03
9	4	Weathered Bedrock	0.10	0.10	0.10	3.00E-04	5.00E-03
10	4,5	East-West Bedrock Faults	2.0	2.0	0.1	5.00E-04	0.10

6.5 Predictive Simulations

6.5.1 Pit inflow rates

Figure 13 shows the estimated groundwater inflow up to year 25 from alluvium, weathered bedrock and fresh bedrock. The estimated total groundwater inflow after 6 months of mining is 1,350 kL/day, increasing to 1,990 kL/day after 1 year. After year 4 of mining, the estimated inflow increases to 4,190 kL/day. Estimated inflows progressively increase to about 6,780 at year 17 and slightly decrease to 6,650 kL/day at year 25.

Proportionally, estimated groundwater inflows from weathered bedrock and alluvium are smaller than those from bedrock. After 25 years, estimated inflows from alluvium and weathered bedrock are about 2,820 kL/day and from bedrock about 3,830 kL/day.

Therefore, the revised groundwater modelling has indicated an increase of approximately 600 kL/day compared to the previous estimates.

6.5.2 Simulated Drawdown Resulting from Open Pit Dewatering

Figures 14 to 21 show the development of the cone of depression with time and the associated groundwater level drawdown that occurs in the palaeochannel aquifer (layer 3 in the groundwater model) weathered bedrock (layer 4) and bedrock (layer 5), based on the staged mining schedule (MRM Open Pit project, 1.8Mtpa LOM Mining Scenario, March 2005).

6.6 Potential Environmental Impacts Associated with Dewatering

6.6.1 Magnitude of Regional Drawdown

Based on the results of the groundwater modelling, bedrock/fault groundwater levels will be lowered significantly in the immediate area of the open pit 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).

By the end of mining, the depth to groundwater in the fresh bedrock/faults will be approximately 230 - 240 m – slightly deeper than the open-pit (ultimate depth 215 m) due to the required depth of dewatering bores. This will result in a total drawdown in the fresh bedrock/faults of about 210 to 220 m below the initial static groundwater level, simular to that previously reported.

The Djirrinmini Billabong is located in the current river channel and the model predicts that about 0.35 m of drawdown in the weathered bedrock and alluvium will occur near this location after 25 years of mining. Although the river pools and alluvium are recharged by stream flow on a seasonal basis, this magnitude of drawdown has the potential to affect both the level and longevity of the pools, as the pools are dependent on groundwater during the dry season. The downstream end of the Djirrinmini Billabong is located on low permeability weathered bedrock but the banks at the upstream end of this pool are in the alluvium, underlain partially by a palaeochannel. The low permeability bedrock and lateral groundwater inflow from the alluvium will assist in reducing any potential drawdown under the pool (caused by lowering of groundwater levels in the fresh bedrock/faults) by attenuating the upward migration of the drawdown. The pool appears to be located far enough from the open pit to be on the edge of the cone of depression developed in both the palaeochannel sand and the weathered bedrock (Figures 20 and 21).

A reduction in groundwater level of 0.35 m in both the weathered bedrock and alluvial aquifers can be expected to result in a reduced lateral flow into the Djirrinmini Billabong. This may result in a decrease in the depth and extent of the pool at the end of the dry season prior to it being replenished in the following wet season. This is slightly decreased from 0.5 m in the previous model.

It should be noted that the predicted drawdown of 0.35 m is a maximum, which will not occur until after 25 years of mining. Prior to that, the drawdown will be significantly less. A program for monitoring groundwater levels in both the weathered bedrock and the alluvial aquifers at the Djirrinmini Billabong has been implemented to provide baseline groundwater levels near the pool. This will allow for the confirmation of the accuracy of the predicted effects on the commencement of mining and provide an early warning of potential environmental impacts allowing management of such impacts.

6.6.2 Potential Reduction in Streamflow

If surface water flow in major rivers is in hydraulic connection with groundwater, there is a potential to reduce annual streamflow if groundwater levels under drainages are significantly lowered thereby reducing potential groundwater discharge to the drainage. Obviously during peak flooding periods in the wet season, this is not an issue, however at low-flow times early or late in the wet season significant loss of groundwater recharge to the drainage could alter flow amounts and duration.

Based on stream gauging measurements, approximately 1,070 kL/day/km of river reach is discharged from the aquifer up to 1.5 kilometers upstream from the proposed open pit bund wall. The extent of groundwater drawdown (less than 1 m) after 25 years, upstream of the McArthur River realignment is approximately 350 m and the corresponding baseflow for this reach of river is 375 kL/day. This flow is the maximum likely reduction in stream flow that can be attributed to drawdown. Based on river gauging measurements, the periods of stream flow of less than 375 kL/day only occur for 14 days per year on average.

7.1 Conclusions

- Based on the interpreted geology and the additional information from the most recent groundwater investigation programme, the conceptual hydrogeological model of the area around the proposed open pit has been revised. The thickness and width of the palaoechannel are similar to that previously interpreted, however the position of the paleochannel has changed slightly and the paleochannel bifurcates south of the proposed open cut in an area of shallow bedrock. Aquifer testing near the proposed open pit has confirmed previous values of hydraulic conductivity of the palaeochannel gravel used for modelling. The results from the recent drilling near Djirrinmini Billabong have confirmed that the pool is groundwater supported.

- The revised groundwater modelling has indicated an increase in the required open pit dewatering rate of approximately 600 kL/day compared to the previous estimates. Estimated groundwater inflows from weathered bedrock and alluvium are smaller than those from bedrock. After 25 years of dewatering, revised estimated groundwater inflows from alluvium/weathered bedrock are about 2,820 kL/day and from fresh bedrock about 3,830 kL/day.

- Observations of stream flow salinity show that pools south west of the proposed open pit are fed by groundwater at discharge at rates ranging between 0.6 and 16.1 L/sec. The sampling in June 2005 (after a relatively dry prior wet season) corresponds approximately to the seasonal low in local groundwater levels. Accordingly, the observed stream flows probably represent a value towards the lower end of the June stream flow range. Flows may vary (probably decrease) during the remainder of a typical dry season and may also vary from year to year.

- The Djirrinmini Billabong is located in the current river channel and the model predicts that about 0.35 m of drawdown in the weathered bedrock and alluvium will occur below this pool after 25 years of mine dewatering. Although the river pools and alluvium are recharged by stream flow on a seasonal basis, this magnitude of drawdown has the potential to affect both the level and longevity of the pools, as the pools are dependent on groundwater during the dry season.

- The area of lowered groundwater levels associated with dewatering will extend about 350 m upstream of the McArthur River realignment where the corresponding baseflow for this reach of river is 375 kL/day. This flow is the maximum likely reduction in stream flow that can be attributed to drawdown. Based on river gauging measurements, these stream flow periods (less than 375 kL/day) only occur for 14 days per year on average.

- Long-term monitoring of groundwater levels under and around the Djirrinmini Billabong will assist in predicting future environmental impacts from dewatering and will allow management and mitigation of such impacts.

7.2 Recommendations

- A program for monitoring groundwater levels in both the weathered bedrock and the alluvial aquifers at the Djirrinmini Billabong has been implemented to provide baseline groundwater levels near the pool and this program should continue.

- It is possible that in the long-term river pools will have to be supplemented from another water source in order to maintain levels during the dry season. This can only be confirmed by long-term groundwater level monitoring and ongoing refinement of the groundwater flow model as new groundwater data become available.

- Ongoing stream flow measurements in the McArthur River at the end of the dry season are probably warranted in order to refine estimates of groundwater discharge to the river, clarify the groundwater dependence of the Djirrinmini Billabong and predict potential environmental impacts associated with open pit dewatering.

BUREAU OF METEOROLOGY, 2005. Australian climate averages, http://www.bom.gov.au/climate/averages/. Bureau of Meteorology: Canberra.

URS AUSTRALIA PTY LTD, 2005. MRM Expansion EIS – Groundwater Investigations to Determine the Potential Impacts of Dewatering, Reference 42905628/589F6848.1. Report to Xstrata Plc.

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 Xstrata Plc 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 15 June 2005, reference 3021750/589-A1002.0.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between 31 August 2005 and 7 December 2005 is based on the conditions encountered and information reviewed at the time of preparation. 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.