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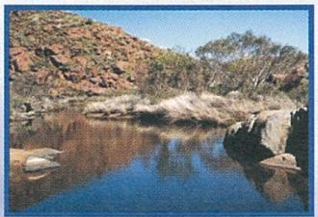
DE GREY RIVER GROUNDWATER ASSESSMENT

SPINIFEX RIDGE PROJECT



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DE GREY RIVER GROUNDWATER RESOURCE ASSESSMENT

SPINIFEX RIDGE PROJECT

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EXECUTIVE SUMMARY

Moly Mines Limited (Moly Mines) is proposing to construct and operate a molybdenum – copper mine at Spinifex Ridge, termed the Spinifex Ridge Project. The proposed mine site is situated approximately 50 km north-east of Marble Bar, Pilbara Region, Western Australia.

The Spinifex Ridge Project has a nominal mine life of 10 years; and plans to produce and process 15 million tonnes of ore per annum (Mtpa) with an estimated peak water supply demand of 18.8 gaga litres per annum (GL/yr). To supply the projects water requirements, two borefields are planned.

- A smaller borefield located 30 km to the north of the project, near the De Grey River to supply water at a rate of approximately 4 GL/annum for use in construction of the ore treatment plant and initial waste mining (pre-strip) of the open cut and to provide a peak demand water supply; with
- A larger borefield developed to supply the mine water supply with approximately 15 GL/annum once the plant is commissioned.

This report assesses the viability of a 4 GL/yr water supply from the De Grey Palaeochannel for a period of 10 years.

To assess the water source a numerical groundwater model was created. This model was based on a site investigation performed during the Pre-Feasibility Study (PFS) and existing published information. The model was constructed using Modflow, which is widely regarded as an industry leading groundwater modelling software package. Once calibrated the model was used to perform predictions for 4 GL, 6 GL and 8 GL/yr groundwater abstraction rates.

The results of the model demonstrated that a 4 GL/yr case is conservatively achievable and a high degree of flexibility exists within the design and operation of the borefield to accommodate unexpected variations within the hydrogeological system.

The borefield design is planned to consist of 15 active pumping bores and 4 standby bores that will be sited to manage a sustainable drawdown across the borefield and limit any impact on the upper aquifer associated with the De Grey River.

The water quality is considered to be moderate to poor for use as a potable water supply and good for a stock or mineral processing purpose. The water quality may change with time due to either leakage from the overlying confining layer or recharge from the De Grey alluvial aquifer. A water monitoring program is proposed and is designed to ensure that any significant change will be observed and will enable a suitable management strategy to be developed in a timely way.

There are currently three groundwater dependant systems that may be affected by abstraction from the borefield; namely, groundwater dependant flora, semi-permanent pools within the De Grey and stygofauna. The risk to these systems from pumping is considered low as water levels within the upper alluvial system can be managed sustainably by seasonal management of the borefield and the palaeochannel aquifer is maintained as a confined or fully saturated aquifer.

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1.1 INTRODUCTION

Moly Mines Limited (Moly Mines) is proposing to construct and operate a molybdenum – copper mine at Spinifex Ridge, termed the Spinifex Ridge Project. The proposed mine site is situated approximately 50 km north-east of Marble Bar, Pilbara Region, Western Australia.

The Spinifex Ridge Project has a nominal mine life of 10 years; and plans to produce and process 15 million tonnes of ore per annum (Mtpa) with an estimated peak water supply demand of 18.8 giga litres per annum (GL/yr).

Three potential water supply options were identified in the Pre-Feasibility Study (PFS) (Moly Mines, 2006), as outlined below:

- Development of groundwater resources within the semi-confined basal alluvial aquifer sequence of the De Grey River, situated approximately 25 km north of the proposed mine site;
- Development of groundwater resources within the confined Wallal Sandstone aquifer in the Canning Basin, situated approximately 60 km north of the proposed mine site; and
- Use of dewatering discharge from Pilbara Mineral Ltd's operational manganese mine at Woodie Woodie, situated 150 km south-east of the proposed mine site.

Each of the above supply options have specific issues relating to capital expenditure and/or the timescales required to gain the necessary environmental approvals and licensing relative to the Project's proposed development schedule. Thus, despite having the highest capital cost estimate, the Woodie Woodie supply option was recommended in the PFS based on potential reliability and being the only option which was considered likely to meet the Project's timeframe.

Additional staged works have been undertaken since the PFS to identify measures to optimise the Project's overall capital cost structure. Within this context, works are on-going to better define the viability, capital cost, timeframe and technical risk profile associated with the other two supply options, i.e. De Grey River and Canning Basin borefield development options.

A potential outcome of the study is the establishment of two borefields, namely:

- A smaller borefield to supply water at a rate of approximately 4 GL/annum for use in construction of the ore treatment plant and initial waste mining (pre-strip) of the open cut and supply peak water demand; with
- A larger borefield developed to supply the mine water supply with approximately 15 GL/annum once the plant is commissioned.

This approach has a number of advantages, notably:

- The availability of two developed sources adds considerable flexibility to the operation of the water supply;
- The smaller borefield will act as a peak supply source once the project is commissioned. Thereby reducing reliance on the larger more distant borefield during periods of extended dry weather; and

- By limiting the reliance on one borefield a robust water management approach can be developed that incorporates a high level of risk mitigation.

The hydrogeological investigations presented in this study form part of the on-going works to better define the groundwater resource, development options, costs and risks associated with the development of the De Grey River borefield.

1.2 REPORT OBJECTIVES

Aquaterra Consulting Pty Ltd (Aquaterra) has been commissioned to review the available hydrogeological data for the De Grey River system, adjacent to the proposed mine, to provide a more robust indication of:

- The groundwater abstraction potential associated with the De Grey River supply option;
- The potential viability and risks of developing this option to provide a reliable water supply; and
- The potential impact of developing this option on the existing environment, with appropriate management and monitoring recommendations.

This study is largely based on the hydrogeological field data generated by Rockwater Pty Ltd (Rockwater) and presented in Rockwater (2006), with supporting data from published sources (see Section 2.1), together with some limited exploration drilling.

It is understood that the findings of this investigation will be used to support the Public Environmental Review (PER) document which is currently being prepared for the Project, as required under Part IV of the Western Australia Environmental Protection Act 1986 (EPA, 2002). Thus, this report has been prepared and structured with reference to the Guidelines for Preparing a Public Environmental Review / Environmental Review and Management Programme (EPA, 2006).

1.3 APPROACH

This investigation has been undertaken with a phased approach outlined below.

- Phase 1 – the general conceptual understanding previously developed for the hydrogeological regime of the De Grey River system in the area of the Muccan-Shay Gap Road crossing (see Rockwater (2006) and Aquaterra (2006)) has been reviewed and refined based on the available field and published data.
- Phase 2 – a numerical modelling approach has been developed, based on the conceptual model, and agreed through discussions with the Department of Water (DoW).
- Phase 3 – preliminary numerical modelling has been undertaken to provide a more robust indication of:
    - The potential groundwater resource associated with the De Grey River supply option; and
    - The potential viability and risks of developing this option to provide a reliable water supply.
- Phase 4 – the potential impacts associated with the development of the De Grey River borefield have been assessed, and appropriate management and monitoring strategies are recommended.

2.1 BACKGROUND

2.1.1 Location

The De Grey River alluvium situated in the Muccan-Shay Gap Road crossing area and closest to the proposed mine site at Spinifex Ridge presents the area of interest for this study (see Figure 2.1). The area extends for approximately 24 km along the river course, with a width of 7 – 12 km; and falls within lands owned by the Yarrie and Muccan stations.

2.1.2 Previous Work

Groundwater Exploration Program

Rockwater undertook a groundwater exploration programme in the De Grey River area of interest in support of the PFS (see Rockwater, 2006), which included the following scope.

- An airborne time-domain electromagnetic (TEM) survey was undertaken to obtain conductivity data; and provide an indication of the depth to basement – i.e. where higher conductive areas were interpreted to represent thicker overburden sequences.
- Exploration drilling was undertaken at 15 target sites identified by the geophysical survey results. The majority of holes were drilled to circa 60 m depths and 7 sites with promising air-lift yields were installed as monitoring bores.
- Test production bores were installed at 3 sites adjacent to exploration bores with the potential for high yields, as indicated by the air-lift results.
- Shallow monitoring bores (12 m depth) were installed at 3 sites adjacent to the test production bores.
- Test-pumping was undertaken in the 3 test production bores, including step tests (x4 steps of 60 minutes between 2.3 and 9.8 L/s), constant rate tests (48 hours at 8.7 – 9.8 L/s), and recovery tests (2 hour minimum).
- A summary of the groundwater monitoring and test production bores installed is provided in Table 2.1 below. The positions of the geophysical survey lines and the locations of these installations are illustrated in Figures 2.2 and 2.3 respectively. The geophysics and drilling identified a palaeochannel, which doesn't necessarily coincide with the current stream.

Preliminary Resource Estimate

Aquaterra undertook a preliminary assessment of the potential groundwater resource associated with De Grey River basal alluvial aquifer (see Aquaterra, 2006), which indicated that the aquifer system appears theoretically capable of supplying the Project's required water demand (of 18.8 GL/yr) for 10 years. This resource estimate was considered to be equivalent to an *inferred resource*, following the JORC Code of reporting (JORC, 2004). However, additional works were recommended to improve the confidence in the resource estimate and reduce the associated level of technical risk, which was considered to be high.

Table 2.1
Groundwater Installation Summary

Bore ID	Easting[1]	Northing[1]	Aquifer Monitored	Bore Type	Total Depth (m)	Slotted Intake Section (mbgl)	
						Top	Bottom
MMDG03A	200811	7712896	basal aquifer	monitoring bore	59.0	47.0	59.0
MMDG04A	199472	7710430	basal aquifer	monitoring bore	57.8	45.0	57.8
MMDG04P	199472	7710430	basal aquifer	test production bore	57.5	27.5	57.5
MMDG04S	199472	7710430	upper aquifer	monitoring bore	12.0	6.0	12.0
MMDG06A	206783	7713067	basal aquifer	monitoring bore	60.2	54.2	60.2
MMDG07A	204810	7712844	basal aquifer	monitoring bore	59.0	41.0	59.0
MMDG08A	208793	7713341	basal aquifer	monitoring bore	53.0	41.0	53.0
MMDG08P	208793	7713341	basal aquifer	test production bore	57.4	45.4	57.4
MMDG08S	208793	7713341	upper aquifer	monitoring bore	12.0	6.0	12.0
MMDG09A	811985[2]	7719210[2]	basal aquifer	monitoring bore	66.0	60.0	66.0
MMDG09P	811985[2]	7719210[2]	basal aquifer	test production bore	64.4	26.4	64.4
MMDG09S	811985[2]	7719210[2]	upper aquifer	monitoring bore	12.0	6.0	12.0
MMDG15A	190742	7714765	basal aquifer	monitoring bore	42.0	28.0	42.0

1 MGA94 Zone 51 (unless indicated)
2 MGA94 Zone 50

2.2 DE GREY RIVER AREA

2.2.1 Setting

The De Grey River basin is situated within the Northern Peneplain physiographic subdivision of the Pilbara region, which is located between the Chichester Ranges and the coastal plain. The river valley forms a gentle topographic feature in a landscape which is typically dominated by broad undulating plains and low rounded hills situated between prominent strike orientated ridges and ranges (e.g. Gorge Ranges).

2.2.2 Climate

The northern Pilbara region has an arid climate with a sub-tropical rainfall pattern, typically characterised by hot, wet summers (October to April) and mild, dry winters (May to September). In general, annual rainfall totals and daily temperature ranges increase with increasing distance inland; however, there is a high level of natural climatic variability from year to year. Two rainfall stations are situated within the De Grey River area, as illustrated on Figure 2.4 and detailed in Table 2.2 below. These stations show low annual rainfall totals of 358 mm and 302 mm for Yarrie and Muccan, of which 74 – 75% occurs during December to March and is typically associated with cyclones and tropical depressions (see Figure 2.5). However, there are years where little significant rainfall was recorded which is reflected by the high co-efficient of variability (0.51 – 0.53) associated with these records.

Average temperatures in the northern Pilbara area typically range from around 11.8 ºC to 41.6 ºC, as recorded in Marble Bar situated approximately 65 km to the south-west of the De Grey River area (representing the long-term mean minimum and maximum daily temperatures for July and December respectively).

Table 2.2
Rainfall and Climate Stations

Station	Reference	MGA Zone	Easting	Northing	LTA Record Duration
Yarrie	004046	51	208940	7711587	1898 - 2005
Muccan	004022	51	193158	7715807	1898 - 1998
Marble Bar	004020	50	785519	7655941	1895 - 2004

2.2.3 Geology

Regional

The area is located within the Archaean Pilbara Craton of north Western Australia; and on the northern margin of the outcropping East Pilbara granite-greenstone terrain (East Pilbara GGT) which hosts a wide range of precious and base metal mineralisation, including the Spinifex Ridge molybdenum-copper deposit (Williams, 2000). One hundred kilometres to the north of the area, the cratonic units are overlain by a Permian to Quaternary sedimentary sequence which comprises the Canning Basin.

Local

The basement in the De Grey River area typically comprises granitic units of the cratonic Muccan Granitoid Complex (circa 3.4 Ba). In addition, cratonic units of the Pilbara Supergroup (including the earlier Warrawoona Group and later Gorge Creek Group) occur towards the eastern and southern margins of the area of interest. The basement surface shows significant relief and is a faulted palaeo-erosion surface with a well defined palaeo-channel (see Figure 2.2), as indicated by interpretation of the geophysical survey results.

The basement is typically unconformably overlain by a sequence of unconsolidated alluvial Quaternary sediments. The thickness of the sedimentary sequence is controlled by the basement surface and varies from up to 64 m thickness in the apex of the palaeo-channel to less than 5 m in areas associated with northward trending basement ridges and minor basement outcrop (see Figure 2.3 for geology).

The alluvial profile typically comprises the following three key lithologies (Rockwater, 2006).

- A laterally restricted basal sequence of coarse sands to very coarse pebble gravels associated with in-fill of the palaeo-channel. The sequence typically comprises poorly sorted, sub-angular and low-sphericity grains / clasts of granitic composition which are likely to be derived by erosion of the granitic basement complex, with short transportational distances and deposition in a high-energy fluvial environment associated with the palaeo-channel.
- A laterally extensive and thick (up to 30 m) horizon of grey, sandy clays which are likely to be derived by chemical and mechanical breakdown of the granitic basement material. The clays contain occasional organic – pyrite rich (bituminous) horizons which indicate deposition in low energy, anaerobic conditions potentially associated with a flood or overbank fluvial environment. The thick clay sequence directly overlies the basement profile in areas where the basal palaeo-channel is absent.

- An upper laterally extensive, 6 – 10 m thick horizon of coarse sands and gravels associated with the active drainage channel.

2.2.4 Surface Water and Drainage

Surface Water Catchments

The De Grey River (Basin 710) has a large catchment area of 56,890 km^2 and the highest median annual flow in the Pilbara region, of 780 GL/yr (WRC, 1996). The area of interest is situated in the middle reaches of the main catchment; approximately 50 km down-gradient of the major confluence of the Oakover and Nullagine Rivers which are the major tributaries at the head of catchment, and approximately 25 km down-gradient of the confluence with the Miningarra Creek, which is another significant tributary to the main river. The area of interest is situated up-gradient of the major Coongan, Shaw and Strelley River confluences. The median annual river flow for the site is calculated at 600 GL (WRC, 1996)

In contrast to the typical north-south trending drainage patterns observed across the northern Pilbara, the De Grey River follows an east-west trend in this area which is likely to reflect a structural control on the drainage course associated with basement faulting (see Figure 2.3).

Five significant creeks discharge to the main De Grey River within the area of interest (see Figure 2.4), including Bamboo, Emu, Kookenyia and Yundinna Creeks which discharge from the south; and Coonieena Creek and Egg Creek which discharges from the north. These creeks typically follow a north-south trend and may be influenced by structural trends and ridges within the basement profile.

Several natural pools also occur within this area and are likely to support dependent ecosystems, including Coolcoolinnarriner, Muccanoo and Mooragoordina Pools (see Figure 2.3). In addition, a significant length of the De Grey River in this area has been gazetted as a wetland on the National register (De Grey River – WA065) as listed on Directory of Important Wetlands in Australia. The wetland is identified as a zone extending from the confluence of the Oakover and Nullagine Rivers to the Indian Ocean (excluding tributaries).

The depth to basement image shows that the course of the buried palaeo-channel is more sinuous and not laterally coincident with the current De Grey River channel. In addition, the depth to basement image may be interpreted to indicate an extension of the palaeo-channel in the area of the present day Kookenyia Creek. These differences are likely to reflect changes in erosional base-levels and topographic gradients associated with recent uplift of the Pilbara plateau (WRC, 2000).

Hydrological Regimes and Climate Variables

Surface water flow in the De Grey River is ephemeral and directly proportional to rainfall. Median run-off rates for the De Grey catchment are typically high, thus flood and over-banks flows are common after periods of heavy or prolonged rainfall (WRC, 2000). Low, or zero, flow conditions prevail during the drier summer months and periods of reduced rainfall. However, the natural pools rarely dry and are likely to be in hydraulic continuity with the shallow groundwater table. River flows are likely to be supported by groundwater baseflow which provides an important mechanism for sustaining flows during dry conditions.

River flow data are not available for the mid reaches of the De Grey catchment. However, limited flow data are available for a gauging station situated upstream of the area on the Nullagine River; and a long-term dataset is available for the gauging station at Coolenar Pool situated 95 km downstream of the area of interest and approximately 40 km upstream of the coast (see Table 2.3 below). These data indicate that flows in excess of 100 L/s occur for more than 130 days each year at Coolenar Pool; in contrast similar flows only occur for more than 91 days each year, and zero flow conditions occur for 110 days each year, at Nullagine. Flows in the De Grey River area of interest are expected to be between these values and may be proportionally more similar to the Coolenar Pool values due to the closer proximity to this site and proportionally larger catchment area. In addition, natural flow durations and magnitudes in the De Grey River may locally be influenced by abstractions.

Water quality in the De Grey River is typically good and river salinities show a negative relationship with flow rates due to dilutional effects – i.e. lower salinities are recoded at higher flow rates. The representative flow-weighted total stream salinity is 186 mg/L TSS at Coolenar Pool (WRC, 2000). In addition, two data points are available for the upstream site at Nullagine, including TDS values of approximately 550 and 910 mg/L; and pH values of 8.3 and 8.5.

In general, rainfall totals in northern Western Australia have increased over the last 50 years (see BoM website); and Global Climate Model scenario projections typically indicate that rainfall totals will continue to increase in this area over the coming decades, possibly as a result of climate change.

Table 2.3
River Gauging Stations

Station	River	Reference	MGA Zone	Easting	Northing	Distance from area of interest[1]	Record Duration
Coolenar Pool	De Grey	710003	50	734,839	7,752,456	95 km	1974 – present
Nullagine	Nullagine	710004	51	201,336	7,576,611	200 km	1997 – 2004

1. Distance along river channel, not direct distance.

2.2.5 Hydrogeology

Regional Hydrogeology

The occurrence of groundwater is ubiquitous across the northern Pilbara region (inland of the Canning Basin aquifer system) and is largely associated with the following main aquifer types.

- Moderate to high yielding alluvial aquifers associated with major river systems and coastal plains;
- moderately yielding fractured and mineralised basement aquifers with enhanced secondary permeability and storage; and
- low yielding basement aquifers with a relatively low degree of fracturing, mineralisation, secondary permeability and storage.

These aquifers are recharged by the direct infiltration of rainfall and run-off where outcrop occurs. In addition, alluvial aquifers are recharged by the leakage of surface water flow within the drainage channel;

and to a lesser extent, by groundwater seepage or through flow from the underlying basement units (depending on the degree of fracturing, mineralisation and secondary permeability).

The alluvial aquifers provide the most important and exploited groundwater resource in is area; however, the basement units may support small to medium abstractions where there is a reasonable degree of fracturing and mineralisation (WRC, 1996).

Groundwater within the alluvial aquifer systems typically flows down hydraulic gradient along the alluvial channel. On a regional scale, groundwater within the underlying fractured basement typically flows northwards towards the coastal plain. However, on a local scale groundwater will flow towards specific discharge points, including alluvial aquifers, drainage channels and springs. Zones of enhanced structural deformation, mineralisation and/or weathering within the basement profile are likely to provide higher permeability conduits and may preferentially channel groundwater flow.

Local Aquifer Characteristics

Two main aquifer systems were identified in this area during the groundwater exploration programme undertaken in support of the PFS (Rockwater, 2006). These include a shallow alluvial aquifer system associated with the active drainage network; and a deeper basal aquifer system associated with a buried palaeo-channel. These aquifer units are separated by a potentially leaky aquitard unit. The properties of these aquifers are summarised in Table 2.4 and outlined below.

Table 2.4
Summary of Aquifer Parameters

Parameter	Upper Alluvial	Basal Alluvial
Aquifer type	Unconfined	Semi - confined
Possible Bore Yield (m^3/day)[1,2]	<500	300 to 1,000
Water Quality (mg/L TDS)[1]	>1,800	1,000 to 3,000
Transmissivity (T) m^2/day[1]	-	150-1,000
Confined Storativity (S)[1]	N/A	$5x10^{-4} – 3x10^{-3}$
Unconfined Storativity (Sy)[2]	10 to 15%	15 to 20%
Continuous width of aquifer (m)[1,2]	500 to 2,000	500 to 6,000
Thickness of aquifer (m)[1]	2 to 5	5 to 15
Continuous length of aquifer (m)	>20,000	>20,000

1 Derived from Rockwater, 2006
2 Based on typical values for alluvial systems elsewhere.

The shallow aquifer comprises a laterally extensive sequence of coarse sands and gravels, 6 – 10 m thick, associated with the active river drainage channel. The water table is typically between 3.4 and 7.1 m below ground level (mbgl) (see Table 2.5); and is likely to be in hydraulic continuity with the natural pools in the river bed. The aquifer is regularly recharged via direct infiltration of rainfall, run-off and river flow; and groundwater levels are expected to rise close to ground level during high flow events. Groundwater levels recede during dry periods as a result of evaporation, groundwater through flow and abstraction. The aquifer provides baseflow to the river and thus sustains river flows and pool water levels during low flow conditions.

The shallow aquifer system is underlain by a thick (30 m) sequence of sandy clays which are likely to present a leaky aquitard unit.

The deeper semi-confined basal aquifer system comprises very coarse sand to very coarse gravel deposits associated with the infill of the palaeo-channel feature. Thus the lateral extent of the aquifer is constrained to that of the palaeo-channel. Groundwater levels are typically between 4.6 and 7.2 mbgl (see Table 2.5) and approximately 45 m above the top of the basal aquifer system. The transmissivity of this aquifer was interpreted to be between 180 and 885 m^2/d; based on standard analysis of aquifer test data from 3 bores (see Rockwater, 2006). The range of values observed is likely to reflect the different positions of the test bore sites relative to the palaeo-channel axis. For example, site MMDG04 exhibited the highest values (800 – 885 m^2/d) and is situated towards the centre of the palaeo-channel (based on interpreted TEM data) near the confluence with the Kookenyia Creek and shows a well developed sequence of coarse alluvial sediments (approximately 23 m thick). In contrast, site MMDG09 exhibited the lowest transmissivity values (180 – 395 m^2/d) and is situated on the margin of the palaeo-channel and shows a more clayey sequence with only minor stratified horizons of coarse sediments. Evidence of boundary effects were observed in the aquifer test data at all sites and are likely to represent the margins of the palaeo-channel. Thus for the purposes of water resource estimation and associated impact assessment, the effective transmissivity of the basal aquifer should be taken from the mid to lower end of the interpreted range. Evidence of leakage was also observed in the aquifer test data at site MMDG09 and may reflect delayed release of water from the more clayey alluvial sequence at this site, or the contribution of water from the adjacent basement. The storage values for the basal aquifer range from $3.4x10^{-3}$ to $5x10^{-4}$, and are consistent with a semi-confined aquifer. Figure 2.6 illustrates the conceptual hydrogeology.

Table 2.5
Representative Groundwater Levels

Bore	Aquifer	Water Level (mbgl)	
		December 2005	October 2006
MMDG04A	basal aquifer		4.63
MMDG04P	basal aquifer	4.85	4.67
MMDG04S	upper aquifer	3.87	3.37
MMDG08A	basal aquifer		7.20
MMDG08P	basal aquifer	6.83	pumping
MMDG08S	upper aquifer	7.13	6.83
MMDG09A	basal aquifer		6.83
MMDG09P	basal aquifer	7.22	6.85
MMDG09S	upper aquifer	6.90	6.49

Groundwater Chemistry

Groundwater associated with the alluvial aquifer systems in this area typically shows good quality. Field electrical conductivity (EC) values of 1,900 – 6,220 uS/cm and pH 7.4 – 7.7 were recorded for the basal aquifer system (see Table 2.6); and the shallow aquifer system is likely to show similar water quality to the river system (see Section 2.2.4).

Groundwater sampled from the basal system at sites MMDG08 and MMDG09 during December 2005 was hard to moderately hard and displayed sodium and chloride ion dominant end-member fluid compositions, which indicate little evidence of recent recharge (see Figures 2.7 – 2.8). Groundwater sampled from the basal system at site MMDG04, near the confluence with Kookenyia Creek, was moderately soft and displayed a sulphate ion dominant fluid composition (or sodium ion dominant composition with indiscriminate anions) consistent with groundwater mixing (see Figures 2.7 – 2.8). The data are provided in Table 2.7 below.

Other Groundwater Users

The WINSITES database of monitoring sites indicates that there are 32 existing groundwater bores and wells in or directly adjacent to the area of interest; of which 14 supplies are reported to be abandoned (based on database entry, geological map or site visit) and 4 are known to be operational - as illustrated in Figure 2.3. The majority of these supplies are shallow (max. ~12 m) hand-dug wells, which abstract groundwater from the shallow aquifer system for stock watering and domestic purposes. Details of the 4 operational sites are provided in Table 2.8 below

Table 2.6
Field Groundwater Quality

Bore ID	MMDG03A	MMDG04A	MMDG06A	MMDG07A	MMDG08A	MMDG09A	MMDG15A
EC (uS/cm)	1,900	3,800	5,100	2,300	3,050	2,390	6,220
pH			7.4	7.4	7.4	7.4	7.7
T (ºC)				32	33	34	32

Table 2.7
Groundwater Chemistry

Analyte	Symbol	Units	MMDG04P	MMDG08P	MMDG09P
Date	-	-	10/12/05	13/12/05	17/12/05
Sample taken	-	-	after test pumping program		
pH	-	none	8.1	7.4	7.5
Electrical conductivity (at 25ºC)	EC	uS/cm	4,200	3,100	2,800
Total Dissolved Solids (at 180ºC)	TDS	mg/L	2,100	1,500	1,300
Sodium	Na^{+}	mg/L	830	460	490
Potassium	K^{+}	mg/L	1.9	4.8	8.5
Calcium	Ca^{2+}	mg/L	7.2	4.7	3.4
Magnesium	Mg^{2+}	mg/L	13	51	41
Chloride	Cl^{-}	mg/L	600	500	460
Bicarbonate	HCO_3^{-}	mg/L	830	380	460
Carbonate	CO_3^{2-}	mg/L	<1.0	<1.0	<1.0

Analyte	Symbol	Units	MMDG04P	MMDG08P	MMDG09P
Sulphate	SO_4^{2-}	mg/L	200	310	150
Nitrate	NO_3^-	mg/L	4.5	<0.2	24
Iron	Fe	mg/L	<0.05	<0.05	<0.05
Ionic balance	-	%	3.96	-4.42	2.24
Hardness	-	-	moderately soft	Hard	moderately hard
Water type[1]	-	-	SO_4^{2-} dominant[2]	Na^+ and Cl^- dominant	

1 Expanded Durov plot classification.
2 SO_4^{2-} dominant or Na^+ dominant with indiscriminant anions.

Table 2.8
Existing Water Supplies

Supply	Easting[1]	Northing[1]	Operational?	Water Level Oct 2006 (mbgl)	Comment
Old Coppin Well	194,784	7,715,675	yes	~	pumping equipment installed
Chinablin Well	195,399	7,710,254	yes	4.53	pumping equipment installed; instable ground around headworks
MMDG08P	208,793	7,713,341	yes	~	solar powered pumping equipment installed
Ram Paddock Well	191,282	7,714,221	yes	~	pumping equipment installed

1 MGA94 Zone 51

A combination of published information and data collected from fieldwork was used to develop a numerical model which would allow predictions of aquifer potential and groundwater drawdown related to abstraction.

3.1 MODEL OBJECTIVES

The objectives of the De Grey groundwater model are to:

- Assess the water supply potential of the De Grey palaeochannel aquifer; and
- Assess potential drawdown impacts of water supply pumping on the De Grey River.

3.2 MODEL SET-UP

3.2.1 Background

The model developed for the De Grey palaeochannel aquifer includes features to simulate:

- The hydrogeological features of the aquifer system over the area of current investigation;
- Rainfall recharge to the aquifer system;
- Groundwater inflow to and outflow from the catchment;
- Groundwater discharge to the De Grey River; and
- Groundwater pumping from the palaeochannel aquifer.

A fully verified and modified version of Modflow (Winston, 1997) that allows leakage to or from a river feature to the highest active or saturated model cell was used for this work, operating under the PMWin Pro Graphical User Interface (IES, 2006). Modflow is one of the industry leading groundwater flow modelling packages.

3.2.2 Model Extent and Grid

The model domain extends 38,700 m east to west; and 29,000 m north to south. The model and all associated data have been plotted using the GDA 94 Zone 50 coordinate system. Coordinates for the four corners of the rectangular model domain are detailed in Table 3.1 below.

The extent, boundary conditions and general features of the groundwater model are shown in Figure 3.1. The model has a uniform grid size of 100 m square cells distributed over 387 columns and 290 rows.

Table 3.1
Model Domain

	Easting* (m)	Northing* (m)
Top right	838000	7727000
Top left	799300	7727000
Bottom left	799300	7698000
Bottom right	838000	7698000

*GDA 94 Zone 50

3.2.3 Data Summary

A summary of the key data used to set up the numerical model is provided in Table 3.2 below.

Table 3.2
Data Summary

Parameter	Data source
Topographic levels	Elevation data from the TEM survey; and topographic maps of the area
Potential aquifer horizons	Geophysical TEM survey (Rockwater, 2005)
Water levels	Measured water levels from previous work (Rockwater, 2005)
Rainfall	Rainfall data from Goldsworthy station
Recharge	Best estimate from model calibration

3.2.4 Model Geometry

Based on the conceptual model presented in Section 2.2.5, the numerical groundwater model has three layers, as outlined in Table 3.3 below and as shown in Figure 3.2.

Table 3.3
Model Layers

Layer	Description	Thickness
Layer 1 (L1)	Surficial aquifer, silt to gravel grade alluvium	15 metres thick
Layer 2 (L2)	Aquitard, leaky silty clay layer surrounded by granite bedrock	35 metres thick
Layer 3 (L3)	Confined (semi-confined) aquifer, sandy gravel surrounded by granite bedrock	10 metres thick

The top of the layer 1 has been taken from the available topographic information together with the TEM survey data and interpolated (Kriging method) to the model finite difference grid using Surfer (griding software). Contours of the elevation of the base of individual model layers, based on topography and the layer thicknesses derived from available hydrogeological information and outlined in Table 3.3 are presented in Figures 3.2 to 3.5. The model set up is shown schematically in Figure 3.6.

3.3 GROUNDWATER INFLOW AND OUTFLOW

3.3.1 Groundwater Throughflow

All model boundaries set consistent with catchment boundaries were assigned as the no flow type (as shown in Figure 3.1). All other boundaries were set as either groundwater inflow boundaries, on the eastern or upstream end of the model domain, or groundwater outflow boundaries on the western or downstream end of the model domain. Groundwater inflows and outflows are based on water level estimates at the model boundaries (100 mRL for the upstream end of the palaeochannel and 5 metres below groundwater at other model boundaries including the downstream end of the palaeochannel). Adopting fixed groundwater inflows and outflows adds some conservatism to model predictions as groundwater inflows do not increase and groundwater outflows do not decrease in response to drawdown as they would if constant head type boundary conditions were used.

3.3.2 Rainfall Recharge

Apart from the groundwater inflow boundary set at the eastern model boundary, all inflow to the groundwater model results from direct infiltration of incident rainfall. The rainfall recharge distribution for the model is shown in Figure 3.7. Rainfall recharge (based on the model calibration, Section 3.4) is applied at;

- 40% of recorded average annual rainfall (130mm/year or 3.3 x10^{-4} m/d) to the De Grey River; and
- 0.17% of recorded average rainfall (0.55mm/year or 1.5 x10^{-6} m/d) to the outwash areas.

These recharge rates provide a further degree of conservatism to the model as recharge from the river to the underlying aquifers resulting from flood events is not included.

3.3.3 River Discharge

As outlined in Section 2.2.4, the DeGrey River is assumed to be baseflow driven over the area of investigation (other than immediately after a major rainfall event) and receive discharge from the surrounding aquifers along its modelled length. The course of the river, as included in the groundwater model, is shown in Figure 3.1. The modelled river is assumed to be 200 metres or 2 cells wide (from bank to bank) along the modelled length. The following parameters are also specified in the Modflow River package:

- Hydraulic conductance of the "river" floor set to 1000 m^2/d.
- Head in the "river", set to 100 mRL at the eastern or upstream end of the model, linearly decreasing to 59.3 mRL close to the western or downstream boundary of the model.
- Elevation of the "river bed" is set 2 m below the assigned head in the river (i.e. 98 mRL at the upstream end to 57.3 mRL at the downstream end).

3.3.4 River Recharge

As outlined in Section 3.3.3, the De Grey River is assumed to be baseflow driven over the area of investigation and does not include recharge after major flood events. Once groundwater pumping from the De Grey palaeochannel commences groundwater levels in the aquifer and the overlying units will be reduced and groundwater discharge to the river from the surrounding aquifers may reduce over time. The interaction between surface water and groundwater is specified in the groundwater model such that if during predictions, baseflow to the river is reduced to zero, the river will provide a recharge source to the underlying units and the palaeochannel aquifer.

3.4 MODEL CALIBRATION

3.4.1 Introduction

Model calibration is the process by which the independent variables of a model are adjusted, within realistic limits, to produce the best match between simulated and measured data (usually obtained from groundwater level monitoring). This process typically involves refining the aquifer properties and boundary conditions of the model to achieve the desired degree of correspondence between the observed data and model simulation.

3.4.2 Steady State Calibration

During steady state model calibration, aquifer parameters (horizontal and vertical hydraulic conductivity) were specified consistent with available data and the applied aquifer recharge was varied until a satisfactory match was obtained between water levels measured in the palaeochannel and surficial aquifers and those predicted by the model. Predicted groundwater contours for the palaeochannel aquifer (Layer 3) are presented in Figure 3.8. Measured and predicted groundwater levels, for both the surficial and palaeochannel aquifers and the palaeochannel aquifer only are presented in Figures 3.9 and Figure 3.10 respectively.

Comparing the measured and predicted water levels for both the alluvial and palaeochannel aquifers, the Root Mean Squared (RMS) error as a proportion of measured range of heads is 25%. This value is higher than the generally accepted scaled RMS of 10% for “greenfield” sites (MDBC, 2001). Significant effort was directed toward improving model calibration; however there still remains some uncertainty in the available water level measurements as the collar elevations of monitoring and test bores are derived from GPS data rather than survey data. It is anticipated that once survey data become available for the existing test and monitoring bores the model performance will be checked against more accurate water level data.

Calibrated aquifer parameters, including the recharge values adopted for model calibration, are summarised in Table 3.4 and illustrated in Figures 3.11 to 3.13. Consistent with the assignment of hydraulic conductivity for the river alluvium, a higher proportion of recharge is assigned to the vicinity of river channel (130 mm/year which is 40% of total average annual rainfall of 324 mm/year) where as in the outwash area only 0.55 mm/year (or 0.15% of total average annual rainfall) has been applied.

Table 3.4
Aquifer Parameters

Model Layer (L)	Aquifer/Aquitard	Aquifer Unit	Recharge applied		Horizontal Hydraulic Conductivity (K_h)	Vertical Hydraulic Conductivity (K_v)	Thickness (z)
m	*no units*	*no units*	*m/d*	*mm/yr*	*m/d*	*m/d*	*m*
L1	unconfined aquifer	River sand gravels	3.3×10^{-4}	130.0	10.0	1.0	15
L1	aquitard	outwash	1.5×10^{-6}	0.55	0.1	0.01	15
L2	aquitard	silt/clay	-	-	1.0×10^{-2}	1.0×10^{-3}	35
L3	aquifer	sand/gravel	-	-	20.0	2.0	10
	basement	granite	0.0	0.0	1.0×10^{-3}	1.0×10^{-3}	

3.4.3 Water Balance

The calibrated steady state water balance is presented in Table 3.5.

Table 3.5
Calibrated Steady State Water Balance

	Steady State Model (kL/d)	
	In	Out
Recharge	9430	0
Groundwater Inflow	230	0
Groundwater Outflow	0	1050
River Leakage	290	8900
Total	9950	9950

3.4.4 Additional Model Calibration Issues

The groundwater model developed was calibrated to steady state or long term average conditions. No calibration to transient or time varying conditions was completed. As a result, the model is not calibrated to values of aquifer storage (both confined and unconfined). Aquifer storage values assigned in the model for transient prediction runs are consistent with similar hydrogeological environments and are summarised in Table 3.5.

Table 3.6
Adopted Aquifer Storage Values

Model layer	Aquifer Unit	Storage Coefficient	Specific Yield
L1	river sand / gravel	1×10^{-4}	0.10
L1	Outwash	1×10^{-4}	0.01
L2	silt/clay	1×10^{-4}	0.01
L3	palaeochannel sand/ gravel	1×10^{-4}	0.10
L3	granite bed rock	1×10^{-5}	0.001

The lack of transient calibration also means that the models are calibrated to a single (non unique) combination of recharge and hydraulic conductivity values.

As outlined in Section 2.2.4, the De Grey River is assumed to be base flow driven within the modelled area and receive groundwater discharge from the underlying and surrounding aquifers. The current model set up assumes a river stage and river bed elevation consistent with available topographic information. The steady state modelled water balance however shows some recharge from the river to the aquifer, which accounts for less than 3% of the total water balance. It is anticipated that this will be addressed as part of further work.

As outlined above the model currently does not make any allowance for groundwater recharge from large flood events. Such recharge events, occurring every few years would serve to refill the upper aquifer and minimise any drawdown impacts. The absence of such recharge will add further conservatism to model predictions.

3.5 MODEL PREDICTION SCENARIOS

3.5.1 Borefield Scenarios

The projected water demand to be sourced from the De Grey palaeochannel aquifer is 4 GL per annum for a period of 10 years. Prediction runs were completed to assess a range of water supply schemes for the projected demand (4 GL per annum) and up to 8 GL per annum from the De Grey palaeochannel aquifer.

Water supply from the De Grey palaeochannel aquifer will be derived from aquifer storage and leakage from overlying units. Available measured groundwater levels in the palaeochannel aquifer suggest that groundwater levels are currently above the top of the aquifer and the aquifer is confined. Removal of any water from the aquifer will act to depressurise the aquifer and groundwater will be released from confined storage. Once water levels are drawn down to below the top of the palaeochannel aquifer, water will be released from unconfined storage. Unconfined storage coefficients are typically two orders of magnitude higher than confined storage coefficients as outlined in Table 3.6.

As outlined above the model was configured with fixed groundwater inflows and outflows, average recharge and river discharge conditions to provide conservatism in model predictions.

A series of model runs were completed to assess if pumping from the palaeochannel aquifer at a rate of 8 GL per annum was sustainable for a period of 10 years. All runs assumed pumping from 29 bores, at a pumping rate of 750 kL/d/bore and bore spacing along the palaeochannel of 1 km with every third bore not utilised (backup bore). A schematic borefield lay out is shown in Figure 3.14.

The following pumping constraints, consistent with an operational borefield were modelled (using the Evapotranspiration Package in Modflow) to obtain the required water demand.

Case A:

Palaeochannel aquifer remains confined in pumping cells with pumping decreasing once water levels are drawn to within 2 metres of the top of the palaeochannel aquifer. Pumping reduces to zero once water levels are drawn down a further 2 metres.

Case B:

Palaeochannel aquifer remains just confined (in pumping cells) with pumping decreasing once water levels are drawn down to the top of the palaeochannel aquifer. Pumping reduces to zero once water levels are drawn down a further 2 metres.

Case C:

Pumping decreases once water levels in pumping cells are drawn down to 2 metres below the top of the palaeochannel aquifer. Pumping reduces to zero once water levels are drawn down a further 2 metres.

Case D:

Pumping decreases once water levels are drawn down to 5 metres below the top of the palaeochannel aquifer (i.e. 50% depletion of palaeochannel aquifer thickness). Pumping reduces to zero once water levels are drawn down a further 1 metre.

Predicted pumping rates for Cases A to D are shown in Figure 3.15 and show a borefield yield of 8 GL per annum can only be sustained for 4, 4, 5 and 6 years for pumping constraints specified for Case A, B, C and D respectively.

Additional prediction runs were also completed, assuming the Case D pumping constraints (i.e. pumping rates decrease once aquifer thickness is depleted by 50% and pumping reduces to zero once water levels are drawn down a further 1 metre) to assess the sustainability of the palaeochannel aquifer for

- 4 GL per annum for 10 years (Scenario 1);
- 6 GL per annum for 10 years (Scenario 2); and
- 8 GL per annum for 5 years followed by 4 GL per annum for 5 years (Scenario 3).

The pumping scenarios are summarised in Table 3.7 and schematic borefield layouts are shown in Figure 3.16 and 3.17 for the 4 GL/annum and 6 GL/annum cases respectively; whereas the 8 GL/annum case is shown in Figure 3.14.

Table 3.7
Summary of Pumping Scenarios.

Scenario	Borefield Description
1	15 bores at 750 kL/d each at 1 km spacing. Total pumping of 4 GL per annum.
2	22 bores at 750 kL/d each at 1 km spacing. Total pumping of 6 GL per annum for 10 years.
3	29 bores at 750 kL/d each at 1 km spacing for 5 years (total pumping of 8 GL per annum) followed by 15 bores at 1 km spacing for 5 years (total pumping of 4 GL per annum).
4	29 bores at 750 kL/d each at 1km spacing. Total pumping of 8 GL per annum for 10 years (Case D).

Predicted pumping rates for Scenarios 1 to 4 are presented in Figure 3.18. The modelling results suggest that a demand of 4 GL per annum (Scenario 1) can be sustained by the palaeochannel aquifer for a 10 year period. Higher demands of 6 GL per annum (Scenario 2) and 8 GL per annum (Scenario 4) can be sustained for a period 9 and 6 years respectively. Additionally, a demand of 8 GL per annum demand for a period of 5 years (Scenario 3) followed by reduced rate of 4 GL/annum for the next 5 year period can be sustained from the proposed borefield.

The model predicted water balance for Scenario 1 at the end of the 10 year prediction period is presented in Table 3.8. The predicted water balance suggests that leakage from the river to the underlying and surrounding aquifers has increased from 290 kL/d to 3400 kL/d and that discharge to the river has decreased from 8900 kL/d to 5600 kL/d after 10 years of pumping from the palaeochannel aquifer. This change in stream flow of 3300 kL/day (1.2 GL/annum) is only 0.2% of the annual stream flow calculated for the site (WRC, 1996)

Table 3.8
Scenario 1 Predicted Water Balance After 10 Years of Borefield Pumping

	(kL/d)	
	In	**Out**
Recharge	9430	0
Groundwater Inflow	220	0
Groundwater Outflow	0	1050
River Leakage	3400	5600
Pumping	0	11250
Storage	4850	0
Total	17900	17900

Predicted drawdown contours for Scenario 1, for the alluvium, clay and palaeochannel aquifers are presented in Figures 3.19 to 3.21. Modelling results suggest that a significant part of the alluvium overlying the palaeochannel may be completely dewatered. A maximum drawdown of 45 metres is predicted in the clay overlying the palaeochannel and within the palaeochannel aquifer.

3.6 SENSITIVITY ANALYSIS

In any modelling exercise, there always remains uncertainty in adopted parameters. A sensitivity analysis was performed to assess the sustainability of water supply pumping from the palaeochannel aquifer under conditions of lower vertical hydraulic conductivity, horizontal hydraulic conductivity and confined aquifer storage. The sensitivity analysis can be used to identify critical controls on sustainability and provide some confidence limits about the predictions. The parameter values for the sensitivity analysis are on the lower end of the scale so they provide even further conservatism in water supply predictions. The following sensitivity runs were carried out for the 4GL per annum case (11,250 kL/d) in order to assess the uncertainty associated with model parameters:

Sensitivity Run 1: Vertical hydraulic conductivity of the clay (Layer 2) decreased to $1x10^{-4}$ m/d from earlier value of 1x10-3 m/d;

Sensitivity Run 2: Horizontal hydraulic conductivity of the palaeochannel aquifer decreased to 10m/d from earlier value of 20 m/d; and

Sensitivity Run 3: Confined storage of all aquifer/aquitard units (except the granite bed rock) decreased from $1x10^{-4}$ to earlier value of $5x10^{-5}$.

The results of the sensitivity analysis are presented in Figure 3.22. The results show that for Sensitivity Run 1, the required pumping rate (4 GL per annum) is not sustainable even for the first year with predicted pumping rates decreasing to 3.1 GL per annum (8,400 kL/d) after 10 years. For Sensitivity Run 2, 4 GL per annum is sustainable for 7 years, with the predicted pumping rate decreasing to 3.9 GL per annum (10,700 kL/d) after 10 years. For Sensitivity Run 3 however, there is no predicted change in borefield yield when the confined storage coefficient is reduced.

The sensitivity analysis shows that the Kv of the clay layer is the most important parameter dictating the supply potential of the basal conglomerate aquifer. If the Kv is low, the leakage from the upper aquifers and any potential recharge is restricted.

4.1 GROUNDWATER RESOURCES

Determination of the available Groundwater Resource from an aquifer requires an appreciation of the environmental, social and economic aspects. After consideration of these three requirements a weighted allocation can be made based on the relative value placed on each facet.

The identified environmental ecosystems that may be dependent on the De Grey groundwater system include:

- Phreatophytes (groundwater dependant vegetation) and the ecosystems they support, located within the riparian fringe of the De Grey River;
- Subterranean fauna that may exist in the aquifer and aquatard strata (e.g. Stygofauna); and
- Semi-permanent pools that persist after flood events and may be supported by groundwater discharge into the river.

The recognised social interests associated with the De Grey River, include:

- A place of recreation for local pastoralists, indigenous groups and occasionally, tourists; and
- A reserve of national significance, which pertains to the De Grey River alignment and aims to protect the ecosystems that depend on the river system.

The economic value of the resource is derived after consideration of:

- Any other competing economic interests;
- The capital cost to develop the water resource against other alternatives;
- The operating cost required to abstract the resource;
- The suitability of that resource for the intended purpose;
- Any constraints or resource specific requirements that may impinge upon the intended purpose; and
- Financial benefit derived from the use of this water resource.

The capital cost to develop the borefield is primarily associated with all installation costs up to the commissioning of the borefield. A number of water supply capital cost and risk studies have been performed by Moly Mines. The results of the studies demonstrated that a borefield along an extended length of the De Grey resource was not suitable for the total mine water requirements (18.8 GL/annum), but a smaller wellfield as outlined above, added significant value as a construction and start-up water supply, due to its proximity to the site. Furthermore it would add flexibility to project water management by serving as a peak demand and contingent source for the duration of the project.

An economic evaluation of borefield operating logistics must first consider the maximum permissible water level drawdown. This is considered analogous to the establishment of a maximum permissible dynamic water level in the pumping bores, which is standard water supply practice.

In the case of the De Grey palaeochannel, this level has been set to coincide to 2 m below the top of the palaeo-channel aquifer, which is between 50 m and 60 m below ground level, based on data from existing boreholes (Rockwater, 2006). An average of 50 m was assumed for modelling purposes. This pumping level criterion maintains the aquifer in confined conditions for the 10 year operating life at a rate of 4 GL per annum.

To successfully manage water levels near the De Grey River and variability within the palaeochannel aquifer, installation additional bores will be required. These bores will be used in rotation to effectively manage water level draw within the borefield.

4.2 GROUNDWATER RESPONSE TO ABSTRACTON

The groundwater model was designed to simulate the current groundwater system associated with the palaeochannel and the De Grey River. For aspects where the system is either poorly understood or disproportionately sensitive to abstraction, the model is constructed to overestimate the drawdown response. Of particular importance are the following parameters:

- The surface water recharge to the river is allows for water sourced only from the sub-catchment in the study area. It does not allow for the enormous volume of water that annually flows down the De Grey River during seasonal flooding. This approach has been adopted as the flood and recharge frequency from the De Grey are unknown. However, flood events are expected annually and the “topping up” of the alluvial aquifer system adjacent to the river is expected.
- A specific yield of 10% was used for the upper alluvium. This value is considered to be lower than typical for this unit (typical values in similar environments are often measured at between 15% and 25%). However in the absence of good field measurements a conservative value has been applied. This will have the effect of potentially over predicting drawdown within the upper alluvium.
- The sensitivity analysis performed for aquifer parameters shows that the abstraction is sensitive to permeability of the confining layer (Figure 3.22). However, at a Kv of 10^{-4} m/d which is considered impermeable for most applications and highly unlikely for this system, a pumping rate of 8.5 ML/day (3.1 GL/yr) is still possible at the end of 10yrs.

The predicted groundwater response to 10 years pumping for the 4 GL/annum scenario is shown in Figures 3.19 to 3.21. The figures graphically show the groundwater drawdown response within the three layers of the model with the pertinent outcomes summarised as:

- The upper alluvial system associated with the De Grey River, is effectively maintained by the limited recharge applied and without the annual flood events that will recharge the upper system during each wet season (Figure 3.19).
- Drawdown within the low permeability material overlying the granitiod is predicted in areas near the palaeochannel. Stock bores and wells located within these areas may suffer a reduction in water level (Figure 3.19).
- Drawdown of between 10 and 40 m is predicted within the confining layer and palaeochannel aquifer, however the palaeochannel aquifer is maintained as a saturated confined aquifer over the 10 year abstraction period (Figures 3.20 and 3.21).

4.3 BOREFIELD OPERATION

The borefield aims to achieve the following operational requirements:

- Supply water for the construction the Spinifex Ridge Mine site to the completion of the commissioning phase; and
- Supply peak demand and contingent water for the Spinifex Ridge Mine once operating.

To achieve these requirements the borefield will need to operate at its designed capacity (4 GL/annum) for the first two years of its operation. Once the primary water supply is installed and commissioned, the De Grey Borefield will serve as a peak demand and contingent water supply, operating within its designed capacity; that is, less than 4 GL/annum.

Internally, the borefield will also have redundant capacity in the form of additional bores. These will allow the management of water levels across the borefield. Examples of how this system will operate are:

- Increasing the spacing between individual bores to reduce interference drawdown between bores.
- Management of recharge to the palaeochannel from the De Grey River by regulating abstraction from near river bores to periods of river recharge. Thereby enhancing recharge without excessive drawdown.

The specific details of the management strategy can only be determined once the borefield is installed and tested. Once operating, this strategy will require ongoing management and review to incorporate the actual response to abstraction against the conceptual.

4.4 BOREFIELD INSTALLATION OBJECTIVES

The target abstraction rate from each bore is an average of 750 KL/day, with a cut-off yield of 500 KL/day. That is, sites capable of less than 500 KL/day will not be completed as production bores. For a 4 GL/annum supply a total of 15 operating bores are required with a further 3-4 bores completed as stand-by bores. For a 6 GL/annum supply a total of 22 operating bores are required with 6 stand-by bores. A baseline plan of a single line of 1 km spaced bores along the palaeochannel alignment is currently envisaged. Where the channel is determined to be wider or more permeable than predicted, two or more lines of bores in a staggered pattern may be possible.

The objectives required to achieve a successful borefield installation are:

- Minimise the number of production bore installations required to achieve the water supply by selecting the most productive sites;
- Ensure that adequate stand-by bores are installed to manage recharge and bore spacing;
- Minimise the borefield footprint and thereby limit ground disturbance and infrastructure cost, with a focus on the southern extent of the palaeochannel to minimise distance from Spinifex Ridge; and
- Ensure that adequate monitoring bores are installed to allow ongoing aquifer management and provide data for accurate model recalibration.

4.5 ESTIMATED BOREFIELD INSTALLATION COST

The estimated cost for completion of the borefield is based on the following assumptions:

- Supplying a demand of 4 GL/yr
- An average depth of all bores will be 60 m.
- Three exploration bores will be required to site one successful production bore.
- All production bores will be completed with 200 ID Class 12 uPVC bore casing with machine slotted screens.
- A total of 19 production bores will be completed (15 operating and 4 stand-by).
- Up to 20 monitoring bore sites will be completed.
- At some of the monitoring bore sites, multiple piezometers will be completed to allow monitoring of the upper and lower aquifers and the aquitard.
- Pump testing of each bore will be completed comprising of a four stage multi-rate test, 4 hour constant rate test and monitored recovery.
- A water sample will be taken from each bore at the completion of the constant rate test to analyse the groundwater chemistry.
- A borefield completion report will be completed by a suitably experienced Hydrogeologist.

Table 4.1
Borefield Installation Cost Summary[1]

Item	Description	Expenditure	Comments
Exploration Bores	57 Exploration Bores (3,420 m)	$500K	Drilling and rehabilitating exploration bore sites.
Monitoring Bores	20 Monitoring bores (completed from exploration borings)	$100K	Additional Expense required to complete with casing and complete as a monitoring bore.
Production Bores	19 Production Bores (1140 m)	1,300K	Includes concrete bore head and lockable bore cap.
Pump Testing	19 Step Tests 19 Constant Rate Tests	$100K	
Chemical Analysis	19 Production Bore Analyses 40 Monitoring Bore Analyses	$30K	Monitoring bores are sampled from both upper and lower aquifers
Total		$2,030K	

[1] Based on 2006 drilling rates with no contingency for drilling difficulties.

5.1 PROPOSED MONITORING PROGRAMME

The design of the groundwater monitoring programme should enable the collection of data that can be utilised in the effective management of the groundwater system. The objectives for the De Grey monitoring programme are:

- Establish a baseline data set;
- Monitor water levels in the upper (surface alluvium and outwash) and lower (palaeochannel) aquifers with a focus on the areas near the De Grey River system;
- Monitor water levels within and outside the palaeochannel to assess the performance of the aquifer and determine its spacial hydraulic characteristics;
- Monitor the chemical constituents of the groundwater in both the upper and lower aquifers to monitor water quality for suitability of use and aquifer performance;
- Monitor the health of groundwater dependent vegetation within and outside the cone of depression.
- Monitor water levels of identified pools located within the De Grey River to allow determination of any dewatering impact;
- Monitor the quantities abstracted from the borefield, both individual bores and total abstraction to allow calibration of the groundwater model and determine sustainable abstraction rates;
- Monitor any water levels in pastoralist bores or wells located within or in the vicinity of the borefield; and
- Collect climatic data, and ensure that data is measured within the vicinity of the borefield (i.e. within 50 km).

5.1.1 Groundwater Level Monitoring

The groundwater level monitoring will be achieved by measuring water levels within paired piezometers and production bores. The monitoring bores will be installed at locations within and outside the borefield with the following rationale:

- Paired piezometers will be installed in the alluvium and sealed in the palaeochannel where the Palaeochannel and the De Grey River cross or follow a common alignment;
- Single piezometers will be installed outside the palaeochannel and alluvium in the basement rocks; and
- Paired piezometers will be installed in the confining layer (aquitard) and palaeochannel where the alluvium is absent (i.e. away from the De Grey River).

The exact location of monitoring bores will be determined during the borefield installation programme.

In additional to water levels measured in monitoring bores, all pumping bores both active and standby will be monitored for water level. Gauging points will also be determined within the De Grey River to monitor the water levels of semi-permanent pools. Pastoralist stock bores and wells that are located within and near the predicted borefield drawdown will also be monitored where possible.

Figure 5.1 outlines the location of all monitoring points described in the proposed monitoring program

5.1.2 Groundwater Abstraction Monitoring

The volume of water abstracted will be measured via individual calibrated flow meters located on each of the production bore headworks. Readings will be collated and reported on a monthly basis.

5.1.3 Groundwater Chemistry Monitoring

Abstraction of water from a groundwater system is a dynamic process that may vary with time. The routine monitoring of groundwater abstracted from the borefield is performed to ensure that the water quality is suitable for its intended use and allow an understanding of aquifer performance to assist in management of the aquifer. The following table details the proposed monitoring program.

Table 5.1
Chemical Monitoring Program

Monitoring Point	Analysis Required				Monitoring Frequency
	Field	Standard	Metals	Other	
Production Bore	pH, Ec, Temperature	pH, Ec@25°C, TDS, Na, K, Ca, Mg, Fe, Cl, SO_4^{2-}, NO_3^{2-}, HCO_3^{2-}, CO_3^{2-}			Quarterly
Production Bore	pH, Ec, Temperature	pH, Ec@25°C, TDS, Na, K, Ca, Mg, Fe, Cl, SO_4^{2-}, NO_3^{2-}, HCO_3^{2-}, CO_3^{2-}	Mn, Al, Pb, As, Ca, Hg, Mo, Se, Ag, Zn, Ni, Cr(VI), Br, Bo, An	NH_3, F	Biannually
Monitoring Bore	pH, Ec, Temperature	pH, Ec@25°C, TDS, Na, K, Ca, Mg, Fe, Cl, SO_4^{2-}, NO_3^{2-}, HCO_3^{2-}, CO_3^{2-}			Biannually
Surface Water (De Grey)	pH, Ec, Temperature	pH, Ec@25°C, TDS, Na, K, Ca, Mg, Fe, Cl, SO_4^{2-}, NO_3^{2-}, HCO_3^{2-}, CO_3^{2-}	Mn, Al, Pb, As, Ca, Hg, Mo, Se, Ag, Zn, Ni, Cr(VI), Br, Bo, An	NH_3, F	Tri annually (March, July, November)

5.2 MANAGEMENT OF GROUNDWATER ABSTRACTION

The De Grey borefield is designed to draw water from a semi-confined palaeochannel aquifer. It relies on leakage from an overlying confining layer and to a limited extent, recharge via direct infiltration from rainfall (Figure 2.6). To manage water level drawdown across the borefield, cycling of production and standby bores will be required to ensure an even drawdown cone across the borefield.

The groundwater modelling performed to date does not allow for direct recharge to the palaeochannel from the annual flood events down the De Grey River. By drawing down water levels in the palaeochannel there is potential that some of the flood waters may recharge the palaeochannel where it crosses the De Grey River. While the recharge volumes would be a minor percentage of the total seasonal flows down the De Grey (600 GL/annum, WRC, 1996), they would further enhance the capacity of the borefield. This connectivity can only be practically determined once the operating borefield is commissioned.

5.2.1 Groundwater Level Triggers

There are primarily three requirements to the successful management of groundwater levels associated with the De Grey Borefield.

1. Minimise the drawdown within the upper alluvial aquifer associated with the De Grey River;

2. Maintain confined conditions within the palaeochannel; and
3. Minimise the interference effects between bores to ensure efficient operation.

Of these three considerations, items 2 and 3 are concerned with pumping bore hydraulics and will be modelled upon completion of the borefield using actual pump test data. Groundwater modelling has demonstrated that these items are achievable with conservative hydraulic parameters.

Item 1 aims to protect the ecosystem that relies on the upper alluvial aquifer associated with the De Grey River. The impact the borefield can have on this aquifer is considered low, due to annual flooding of the De Grey River each year, which effectively recharges the aquifer.

In the event that drawdown within the upper aquifer is observed to be excessive and the two aquifers are in direct connection, a seasonal pumping strategy can be implemented to replenish the palaeochannel during times of flood and reduce drawdown close to the river during the drier months.

6.1 CONCLUSIONS

The field investigation and groundwater modelling completed to determine the groundwater resource associated with the palaeochannel and De Grey alluvial system has demonstrated that a water supply of 4 GL/annum is conservatively sustainable from the palaeodrainage system for an operating life of at least 10 years. The borefield is planned for use as a start-up construction water supply and a peak demand water supply once the project is operating at full capacity.

6.1.1 Groundwater Resource

The resource determination is considered conservative due to the following constraints placed on abstraction:

- Water levels within the upper aquifer in the vicinity of the De Grey are maintained within natural variation;
- The lower aquifer remains fully saturated; and
- No additional recharge from the De Grey River to the palaeochannel is included within the model.

The aspects of the conceptual hydrogeological model that are poorly understood or of low confidence have been incorporated with conservative values. The most significant of these is the recharge model, which does not include provision for the very large volumes of water that may recharge the aquifer during annual flood events.

6.1.2 Borefield Configuration

The borefield configuration has been designed based on the results of the field investigation and existing borefields completed in similar settings. The borefield is planned to consist of 15 active pumping bores and 4 standby bores that will be sited to manage a sustainable drawdown across the borefield and limit any impact on the upper aquifer associated with the De Grey River.

6.1.3 Water Quality

The water quality is considered to be moderate to poor for use as a potable water supply and good for a stock or mineral processing purpose. The water quality may change with time due to either leakage from the overlying confining layer or recharge from the De Grey alluvial aquifer. The water monitoring program is designed to ensure that any significant change will be observed and enable a suitable management strategy to be developed in a timely way.

6.1.4 Groundwater Dependant Systems

There are currently three groundwater dependant systems that may be affected by abstraction from the borefield; namely, groundwater dependant flora, semi-permanent pools within the De Grey and stygofauna. The risk to these systems from pumping is considered low as water levels within the upper alluvial system can be managed sustainably by seasonal management of the borefield and the palaeochannel aquifer is maintained as a confined or fully saturated aquifer.

6.1.5 Monitoring and Management

The groundwater monitoring program is designed to ensure that the groundwater resource is able to be managed sustainability. This is achieved by installation of a monitoring bores within the palaeochannel aquifer, alluvial aquifer (DeGrey River) and surrounding basement. In addition to the monitoring bores is the monitoring of semi-permenant pools within the DeGrey River, nearby pastoral bores, subterranean fauna sampling and phreatophyte monitoring. Once operational, data collected from the monitoring network will be utilised to calibrate the DeGrey numerical model. This will allow detailed management of the borefield with establishment of individual bore abstraction rates, trigger water levels and a seasonal abstraction strategy.

Aquaterra (2006) Assessment of De Grey and Canning Borefields. Report 689/R099b (July 2006).

Eamus, D., and Froend, R. (2006), Groundwater-dependent ecosystems: the where, what and why of GDE's. Australian Journal of Botany, (2006), 54, 91-96.

Bureau of Meteorology website: http://www.bom.gov.au/climate/change/

Environmental Protection Authority (2002) Environmental Protection Act 1986, Environmental Impact Assessment (Part IV, Division I) – Administrative Procedures 2002.

Environmental Protection Authority (2006) Guidelines for Preparing a Public Environmental Review (PER) / Environmental Review and Management Programme (ERMP). Version 3 (July 2006).

Harbaugh, A.W., and McDonald, M.G., (1996), User's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96-485, 56 p.

JORC (2004) Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserved – The JORC Code. 2004 Edition (December 2004). [Prepared by: The Joint Ore Reserved Committee of the Australasian Institute of Mining and Metallurgy, Australia Institute of Geoscientists and Minerals Council of Australia (JORC)].

Moly Mines (2006) Spinifex Ridge – Molybdenum Project Pre-Feasibility Study (PFS) (February 2006).

Murray-Darling Basin Commission (2001), Groundwater Flow Modelling Guideline.

Rockwater (2006) Spinifex Ridge Pre-Feasibility Study: Bore Completion Reports De Grey River Area Groundwater Exploration Programme. Report 325.0/06/01 (February 2006).

Water and Rivers Commission (1996) Pilbara Region Water Resources Review and Development Plan 1996 (Volume 1 o 2). Water Resources Allocation and Planning Series Report WRAP 4 1996.

Water and Rivers Commission (2000) Surface Hydrology of the Pilbara Region: Summary Report. Surface Water Hydrology Series Unpublished Report SHW 32 2000.

Williams, I. R., (2000) Archaean geology of the Muccan region, East Pilbara Granite-Greenstone Terrane, Western Australia, Geological Survey of Western Australia Dept. of Minerals and Energy, (2000).

Winston, R.B., (1997), Riv6W and STR3W: Documentation of Modified Versions of the River and Streamflow-Routing Package that Retains Correct Boundary Conditions When Cell Go Dry, Baton Rouge, La.