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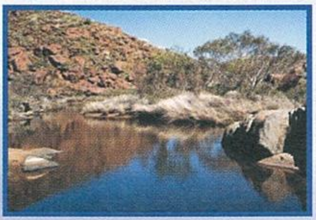
SPINIFEX RIDGE MINE



GROUNDWATER RESPONSE TO MINING

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SPINIFEX RIDGE
MINE DEWATERING AND GROUNDWATER DRAWDOWN

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EXECUTIVE SUMMARY

Moly Mines proposes to develop a Molybdenum-Copper resource in the Spinifex Ridge area, south of the Talga Range, located 50 km north east of Marble Bar and lying within the Shire of East Pilbara and on the Yarrie Pastoral Station. The mine is planned as a single open-cut mine to a depth of approximately 400 mbgl. The mine aims to produce approximately 15 Mt per annum which will be processed by the crushing, grinding, floating and leaching of molybdenum and copper sulphides to produce molybdenum and copper concentrates. The project is planned with a twelve year life of mine.

The hydrogeology of the Spinifex Ridge Mine is characterised by shallow alluvial and calcrete units overlying a weakly weathered rock mass, with rocks of low permeability. It is expected that upon excavation, moderate inflows up to 20 L/s will be encountered in the upper benches to a depth of 80 mAHD. Subsequent benches can expect inflows in the vicinity of 4 to 5 L/s. For a mine of this size these inflows are considered low. To achieve adequate dewatering of the mine, it is recommended that a sump pumping system is utilised. A system capable of pumping a peak of 30 L/s at 400m vertical head is recommended. After a more detailed understanding of where inflows occur, in-pit bores may assist in the dewatering effort.

In addition to managing groundwater inflows, significant pumping capacity will be required to manage seasonal surface-water inflows. The required capacity will be function of mine schedule flexibility and the level of acceptable risk to ore supply due to cyclonic rain events.

The regional groundwater response to dewatering is expected to be relatively localised with development of a steep hydraulic gradient surrounding the Spinifex open-cut mine due to the low permeability of the surrounding fresh rock mass. Potential exists for drawdown, in excess of natural variation, to occur within the calcrete and alluvial aquifers adjacent to the pit, particularly in the vicinity of drainage lines between the mine and Coppin Gap. Due to the high groundwater table and steep hydraulic gradient within the pit walls, a pit wall depressurisation system will be required. Further work is necessary to develop the system and integrate it into the mine planning process.

To manage any excessive drawdown at Coppin Gap while the mine is operating, artificial supplementation by either recirculating mine dewatering water (if of acceptable quality) or using surplus capacity from the mine water supply system can be implemented. Inflow into the mine via surface water and shallow groundwater will be mitigated by installation of a diversion drain and bunds across the drainage lines that are intersected by the pit.

Upon mine closure it is proposed that the surface water diversion bunds will remain in place and the mine void will behave as a ground water sink, with evaporative loss exceeding surface and groundwater inflow. The water levels within the void are expected to rise to between -90 and -30 mAHD over a period of up to 1000 yrs depending on climatic variation. The void water quality will, with time, increase in salinity but is not expected to acidify. Metals such as molybdenum and arsenic are likely to be present at levels that exceed guidelines for some uses; this is currently the case with natural Coppin Gap water. It may be possible to develop a sustainable lake system upon closure, however without a detailed and demonstrated understanding of the subsurface hydrogeology and geochemistry, the environmental impact of this closure strategy is difficult to predict with sufficient confidence at this stage.

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SECTION 1 - INTRODUCTION

1.1 PROJECT DESCRIPTION

Moly Mines proposes to develop a Molybdenum-Copper resource in the Spinifex Ridge area, south of the Talga Range, located 50 km north east of Marble Bar and lying within the Shire of East Pilbara and on the Yarrie Pastoral Station (Figure 1.1). The mine is planned as a single open-cut mine to a depth of approximately 400 mbgl. The mine aims to produce approximately 15 Mt per annum which will be processed by the crushing, grinding, floating and leaching of molybdenum and copper sulphides to produce molybdenum and copper concentrates. The mine and crusher will be located on the southern side of the Talga Range, while the plant is located on the northern side. The crusher will be connected to the plant grinding and floatation circuit via a conveyor system which will pass through the Talga Range by means of a tunnel. The mine tails dam will consist of a circular upstream raised impoundment and will also be located on the northern side of the range. The project is planned with a twelve year life of mine.

1.2 REPORT OBJECTIVES

The hydraulic interaction that the mine may have with the local surface and groundwater system has not been firmly established. An understanding of this issue is required to address both the dewatering and depressurisation requirements and to assess the influence the mine will have on the natural system. Of specific importance is the impact the mine operation may have on a semi-permanent pool known as Coppin Pool.

Aquaterra have been commissioned by Moly Mines to investigate the possible environmental impact due to the proposed dewatering; predict the dewatering volumes and water level drawdown in and around Coppin Gap area and to describe the groundwater regime upon closure of the mine.

The purpose of this report is to:

- Present the results of field investigations and describe the regional hydrogeology and detail the local hydrogeology;
- undertake numerical groundwater modelling to assist with the predictions of dewatering drawdown, dewatering requirements and the hydraulic behaviour of the mine void upon closure; and
- recommend an appropriate groundwater monitoring and management programme that focuses on the operational, environmental and closure requirements.

SECTION 2 - FIELD INVESTIGATION

2.1 PREVIOUS WORK

Since acquiring the Spinifex Ridge Project, Moly Mines has developed the Spinifex Ridge Resource to a Feasibility level. The investigations performed as part of this study include hydrogeological investigations, water sampling and water level monitoring and detailed observations associated with the resource drilling.

2.1.1 Resource Investigation

During the development of the resource, several drilling programs have been completed with conventional air percussion, reverse air circulation and diamond drilling methods. The primary aim of the resource drilling is to statistically quantify the Spinifex Ridge Ore Deposit to a resource definition code (JORC).

During the resource drilling investigation a large quantity of non-resource related data is collected to aid the understanding of subsurface features likely to be encountered upon development of the resource. Some of the information collected that is pertinent to the determination of groundwater includes:

- water strikes and estimates of yield or increase in yield;
- structural defects and areas of difficult drilling or lost of drilling circulatory fluids, and;
- drilling penetration rates.

From the drilling records the following water related features have been observed:

- Boreholes drilled with water yields greater than 0.25 L/s have been encountered within or associated with surface water drainage systems (refer Figure 2.1).
- The subsurface intersection credited with providing a majority of the water yielded has been encountered from 2 to 12 mbgl (m below ground level).
- Samples from diamond core indicate that:
    - Large structural defects such as faults and shears are generally narrow (<1 m) and appear to be compressive rather than dilated. There is little or no evidence of secondary mineral growth within defects;
    - Most secondary defects such as joints and fractures are healed within the fresh rock and weakly stained or with only minor (<2 mm) fill within weakly weathered rock.
- The weathering profile across the site is weakly developed with near surface rocks being moderate to weakly weathered and typically fresh from 50 to 70 mbgl. The depth of weathering is deeper where large scale shears or faults exist.
- Most rock types have proven “hard” and featureless, consequently penetration rates have been low.
- Siting water bores away from drainage lines is difficult with a number of “prospective” sites proving to have limited capacity and “going dry”.

Overall, a large number of exploration boreholes have been drilled into the ore body at Spinifex Ridge. Many extend to depths over 300 mbgl. To date, only a limited number of boreholes with marginal groundwater yields (~2 L/s) have been encountered, with a large majority of these associated with the creek system.

2.1.2 Previous Hydrogeological Investigations

Rockwater Pty Ltd was engaged to assess the dewatering requirements and groundwater interaction with the surface water expression at Coppin Gap. A report was completed in January 2006 titled ‘Dewatering Assessment for Proposed Spinifex Ridge Molybdenum Mine’. The investigation was designed to estimate the dewatering requirements and potential drawdown on the surrounding area. The report documents hydraulic testing carried out in the pit area at Spinifex Ridge, characterises the rock mass and a basic numerical model was constructed to estimate the potential dewatering requirements and influence of the mine on water levels in the vicinity of Coppin Gap.

During the course of the investigation fourteen airlift tests were carried out on previously drilled diamond holes. The diamond holes were chosen, as they are drilled with minimal wall rock degradation or erosion of fractures. With the exception of two anomalous results associated with inflow contribution from the creek system, the testing showed the rock types relevant to the proposed open cut mine to have low permeability and transmissivity. Consequently, the groundwater modelling predicted that dewatering requirements would be low and the impacts on groundwater levels at Coppin Gap would be minimal. At the time of their investigation, access to investigate the subsurface zone between the proposed mine and Coppin Gap was not possible.

2.1.3 Groundwater Monitoring

2.1.3.1 Water Levels

Subsequent to the Rockwater investigation Moly Mines have undertaken an extensive monthly groundwater monitoring program across the project area. Up to 80 monitoring points have been established utilising open exploration boreholes to measure the groundwater levels. A monthly plot of groundwater contours is displayed in Appendix D.

2.1.3.2 Water Chemistry

To establish a baseline water quality, samples were taken from four of the test bores as part of the Rockwater investigation and monthly samples have been taken from the surface water expression at Coppin Gap. The samples from the bores were analysed for major constituents while the Coppin Gap samples are analysed for major anions, cations and metals.

2.2 OBJECTIVES

Aquaterra Consulting Pty Ltd (Aquaterra) has been commissioned to review the available hydrogeological data, complete a field investigation and construct a 3D numerical groundwater model in order to achieve the following outcomes:

- a time dependent estimate of the dewatering requirements during the mining phase;
- the potential water table drawdown associated with mine dewatering on the existing environment, with appropriate management and monitoring recommendations during operation; and
- predict the groundwater system upon closure of the mine and recommend appropriate closure strategies to re-establish the groundwater system.

This study is based on a combination of hydrogeological field data generated by Rockwater Pty Ltd (Rockwater) and presented in Rockwater, 2006, with additional data from subsequent resource drilling programs, hydrogeological investigations performed by Aquaterra and Moly Mines exploration staff. The results of all field investigations are presented within this report.

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).

2.3 APPROACH

The approach for the investigation was developed based on the following background understanding:

- Results from the Rockwater investigation demonstrated that the rock mass within and surrounding the Spinifex Ridge deposit was typically of very low permeability. This conclusion was derived from hydraulically testing a large number of exploration boreholes and is regarded as satisfactory to characterise the majority of the rock mass present within the proposed mine.
- The zones of highest permeability were associated with near surface features coincident with drainage lines across the site.
- The main area of hydrogeological uncertainty concerns the rock mass between the proposed open-cut and Coppin Gap.
- Although no areas of significant hydraulic conductivity were encountered during the resource drilling or hydraulic testing programmes, the deposit is heavily faulted and hydraulically conductive structures may exist, further drilling was performed, targeting the larger and more prominent of the interpreted structures.

The investigation has been undertaken with the following phased approach:

- ❍ ***Phase 1*** – Review existing data and develop a program of work to investigate unexplored areas, notably between the proposed mine and Coppin Gap;
- ❍ ***Phase 2*** – Complete necessary field work to complete the hydrogeological understanding of the Spinifex Ridge Site including the tailings dam area;
- ❍ ***Phase 3*** – Construct a three dimensional numerical groundwater model to assess the dewatering requirements, spacial change in groundwater levels during mining and post mining, and
- ❍ ***Phase 4*** – Devise suitable management strategies to mitigate any unacceptable outcomes.

2.4 HYDROGEOLOGICAL SITE INVESTIGATION

Three areas within or near the project area were investigated to understand the hydrogeology of the area and its potential hydrogeological response to the intended mining activity.

2.4.1 Coppin Gap

The hydraulic mechanism that controls the existence of the surface water expression at Coppin Gap is understood to be a function of both surface and groundwater systems. While the surface water system is well understood, an understanding of the conceptual groundwater model for the zone between the proposed Spinifex Ridge Open-Cut mine and Coppin Gap was less clear.

The investigation was designed to enable a formation of a sound conceptual model. The field work consisted of:

- A drilling investigation was completed between 9 October - 5 November 2006.
- Hydraulic testing program completed between 5 - 10 December 2006 and during March 2007.
- Groundwater sampling program completed on 2 January 2007.
- Laboratory analysis of groundwater samples completed by 2 March 2007.

The drilling investigation was performed in accordance with 26D licence No.CAW161199(1), issued by the Department of Water (DoW) on 6 July 2006 (Appendix G). The drilling was performed with a T685WS Schramm Rotadrill owned and operated by McKay's Drilling. The rig was equipped with a 1360 cfm / 500 psi onboard compressor and supported by a booster and auxiliary compressor. The drilling methods utilised were a combination of Open Hole Rotary Air Percussion, Reverse Circulation Rotary Air Percussion and Casing Advance (ODEX) Rotary Air Percussion.

The approach for each site was to drill a deep borehole, recording fracture intersections, penetration rates and air-lift yields (at the end of each 6m rod). From the data collected and the geological log, one sealed piezometer bore was completed in the fresh rock type and depending on the identified aquifer or aquitard above, additional monitoring bores were completed in the different layers encountered.

From the drilling investigation four distinct hydraulic units were observed. These are - alluvium, a weakly formed calcrete, weathered rock and fresh rock. The number and type of monitoring bore(s) installed at each site was designed to screen rock types of different hydraulic character. That is, where the rock type intersected was determined to be hydraulically dissimilar over an intersection of greater than 6m, a separate monitoring borehole was completed to discretely screen that unit.

At each of the seven monitoring sites, two distinct zones were identified and two monitoring bores were installed at each site with the exception of:

- Site SRWB07 where only one bore was completed due to difficult drilling conditions and limited drill pad size; and
- Site SRWB05 where three dissimilar units were identified and drilling difficulties prevented completion of a sealed piezometer within the fresh rock mass.

A total of 13 monitoring bores were completed at 7 sites. A summary of each monitoring bore completion is captured in Table 2.1. Comprehensive borelogs are presented in Appendix A.

Table 2.1
Monitoring Boreholes

Bore Hole	Northing m(GDA94)	Easting m(GDA94)	TOC m(AHD)	Water Level mAHD	Hole Depth (m)	Screened Rock Type	Screened Interval (m bc)
SRWB04(S)	199843.159	7687351.305	160.588	156.09	12	Weathered Felsic	6 - 12
SRWB04(D)	199839.11	7687355.314	160.376	152.18*	60	Fresh Basalt	43.5 - 55.5
SRWB05(S)	199954.784	7687481.289	159.514	156.09	30	Weathered Felsic	16.3 - 28.3
SRWB05(D)	199955.969	7687485.023	159.439	155.96	96	Weakly Weathered Felsic	53 - 65
SRWB06(S)	200014.963	7687610.467	158.382	155.73	20	Calcrete/Weathered Ultramafic	12 - 18
SRWB06(D)	200016.466	7687614.291	158.158	155.81	65	Fresh Ultramafic	51.5 - 63.5
SRWB07(S)	200069.85	7687790.858	156.637	154.74	54	Alluvium	0 - 6.7
SRWB08(S)	200041.34	7687906.552	160.021	153.87	18	Calcrete (weak)	12 – 18
SRWB08(D)	200046.176	7687912.216	159.812	140.21*	60	Ultramafic (fresh)	48 – 60
SRWB09(S)	199847.217	7687885.017	156.666	153.97	14	Calcrete (weak)	2 – 14
SRWB09(D)	199847.401	7687880.67	156.765	142.07*	54	Ultramafic (fresh)	42 – 54
SRWB10(S)	199571.797	7687820.482	157.787	155.59	20	Calcrete (weak)	2 – 20
SRWB10(D)	199568.078	7687817.887	157.78	150.23*	60	Ultramafic (fresh)	48 - 60

* Note – water levels were recovering during the reading. Due to very low permeabilities actual rest water levels were difficult to determine.

2.4.2 Proposed Mine

The previous investigation completed by Rockwater had failed to identify an aquifer capable of sustaining a bore yield greater than 5 L/s from units intersected at depths greater than 50 mbgl. With the advantage of information from additional resource drilling and an interpretation of large scale structures by Moly Mines Geological Staff, a program of up to four (4) drill holes to a depth of 200 mbgl was devised. The location of the boreholes and major structures are shown on Figure 2.2. None of the four holes, or any additional resource boreholes drilled subsequent to the Rockwater investigation, have recorded water strikes worth completing as a water bore (i.e. airlift yields greater than 1 to 2 L/s). A plan of all resource boreholes that have recorded water strikes greater than 0.25 L/s is presented as Figure 2.1.

2.4.3 Hydraulic Testing

A comprehensive programme of hydraulic testing has been performed on the various rock types encountered at Spinifex Ridge. Given that the majority of rock types encountered across the deposit are weakly weathered or fresh from the surface, any permeable zones within the rock mass are likely to be associated with faults, shears or large defects. To reduce the risk of “missing” a significant hydraulic feature, all tests have been performed on open holes rather than sealed holes or packed holes. This approach ensures that any transmissive fault will not be missed or isolated during the tests and provides an approximation on the total permeability of the rock unit rather than isolated features. Notwithstanding this approach, none of the resource drilling to date has identified significant groundwater yields that are associated with a structural feature.

The hydraulic tests performed consisted of:

- Short term airlift tests.
- Medium term, low yield constant rate pumping tests.
- Pumping and airlift recovery tests.
- Falling head tests.
- Slug Tests.

The tests completed and results are presented in Table 2.2. Plots of the analysed data are presented in Appendix B.

2.4.4 Groundwater Chemistry

During the field investigations undertaken within the project area, water samples have been taken at a number of locations, namely:

- Proposed Spinifex Ridge Mine (Rockwater, November 2005).
- Proposed Tailings Dam (Moly Mines, January, 2007).
- Creek System between Mine and Coppin Gap (Moly Mines, January 2007).
- Monthly water samples from Coppin Gap pool (From November 2005).

The samples were taken in accordance with Australian Standards for Water Sampling (AS, 1998) and submitted to a NATA accredited laboratory. A summary and copies of the laboratory results are presented in Appendix C, with results discussed in Section 3.2.3.5.

Table 2.2
Hydraulic Tests Performed on Boreholes

Bore Name	Easting GDA94 Z51	Northing GDA94 Z51	RL(TOC) mAHD	Test Method	Aquifer Tested	Aquifer Thickness Tested	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Test Performed by	Comments
SRD50	198747	7687404	170.4	Airlift	Felsic	100	0.04	0.004	Rockwater	
SRD55	198732	7687194	173	Airlift	Felsic	100	0.004	0.0004	Rockwater	
SRD56	198986	7687191	163	Airlift	Basalt	100	0.001	0.0001	Rockwater	
SRD59	198432	7687299	183.18	Airlift	Basalt	51	0.03	0.00003	Rockwater	
SRD62	198919	7687411	175.143	Airlift	Basalt	58	0.13	0.002	Rockwater	
SRD65	198922	7687576	163.5	Airlift	Weathered Felsic	11	370	34	Rockwater	
SRD69	198824	7687560	180.02	Airlift	Felsic	100	0.04	0.004	Rockwater	
SRD70	198584	7687708	186	Airlift	Basalt	100	0.12	0.012	Rockwater	
SRD75	198810	7687730	172.661	Airlift	Felsic	100	0.0004	4x10-6	Rockwater	
SRD76	199055	7687703	174.18	Airlift	Basalt	100	0.26	0.0026	Rockwater	
SRD77	198968	7687659	161.636	Airlift	Basalt	69	830	12	Rockwater	
SRD79	199049	7687478	162.002	Airlift	Felsic	40	0.5	0.01	Rockwater	
SRD80	198541	7687411	183.042	Airlift	Felsic	50	0.8	0.02	Rockwater	
RC93	198833	7687414	168.44	Airlift	Basalt	85	0.12	0.001	Rockwater	
SRC1	197754	7687439	185.587	Slug	Ultramafic	43	0.04	0.0009	Rockwater	
SRC2	197773	7687313	174.669	Airlift	Ultramafic	54	130	2.4	Rockwater	
SRC3	197756	7687201	176.635	Airlift	Basalt	52	0.12	0.002	Rockwater	
SRC4	197729	7687093	193.697	Slug	Basalt	40	0.025	0.0006	Rockwater	
SRC7	197389	7687199	175.722	Airlift	Ultramafic	60	0.0002	0.000003	Rockwater	
SRC27	195953	7687333	187.729	Airlift	Ultramafic	51	0.02	0.0004	Rockwater	
SRC32	195616	7687428	201.518	Slug	Ultramafic	34	0.03	0.0009	Rockwater	
SRC33	195618	7687330	184.932	Airlift	Ultramafic	53	0.1	0.002	Rockwater	
SRC34	195595	7687205	186.177	Airlift	Ultramafic	52	0.09	0.002	Rockwater	
SRC35	195599	7687086	194.886	Airlift	Ultramafic	45	0.05	0.001	Rockwater	
TDRC01	197019.739	7692199.766	136.911	Falling	Weakly Weathered Granite	42	36	0.86	Aquaterra	
TDRC03	198599.705	7692197.802	142.296	Falling	Weakly Weathered Granite	28	8.1	0.29	Aquaterra	
TDRC05	197401.184	7691403.453	141.177	Falling	Weakly Weathered Granite	42	1.6	0.04	Aquaterra	
TDRC06	198198.343	7691400.964	142.946	Falling	Weakly Weathered Granite	44	0.9	0.02	Aquaterra	

Bore Name	Easting GDA94 Z51	Northing GDA94 Z51	RL(TOC) mAHD	Test Method	Aquifer Tested	Aquifer Thickness Tested	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Test Performed by	Comments
TDRC07	199249.661	7691399.017	147.81	Falling	Fresh Granite	35	0.004	0.0001	Aquaterra	
TDRC08	196601.146	7690599.696	146.697	Falling	Weakly Weathered Granite	44	35	0.80	Aquaterra	
TDRC09	197400.506	7690596.313	144.253	Falling	Weakly Weathered Granite	45	9.4	0.21	Aquaterra	
TDRC10	198199.504	7690600.134	144.657	Falling	Faulted Granite	8	16	2	Aquaterra	
TDRC11	199248.031	7690602.664	147.997	Falling	Weakly Weathered Granite	43	13	0.31	Aquaterra	
TDRC13	198199.668	7689802.117	150.379	Falling	Faulted Granite	34	280	8.2	Aquaterra	
SRWB04(S)	199843.159	7687351.305	160.588	AR	Calcrete	12	6.7x10^{-1}	5.6x10^{-2}	Aquaterra	
SRWB04(D)	199839.11	7687355.314	160.376	AR	Basalt	12	2.1x10^{-1}	1.8x10^{-1}	Aquaterra	
SRWB05(S)	199954.784	7687481.289	159.514	FH	Calcrete	12	5.3	4.6x10^{-1}	Aquaterra	
SRWB05(S)	199954.784	7687481.289	159.514	AR	Calcrete	12	59	5	Aquaterra	
SRWB05(D)	199955.969	7687485.023	159.439	AR	Fault Zone?	80	3	2.5x10^{-1}	Aquaterra	
SRWB06(S)	200014.963	7687610.467	158.382	Slug	Calcrete	12	31	2.6	Aquaterra	
SRWB06(S)	200014.963	7687610.467	158.382	AR	Calcrete	12	0.6	0.05	Aquaterra	Poor fit
SRWB06(D)	200016.466	7687614.291	158.158	Slug	Ultramafic	16.5	12	7x10^{-1}	Aquaterra	
SRWB06(D)	200016.466	7687614.291	158.158	AR	Ultramafic	16.5	6x10^{-2}	3.7x10^{-3}	Aquaterra	
SRWB07(S)	200069.85	7687790.858	156.637		Alluvium	6.7				Water Level only
SRWB08(S)	200041.34	7687906.552	160.021	AR	Calcrete	12	1.8	0.15	Aquaterra	
SRWB08(D)	200046.176	7687912.216	159.812		Ultramafic	12			Aquaterra	No effective test
SRWB09(S)	199847.217	7687885.017	156.666		Calcrete	12			Aquaterra	No effective test
SRWB09(D)	199847.401	7687880.67	156.765	AR	Ultramafic	12	1.3x10^{-5}	1.1x10^{-6}	Aquaterra	
SRWB10(S)	199571.797	7687820.482	157.787	CR-Rec	Calcrete	20	132	6.6	Aquaterra	
SRWB10(D)	199568.078	7687817.887	157.78	AR	Ultramafic	12	1.7x10^{-6}	1.4x10^{-7}	Aquaterra	
SRC103	198644.26	7687250.72	167.98	CR	Basalt	250	1.4x10^{-2}	8x10^{-5}	Aquaterra	
SRC103	198644.26	7687250.72	167.98	CR- Rec	Basalt	250	1x10^{-3}	6x10^{-6}	Aquaterra	
SRD087	198541.19	7687410.01	182.91	CR	Weathered Felsic	182	1.8 to 98	6.3x10^{-3} to 0.3	Aquaterra	Storage 3x10^{-4} to 8x10^{-3}
SRD087	198541.19	7687410.01	182.91	CR-Rec	Weathered Felsic	182	0.37	1.3x10^{-3}	Aquaterra	
SRD067	198698.4	7687558	191.04	CR	Fresh Felsic	450	4.5x10^{-2}	1x10^{-4}	Aquaterra	
SRD067	198698.4	7687558	191.04	CR-Rec	Fresh Felsic	450	2.3x10^{-1}	4.7x10^{-4}	Aquaterra	

CR = Constant Rate Test, AR = Airlift Recovery, Slug = Slug Test, FH= Falling Head Test

SECTION 3 - PHYSICAL ENVIRONMENT

3.1 REGIONAL

3.1.1 Regional Geology

The regional geology of the area is explained in the reports linked to the Muccan (1:100,000) and in Yarrie (1:250,000) geological sheets. 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. Most of the area is underlain by greenstone successions and granitoid complexes and are unconformably overlain by volcanogenic sedimentary rocks of Fortescue group, Eel Creek Formation, fluvioglacial Paterson Formation (Lower Permian) and fluvial deposits of Jurassic-Cretaceous Callawa formation. The greenstone succession comprises metamorphosed mafic and felsic igneous and sedimentary rocks of the Warrawoona Group (Williams, 1999). The Warrawoona Group mainly outcrop in the eastern extension of Marble Bar Belt and are intruded by younger plutons of Mount Edgar Granitoid Complex (Williams and Collins, 1990). The steeply dipping metamorphosed mafic and ultramafic volcanic and intrusive rocks with banded cherts of unassigned Warrawoona Group outcrop northeast of Coppin Gap and in the Kennedy gap near Yarrie Mining Village area indicates the occurrence of continuous greenstone belt in the past.

The Cainozoic rocks cover most of the area and are common on the granitoid complexes. The superficial material comprises both consolidated and unconsolidated alluvium, colluvium and residual deposits. To the south of De Grey River the granitoid rocks are overlain by deposits of consolidated clay, carbonate cemented poorly stratified gravel, sand and silty alluvial (Williams, 1999).

The basement rocks are dissected by several faults trending northwest to northeast and numerous intrusions of dolerite dykes and quartz veins. The dykes are generally trending north and north-northeast direction.

3.1.2 Regional Climate and Hydrology

In the Pilbara region, the climate would be described as arid with wet summers, while the waterways are typically ephemeral, generally flowing only a few times a year.

In the Spinifex Ridge area, daily maximum winter temperatures average 27°C during the day and daily minimums average 13°C at night. With further distance inland the overnight temperatures drop even lower. Daily maximum summer temperatures average 41°C during the day and daily minimums average 26°C at night. Average temperatures are higher further inland due to the absence of a cooling sea breeze. Marble Bar, some 50km south west, is widely known as the hottest town in Australia due to its consistently high temperatures. It holds a record of 160 consecutive days of +100 degrees F, set in 1923/24. Due to the hot dry climatic conditions, bush fires are common in this region.

The average annual rainfall for the Spinifex Ridge area is 360mm and this falls mostly in the summer months due to cyclone activity and localised thunderstorms. The average annual evaporation is 3,285mm, with average monthly evaporation far exceeding the average monthly rainfall.

Table 3.1
Climate Stations

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

The De Grey River catchment is the main drainage system in the north east Pilbara area, as shown on Figure 3.1. It is one of the largest river systems in the Pilbara, with a total catchment area of around 50,000 km^2 and extends as far eastwards as the Great Sandy Desert. The Oakover and Nullagine Rivers (large rivers themselves) combine about 50 km south east of Shay Gap to form the De Grey River. Further downstream near the mouth of the De Grey River (located about 70 km north east of Port Hedland), several major rivers join into the De Grey River. These rivers include the Coongan, Shaw, East Strelley and West Strelley.

The Spinifex Ridge catchment drains northwards into Kookenyia Creek which discharges into the De Grey River. Immediately east of Spinifex Ridge, Bamboo Creek and Miningarra Creek also flow northwards before discharging into the De Grey River. Immediately south, Eight Mile Creek flows westwards, before discharging into the Coongan River.

Flood discharge, flow and water level data are not recorded on the waterways in the general Spinifex Ridge area, so accurate relationships between rainfall, runoff and flood level have not previously been derived. Therefore, analytical techniques that calculate the run-off characteristics on a regional basis have been relied upon to produce discharge estimates in this area.

3.1.3 Regional Hydrogeology

The occurrence of groundwater is ubiquitous across the northern Pilbara region and largely associated with the following main aquifer types:

- Moderate to high yielding alluvial aquifers associated with either major river systems or the 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 they outcrop. 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 greatest potential for large scale groundwater exploitation in the area directly adjacent to the proposed mine. 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.

3.2 SPINIFEX RIDGE

3.2.1 Spinifex Ridge Geology

The geology of the Spinifex Ridge Mine Site and surrounding area consists primarily of Archean Rocks that are overlain by recent alluvial deposits where modern drainage systems occur. The geological structure is defined by two granitoid complexes to the north (Muccan Granitoid Complex) and south (Mt Edgar Granitoid Complex) of the proposed pit with sedimentary and volcanic sequences interleaved within the two plutons. The interleaved sequence consists of rocks pertaining to the Warrawoona Group and Gorge Creek Group (Willams, 1999).

Structurally, the area is complex, with extensive faulting and shearing. The rocks of the Warrawoona Group and George Creek Group are tightly folded to form an east-west trending syncline (Coppin Gap Syncline). The syncline has been extensively faulted and sheared, displacing units by significant distances (hundreds of metres). The axis of the syncline in the vicinity of Spinifex Ridge is coincident with the Talga Range. Faulting is typically sub-vertical with fault sets of east-west and north-south trending orientation that obliquely transect rock units or terminate locally along discontinuities. The structural evolution of the region is broadly defined as an early extensional phase characterised by listric normal faulting which created large scale shear zones such as the Bamboo Creek Shear Zone. These shears were associated with the intrusion of the Muccan and Mt Edgar Batholith’s. Subsequent deposition of the sediments and volcanics of the George Creek Group is characterised by compressive folding and faulting events during the emplacement of the formations within the group and attributed to the tectonic activity associated with the continued rise of the Muccan and Mt Edgar Batholiths. Faulting associated with these events is compressional (Nijman et al, 1999). The fault system generated by these events is interpreted to have provided a zone of weakness that is exploited by the younger mineralised Granodiorite which deposited the Spinifex Ridge Ore Body.

The Talga Range is defined by rocks of the Nimingarra Iron Formation (George Creek Group) which is comprised of BIF Jaspilite (Banded hematite and red jasper), ferruginous chert, black (pyritiferous) shale and mudstone. The Nimingarra Iron Formation is unconformably underlain by the Warrawoona Group. On the northern limb of the syncline this consists of a relatively thin (<200m) zone of unassigned units within the Warrawoona Group namely, tremolite-chlorite schists and metamorphosed basalts (upper green schist facies). On the southern limb, beneath the Nimingarra Iron Formation are the units that consist of ultramafic and High-Mg basalts collectively termed Euro Basalt. This unit dips at between 70 and 80 degrees towards the ridge (north) in the vicinity of the Spinifex Ridge Site.

The unit (particularly the ultramafic units) are sheared by a large shear known as the Bamboo Creek Shear Zone. The shear zone extends from the Seven Oaks mining area through the Bamboo Creek Mining area and to the west of Spinifex Ridge. In the vicinity of Spinifex Ridge the shear zone is coincident with the southern side of the ridge. Intruded within the Euro Basalt is a rhyodacite porphyry that strikes and dips at a similar orientation to the Euro Basalt Formation. It is postulated that the porphyry is an apophyses of the Coppin Gap Granodiorite (Jones, 1990), which forms the granitoid to the south and is encountered at depth as one of the sulphide mineralised host rocks of the Spinifex Ridge Mo/Cu deposit. The occurrence of the Spinifex Ridge Deposit understood to be associated with the intrusion of the porphyry and Granodiorite.

Underlying the Euro Basalt Formation and rhyodacite intrusion are the discontinuous felsic volcanic and chert units of the Panorama Formation. These units are up to 800m thick in the vicinity of Kitty's Gap and thin to approximately 100m to the south of Coppin Gap (Willliams, 1999). The unit forms a discontinuous, disconformable contact with the tholeiitic and ultramafic lavas of the underlying Apex Basalt Formation. All Formations of the Warrawoona Group are steeply dipping, typically towards the north at between 60 and 80 degrees in the vicinity of Spinifex Ridge.

Surficial Quaternary deposits of alluvium and colluvium are associated with current drainage lines and hill slopes. In the vicinity of Spinifex Ridge there are alluvial deposits of up to 10m thick within and surrounding the ephemeral creeks (Coppin and Kookenyia). Associated with the drainage system is a weakly formed calcrete that is largely derived from altered carbonate-rich ultramafic rocks. The calcrete forms sheets, encrustations and joint fills within the carbonate-tremolite-chlorite altered rocks (Williams, 1999). Colluvial deposits in the form of scree and talus form at the base of the Talga Range and are largely derived from the erosive product of the George Creek Group.

3.2.2 Spinifex Ridge Hydrology

The general Spinifex Ridge Project area is set in a rugged landscape. Two breaks in Spinifex Ridge known as Coppin Gap and Kitty's Gap, concentrate flow from the upstream catchments and allow it to pass through the ridge. Floodwaters downstream from these two gaps then flow about 25km northwards before discharging via Kookenyia Creek into the De Grey River. The catchment area of the De Grey River upstream from the confluence with the Coppin and Kitty's Gap waterways is 27,000km^2. This is much larger than the Coppin and Kitty's Gap catchments (combined catchment area of about 82km^2).

The catchment upstream of Kitty's Gap has an area of 2.9km^2. This catchment is relatively small in comparison to the catchment area upstream of Coppin Gap of 79km^2, as illustrated on Figure 3.1. Kitty's Gap catchment has a relatively high relief and hence rapid response to rainfall. The waterways in the catchment are clearly defined incised channels and typically pass between rocky outcrops. The vegetation is typically low scrub and trees scattered across the terrain with the dominant vegetation type being Spinifex.

There are two main catchments upstream of Coppin Gap. The first of these catchments is the area to the east which has an area of 25km^2. This eastern catchment has similar geomorphology to Kitty's Gap catchment in that it is has a rocky terrain with high relief and a rapid response to rainfall. In addition, the vegetation is similar with low scrub (predominately Spinifex) and sparse tree coverage.

The second of the Coppin Gap catchments to the south and west of Coppin Gap has an area of 54 km^2. This catchment predominately has a relatively low relief and hence a slower response to rainfall. The main river channel consists mainly of pebbles, gravels and sands with dense tree growth and meanders along a gently undulating broad plateau. The floodplains are rockier than the main waterway with typically low scrub and trees scattered across the terrain with the dominant vegetation type being Spinifex.

At Coppin Gap, the waterway is confined to the narrow gap in the ridge. This “venturi” effect increases flow velocities through the gap such that a scour depression has formed in the gap and sediments carried in floodwaters from upstream are washed through the gap. Just downstream of Coppin Gap, the floodplain expands to a gently undulating broad plateau. This has the effect of slowing flow velocities and allowing sediments to settle from the floodwaters, forming a sandbar on the downstream side of Coppin’s Gap. As a result of the scouring and sandbar, a semi-permanent pool has been formed at Coppin Gap.

At Kitty’s Gap, the waterway is also confined to the narrow gap in the ridge and a similar “venturi” effect to Coppin Gap occurs. Also, just downstream of Kitty’s Gap, the floodplain expands to a gently undulating broad plateau, but no sandbar has formed as is the case at Coppin Gap. This may be explained by the catchment upstream of Kitty’s Gap being much smaller (2.9 km^2 compared to 79km^2 at Coppin Gap), and rocky compared to Coppin Gap. As such, the volume of sediment transported and deposited will be much smaller, hence the lack of sandbar.

Downstream of Coppin Gap and Kitty’s Gap, the terrain is a gently undulating broad plateau. The vegetation is typically low scrub and trees scattered across the terrain with the dominant vegetation type being Spinifex.

3.2.3 Spinifex Ridge Hydrogeology

The groundwater system at the Spinifex Ridge Site is broadly defined by the surface water catchment boundaries. Figure 3.1 illustrates the three catchments that affect the Spinifex Ridge Site. Of these three, the two catchments that drain through Coppin Gap, also directly influence the groundwater system of the proposed open-cut mine. Recharge to groundwater within the catchment is limited to direct infiltration from rainfall within the catchment. There are no identified sources of groundwater inflow from outside the surface water catchment boundary.

Within the catchment of Spinifex Ridge, the identified aquifer types are:

- Fractured bedrock.
- In-situ calcretes, overlying ultramafic bedrock.
- Alluvial sediments associated with recent drainage lines.

3.2.3.1 Fractured Rock

Most rock types within the area are potentially capable of supporting fractured rock aquifers. Of the rock types identified at Spinifex Ridge, all are metamorphosed and have very little preserved primary porosity. Porosity within the rock mass will therefore be limited to secondary structural features such as faults, shears, joints and fractures. These features will have highly variable permeability characteristics but limited storage.

The fractured rock aquifer system within the Spinifex Ridge area has developed after direct infiltration of recharge water into the structural features of the rock. The larger of these features (faults and shears) will provide conduits to, and interconnect the smaller scale defects (joints and fractures). The effective permeability and storage characteristics of the rock will be determined by the degree to which this system has developed. On site, the fractured rock aquifer is developed in the weak to moderately weathered bedrock. In particular the more silicious rock types (Granitic, felsic volcanics and rhyodacitic porphyry's) can support a more transmissive aquifer in the weathered zone as their weathering products have a lower clay content than mafic rock types and therefore will allow better interconnection between fractures. Where the rock mass is fresh, many of the small scale defects (eg. joints and fractures) are filled with non-porous media such as quartz, calcite and sulphide minerals and do not permit the flow of water. However large scale faults that are open will allow the flow of water.

Within the Spinifex Ridge Site the possibility of encountering a high yielding, sustainable, fractured rock aquifer system is very low. This is due to a poorly developed weathered profile, with no source of primary porosity in any identified rock type. In addition, the geological history of the area characterises most of the deformation events as compressional, with only faults radiating from the Mt Edgar Granitoid (North-South vertical faulting) being strike-slip or extensional in character, within the fresh rock these structures are "healed" with infill of quartz-carbonate. Core photos of each rock-type in weathered, fractured and fresh characters are displayed in Appendix C.

The hydraulic character of the various rock types encountered at Spinifex Ridge is shown in Table 3.2, while Appendix C displays photographs of the various rock types and aquifer types encountered on site. The photographs are a combination of core photographs and surface photographs of outcrop.

3.2.3.2 Insitu Calcrete

Development of a weak calcrete has been observed within the creek systems of the catchment. These calcrete zones are best developed where drainage lines overlie ultramafic units (Euro Basalt Formation) and in close proximity to the Bamboo Creek Shear Zone. The calcrete forms as a weathering product of the ultramafic rocks. The amount of calcretisation decreases with depth, with carbonate encrustations in the upper sections, decreasing to dissolution of joint and fracture fills within the ultramafic rocks at greater depth. The calcretisation typically extends to a depth of approximately 10 m and results in a moderate to highly permeable system (horizontal hydraulic conductivity in the order of 10 m/day). Ultramafic rocks encountered beneath the calcrete are weakly weathered to fresh and of very low permeability ($<10^{-4}$ m/day).

3.2.3.3 Recent Alluvial Deposits

Alluvial deposits are associated with current drainage lines. No evidence exists for the presence of concealed sedimentary deposits such as palaeo-channels, as exposures of Archaean outcrop are encountered across the majority of the catchment. The alluvium encountered in the vicinity of Spinifex Ridge consist of a poorly sorted gravel in the base of the creeks, with poorly sorted sandy silts forming "out-wash" on the banks of the creeks. The alluvium thickness is typically from 2 to 10 m. The horizontal conductivity of the alluvium is estimated at between 10^{-1} and 10 m/day. The alluvial deposits in the vicinity of Spinifex Ridge are relatively thin and have relatively poor capacity to store significant volumes of groundwater.

Figure 3.2 displays 2 schematic cross sections through the pit. Figure 4.4 illustrates the modelled surface distribution of aquifer types.

Table 3.2
Geology and Hydrogeological Units - Spinifex Ridge

Geological Group[1]	**Sub Group**	**Formation**	**Rock Type**	**Weathering with Project Area**	**Aquifer Potential within Project Area**	**Location**	**Adopted Horizontal Hydraulic Conductivity**
Quaternary Deposits			Unconsolidated Alluvium	N/A	Good	Modern Drainage Lines	5^{**}
Paleoproterozoic Granodiorite			Granodioite	Moderate to Weak	Moderate where fractured/faulted	Along faults	0.1 to 1
					Very Poor	Majority of rock mass	0.001
George Creek		Niminagarra	Jasperlitic Banded Iron Formation	Weak to Fresh	Low	Talga Range	0.001
Intrusive into Euro Basalt from Mount Edgar Granitoid			Quartz-Feldspar porphyry; dacite and rhyodacite	Moderate to Weak	Moderate	East of Pit	0.05
				Fresh	Poor	East of Pit	0.001
Muccan Granitoid			Folliated to Gneissic Granitoid	Faulted	Moderate	Beneath Tailings Storage Facility	0.1
				Weak	Poor		0.01
				Fresh	Very Poor		0.01
Mount Edgar Granitoid		Coppin Gap Granodiorite	Massive Granodiorite	Faulted	Moderate	Associated with Ore Body	0.1
				Weak	Poor		0.01
				Fresh	Very Poor		0.01
Warrawoona	Salgash	Euro Basalt	Tremolite-Chlorite-serpentinite-carbonate (after Komatiite) Sheared	Calcretised	Very Good	Creeks east and west of Coppin Gap	10^{**}
				Fresh	Very Poor	Base of the Talga Range	0.0001
			Pillow and High Mg basalt	Fresh	Very Poor	Within and surrounding mine site.	0.0001
		Apex Basalt	High Mg Basalt	Fresh	Very Poor	Within and surrounding mine site.	0.01
		Panorama	Felsic Volcanics, Rhyolite	Weak	Poor	Within and surrounding mine site.	0.05
				Fresh	Very Poor	Within and surrounding mine site.	0.001

[1] After Williams, 1999
** Vertical Hydraulic Conductivity is assumed to be 10 times less than horizontal conductivity.

3.2.3.4 Groundwater Flow

The groundwater flow patterns across the Spinifex Ridge Site have been derived from monthly measurements from up to 80 monitoring holes. A majority of these monitoring points are open exploration holes that fully penetrate the subsurface to a depth of at least 300 m. Analyses of monthly water levels demonstrate that the groundwater profile broadly follows the overall trend of the surface water drainage system, converging at Coppin Gap. Figure 3.3 shows the groundwater profile across the Spinifex Ridge Site.

A groundwater divide is inferred to exist between the southern and northern sides of the Talga Range in the vicinity of Spinifex Ridge. Groundwater levels are between 30 and 20 m higher on the southern side of the range and the groundwater flow direction is to the north on the northern side (following topography) and to the east on the southern side towards Coppin Gap.

Due to the low permeability of the Archaean rock mass, localised groundwater anomalies are encountered. Groundwater "highs" and "lows" are observed in low permeability strata. Possibly, the highs could be due to induced water or fluids under pressure from drilling or testing (Rockwater, 2006) that have not equilibrated, while lows could be due to water sampling or airlifting (part of the drilling process). Boreholes drilled exclusively in fresh rock are observed to display this characteristic.

3.2.3.5 Groundwater Chemistry

During the field investigations undertaken within the project area, water samples have been taken at a number of locations:

- Proposed Spinifex Ridge Mine (Rockwater, November 2005).
- Proposed Tailings Dam (Moly Mines, January, 2007).
- Creek System between Mine and Coppin Gap (Moly Mines, January 2007).
- Monthly water samples from Coppin Gap Pool (From November 2005).

The groundwater quality at Spinifex Ridge can be described as relatively fresh with a Total Dissolved Solid (TDS) concentration typically between 800 and 1300 mg/L. To characterise the water type by major anions and cations, Expanded Durov Plots were created. Figures 3.4 to 3.8 which show the graphical typing of groundwater by aquifer type and location. From the graphs the following observations were made:

- Water samples taken from the fractured rock Spinifex Ridge orebody at the end of the dry season of 2005 are typically dominant in HCO_3^{2-}.
- Water samples taken from the calcrete or upper aquifer in the creek systems that drain through Coppin Gap are dominant in HCO_3^{2-} with an increase in SO_4^{2-} or Cl^- towards Coppin Gap (SRWB008S & 009S).
- Water samples taken from the surface water expression at Coppin Gap show a steady increase in salinity (Na^+ and Cl^-) from the end of the wet season to the end of the dry season.
- Water samples taken from less weathered to fresher rock beneath the shallow aquifer monitoring bores within the drainage system of Coppin Gap show elevated SO_4^{2-} and salinities (compared with mine and shallow aquifer samples).
- Groundwater samples taken from the area of the proposed TSF are Na^+ dominant with indiscriminate anions.

Typically bedrock water in semi-arid environments has dominant ions of Na^+/Cl^-. The higher proportion of HCO_3^{2-} ions within the water taken from the fractured rock aquifer on site suggests that there is a higher proportion of recently recharged water. This is not unexpected where bores are against the side of the ridge close to a watershed where predominantly "recent" recharge water exists. As groundwater progresses down-slope from the mine site towards Coppin Gap, there is evidence of groundwater mixing of younger "recharge" and "older" waters. Over time and in the absence of subsurface dissolution processes, the proportion of Cl^- and Na^+ ions or salinity would be expected to increase. This is observed in Figures 3.4 to 3.8, where the minesite has "fresher" water dominant in HCO_3^{2-}, while the surface water at Coppin Gap and the deeper aquifers report higher salinities and a strong Na^+/Cl^- nature. The Na^+/Cl^- nature of the surface water expression at Coppin Gap suggest that the water is in part sustained by “older” groundwater for part of the year (drier months), with Na^+/Cl^- content probably also increasing due to evapotranspiration.

Groundwater quality in the shallow bores installed near the TSF is subject to mixing and probably the product of direct infiltration of rainfall and groundwater of longer residence time.

Analyses for metals conducted on water samples taken from the creek monitoring bores and the surface water expression at Coppin Gap show natural elevated levels of arsenic and molybdenum that exceed Australian Drinking Water Guidelines (NHMRC, 2004) and Australian Livestock Guidelines for Molybdenum (ANZECC, 2000). The chemical mobility of both Arsenic (As) and molybdenum (Mo) in the natural groundwater system is complicated. Unlike most metals both As and Mo are mobile over a range of pH (both acidic and alkaline) and redox conditions (oxidising and reducing) (Fetter, 1992). Concentrations of Mg, As and Mo taken from the surface water at Coppin Gap show increasing concentrations during the year with the lowest concentrations coinciding with samples taken after, or during the wet season. The highest concentrations are observed in samples taken at the end of the dry season. The change in concentration of Mo and As from samples taken at Coppin Pool is shown in Figure 3.9.

Water samples taken from the proposed Tailings Storage Facility (TSF) area do not contain metal concentrations in excess of drinking water guidelines (NHMRC, 2004) and they are not comparable with those at Spinifex Ridge and Coppin Gap (i.e. not elevated in Mo and As).

A summary of the chemical analyses performed and laboratory reports are presented in Appendix C.

4.1 MODEL OBJECTIVES

The objectives of the Coppin Gap groundwater model are to:

- Assess the groundwater inflows associated with the proposed Spinifex Ridge open cut mine; and,
- Assess potential impacts of mine dewatering on flows and water levels at the Coppin Gap pool.

4.2 MODEL SET-UP

4.2.1 Background

The model developed for the Coppin Gap catchment includes features to simulate:

- The hydrogeological features of the aquifer system over the area of current investigation;
- Rainfall recharge to the aquifer system via surface water features;
- Groundwater recharge to and discharge from both Coppin Gap and creeks within the catchment;
- Groundwater outflow from the catchment;
- Evapotranspiration from vegetation along the creeks;
- Groundwater inflow into the pit; and,
- Post mining recovery of groundwater levels within the final mine void.

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 an industry leading groundwater flow modelling package.

4.2.2 Model Extent and Grid

The model domain extends 14,000 m east to west; and 8,650 m north to south. The model and all associated data have been plotted using the GDA 94 Zone 51 coordinate system. Coordinates for the four corners of the rectangular model domain are detailed in Table 4.1.

The extent, boundary conditions and general features of the groundwater model are shown in Figure 4.1. The model has a grid size of 25m in the proposed pit area and 50m outside of the pit area, distributed over 354 columns and 247 rows.

Table 4.1
Model Domain

	Easting* (m)	**Northing* (m)**
Top left	194000	7688650
top right	208000	7688650
Bottom left	194000	7680000
bottom right	208000	7680000

*GDA 94 Zone 51

4.2.3 Data Summary

A summary of the key data used to set up the numerical model is provided in Table 4.2.

Table 4.2
Data Summary

Parameter	Data source
Topographic levels	Elevation data from the topographic maps of the area and data provided by Moly-Mines
Potential aquifer horizons	In situ measured using bore holes and from Rockwater Report, 2006.
Water levels	Measured water levels from previous work (Rockwater, 2006) and current work undertaken by Aquaterra
Rainfall/ Evaporation	Rainfall/ Evaporation data from Marble Bar station
Recharge	Best estimate from model calibration

4.2.4 Model Geometry

Based on the conceptual hydrogeology presented in Section 3, the numerical groundwater model has eight layers, as outlined in Table 4.3.

Table 4.3
Model Layers

Layer	Description	Thickness
Layer 1 (L1)	Surficial aquifer, silt to gravel grade alluvium and calcrete surrounded by weathered bed rocks	12 metres thick
Layer 2 (L2)	Weathered bedrock	68 metres thick
Layer 3 (L3)	Competent bedrock	60 metres, base at -60mAHD
Layer 4 (L4)	Competent bedrock	60 metres, base at -60mAHD
Layer 5 (L5)	Competent bedrock	60 metres, base at -120mAHD
Layer 6 (L6)	Competent bedrock	60 metres, base at -180mAHD
Layer 7 (L7)	Competent bedrock	60 metres, base at -240mAHD
Layer 8 (L8)	Competent bedrock	60 metres, base at -300mAHD

The base of layers 1 and 2 was set such that the saturated thickness of layer 1 was up to 12 metres and 68 metres in layer 2, consistent with available geological information. The remainder of the model layers were set a uniform thickness of 60 metres to allow modelling of the final mine void; discussed further in Section 4.6. The model set up is shown schematically in Figure 4.2.

4.3 GROUNDWATER INFLOW AND OUTFLOW

4.3.1 Rainfall Recharge

Rainfall recharge to the model is applied at the following proportions of average rainfall (360 mm per year) for the steady state model.

- 12% of recorded average annual rainfall (44mm/year or 1.2 x10^{-4} m/d) to the alluvium and neighbouring outwash area.
- 25% of recorded average annual rainfall (90mm/year or 2.5 x10^{-4} m/d) to the calcrete.

- 0.1% of recorded average rainfall (0.36mm/year or 1.0 x10^{-6} m/d) to the rest of the model domain with the exception of Ultramafic outcropping areas where no recharge was applied.

For transient or time varying conditions the same proportions of recorded rainfall are assigned as recharge for the wet season months only (January, February and March).

The modelled rainfall recharge distribution is shown in Figure 4.3.

4.3.2 Coppin Gap and Surface Water Recharge and Discharge

Surface/groundwater interaction at Coppin Gap, and along other creeks in the catchment are simulated using the River Package (RIV6) in Modflow. The RIV package can be used to simulate either discharge from, or leakage to a creek system from an underlying aquifer system based. Modelled river cells, including Coppin Gap and other creeks within the catchment are shown in Figure 4.1.

The RIV package is used as follows:

- ***Discharge of groundwater to Coppin Gap*****:** The current model set up assumes that the majority of groundwater flow within the catchment discharges to surface water pools at Coppin Gap and evaporates and there is only a small amount of groundwater flow out of the catchment. The Coppin Gap pools are simulated as groundwater discharge areas as shown on Figure 4.1. The discharge areas are modelled by setting river bed levels and river stage consistent with the topography or base of the Coppin Gap pool. The river feature removes the water from the modelled area as evaporation would from the open water body or pool. In this case the underlying aquifer water level is greater than that in the Coppin Gap pool and water is removed from the aquifer via the assigned boundary condition. These features are modelled such that they can predict any decrease in discharge volumes to the pools during simulated climatic change or due to the influence of mine dewatering.
- ***Surface groundwater interaction along creeks within the catchment:*** As the creeks within the catchment are ephemeral in nature, the RIV package is used to simulate the recharge and discharge processes between the creek systems and the underlying calcrete and alluvial aquifer systems. This is achieved by setting river bed levels consistent with available topographic data and assuming a river flow depth of 1 metre for Coppin Gap and other creeks during the wet season period. As the water level assigned in the river is higher than that in the aquifer, water recharges the underlying aquifer. For the remainder of the calibration period (April to December), Coppin Gap and the creek allow groundwater discharge from the surrounding aquifer systems to the creek. As outlined above, the river package requires the input of a river bed elevation and a river stage. The river stage is set equal to the bed elevation to simulate this discharge process.

For both the Coppin Gap pools and the surface/groundwater interaction along the creeks, the amount of leakage into or out of the river is controlled by a conductance term. This term is calculated for each modelled river cell based on a river bed thickness of 1 metre with a hydraulic conductivity value of 1 m/d and the assumed length of river across each modelled cell. The resulting river bed conductance values range between 1 and 1400 m^2/d.

4.3.3 Evaporation

The Evapotranspiration (or ET) package in Modflow is used to represent water usage by phreatophytic vegetation along the creek systems within the catchment. Modflow uses a depth dependent relationship to calculated ET such that if aquifer water levels rise to, or above, a specified evapotranspiration surface, ET occurs at the maximum specified rate. If the aquifer water level falls to below the specified ET surface, the ET rate decreases linearly until the water levels falls to below an elevation equal to the ET surface minus the extinction depth. The maximum ET rate is applied at a rate of 10% of monthly average evaporation data (for Marble Bar). The ET surface is assigned consistent with ground surface along with an extinction depth of 5 metres.

4.3.4 Groundwater Outflow

All model boundaries are set consistent with catchment boundaries and were assigned as the no flow type (as shown in Figure 4.1). A constant head outflow boundary is assigned north of Coppin Gap at 152 mAHD to simulate groundwater out flow from the model domain.

4.4 MODEL CALIBRATION

4.4.1 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.

The available monitoring data suggests that there is a distinct seasonal trend measured in groundwater levels in the Coppin Gap catchment driven by wet season surface water flows. As a result, it is difficult to define any absolute steady state or predevelopment conditions. During the current model calibration exercise, some effort was directed at obtaining a steady state model calibration such that the conditions could be used as initial conditions for transient model calibration. As is often the case for groundwater systems with a distinct surface water contribution, a transient calibration process is much more suitable. In this case, conditions simulated by the transient model provide a much better representation of the initial conditions or beginning of the calibration data set.

4.4.2 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 model domain and those predicted by the model. As outlined above, this was only completed to provide initial conditions for the initial transient model and significant effort was not directed at achieving an absolute steady state calibration.

4.4.3 Transient Calibration

The model was calibrated or history matched to groundwater monitoring data collected between January and December 2006. As outlined above, a dynamic calibration process was adopted whereby the model was run in transient mode until the model output better matched the water levels at the beginning of the calibration period (January 2006).

Calibrated aquifer parameters are presented in Table 4.4. Aquifer parameter distributions for model layers 1, 2 and 3 (through 8) are presented in Figures 4.4 to 4.6.

Table 4.4
Calibrated Aquifer Parameters

Aquifer Unit	Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Specific Yield	Specific Storage
Calcrete	10	1	0.1	Na
Alluvials	5	0.5	0.1	Na
BIF (layers 1 and 2)	0.01	0.01	0.005	1.5e-7 (layer 2 only)
BIF (layers 3 to 8)	0.001	0.001	0.001	2.5e-8
Felsic (layers 1 and 2)	0.05	0.05	0.005	1.5e-7 (layer 2 only)
Felsic (layers 3 to 8)	0.0011	0.0011	0.001	2.5e-8
Basalt (layers 1 and 2)	0.01	0.01	0.005	1.5e-7 (layer 2 only)
Basalt (layers 3 to 8)	0.001	0.001	0.001	2.5e-8
Ultramafic (layesr 1 and 2)	0.0001	0.0001	0.001	1.5e-7 (layer 2 only)
Ultramafic (layers 3 to 8)	0.0001	0.0001	0.001	2.5e-8
Granite (layers 1 and 2)	0.011	0.011	0.005	1.5e-7 (layer 2 only)
Granite (layers 3 to 8)	0.011	0.011	0.005	2.5e-8
Faults (layers 1 and 2 only)	0.1	0.1	0.005	1.5e-7 (layer 2 only)

The locations of monitoring bores used during model calibration are shown in Figure 3.3. Calibration hydrographs showing measured and modelled water level responses are shown in Figures 4.7 to 4.11. Hydrogeological features which cannot be justified on the basis of current hydrogeological understanding have not been included in the model to force model calibration. Measured water level trends are generally reasonably well replicated. A good match between measured and observed water levels is predicted at SRC4 (Figure 4.7) and SRD65 (Figure 4.8) for the duration of the calibration period. The water level trend is reasonably well matched at SRC2 and SRC3 (Figure 4.7), SRD50 (refer Figure 4.8) and SRD75 and SRD76, SRD77 and SRD79 (Figure 4.9); however the water levels are over predicted (higher) by the model. At a number of monitoring locations data collected between January and May 2006 is well replicated, however the observed water level recession observed at the end of the year is not matched by the model; for example at SRC1 (Figure 4.7), SRD55 and SRD62 (Figure 4.8). At monitoring locations where data is only available for one occasion the model provides a reasonable match to measured water levels (SRWB6, SRWB8 and SRWB9 refer Figures 4.10 and 4.11).

4.4.4 Water Balance

The calibrated annual water balance is presented in Table 4.5

Table 4.5
Calibrated Annual Water Balance (ML)

Water Balance Component	In	Out
Recharge	220	0
River Leakage	1236	697
Groundwater Outflow	0	19
Evaporation	0	285
Storage	593	1048
Total	**2049**	**2049**

4.5 MODEL PREDICTION SCENARIOS

4.5.1 Prediction Runs

It is planned that the Spinifex Ridge open cut mine will operate for 12.5 years beginning in January 2008 until the end of June 2020. Dewatering (via sumps) will be required to remove groundwater inflow to the open pit. The calibrated groundwater model was used to estimate groundwater inflows over the life of the mine under a range of recharge conditions as outlined in Table 4.6. This also included modifying the path of the creek consistent with the planned operational diversion as shown on Figure 4.1. Where the creek is assumed to be diverted from the alluvial aquifer, a reduced hydraulic conductivity is assumed (0.01 m/d) consistent with the diverted creek flowing across lower permeability material.

Groundwater inflows to the open cut mine were simulated by the use of the Drain Package in Modflow assuming drain elevations consistent with the projected mining depth. Specific impacts on Coppin Gap were assessed by running each climatic scenario with and without dewatering from the mine.

Table 4.6
Prediction Recharge Scenarios

Recharge Scenario	Description
A Base Case	Stream flow assigned to a depth of 1 metre in Coppin Gap and creeks (via the RIV6 package) in January, February, March and December of each year Recharge assigned to aquifer units at proportions consistent with transient calibration and monthly average rainfall totals for January, February, March and December of 76.2mm, 87.8mm, 56.6mm and 39.1mm respectively)
B Drought Conditions	No stream flow and no recharge
C Wet Conditions	Stream flow assigned to a depth of 1 metre in Coppin Gap and creeks (via the RIV6 package) in January, February, March and December of each year. Recharge assigned to aquifer units at proportions consistent with transient calibration and 9th decile rainfall totals for January, February, March and December of 172.1mm, 182mm, 137mm and 90.7mm respectively.

4.5.2 Results

4.5.2.1 Dewatering Rates

Predicted dewatering volumes for each scenario are presented in Figure 4.12 and suggest that for all cases considered, dewatering rates will peak at around 22 L/s in October 2008 reducing to 7 L/s in 2009 and reduce to less than 5L/s by early 2011. A further increase in dewatering rate to around 5 L/s is predicted in mid 2014 and dewatering rates are predicted to remain constant for the remainder of the projected mine life. The assumed recharge scenarios applied are not predicted to have a significant impact on total predicted dewatering volumes with a similar cumulative volume of between 1700 ML and 1850 ML predicted for all 3 cases.

4.5.2.2 Predicted Drawdown

Predicted drawdowns at the end of mine life, assuming base case recharge, are presented in Figure 4.17. Maximum drawdown is predicted in the vicinity of the proposed pit of close to 400 metres.

Predicted water levels in the aquifer immediately underlying Coppin Gap, at the Northern end, centre and southern end for the base case recharge scenario with and without the mine included are presented in Figures 4.13a, b and c. The base case recharge scenario assumes that each year there is wet season of three month duration, which recharges the aquifer feeding the Coppin Gap pool. Over the life of the mine there is however a small predicted decrease in water level in the Coppin Gap area due to mine dewatering. The results suggest that this impact is at a maximum at the end of the dry season and less than a metre, which when compared with natural variation is low.

When drought conditions are considered, predicted water levels in the Coppin Gap area are predicted to decrease after several consecutive dry years. The predicted decrease in water levels resulting from consecutive dry years is in fact greater than that predicted for the base case recharge case when the mine development is included. When the mine development is included in the drought conditions case the greatest impact is predicted at the southern end of Coppin Gap and is of the order of less than 0.5 metres.

4.5.2.3 Impacts on Flows at Coppin Gap

Predicted flows at Coppin Gap for December of each year, assuming the recharge conditions outlined in Table 4.6, are presented in Figure 4.16. For the case where average recharge conditions are assumed, the model predicts a decrease in flows into Coppin Gap from around 110 kL/d to around 95 kL/d over the life of the mine. For the drought case, predicted inflows at Coppin Gap, assuming no dewatering are predicted to decrease from around 90 kL/d by the end of the first drought year and decrease further to 50 kL/d by the end of 2019. When mine dewatering is included, a more rapid decrease in flows to Coppin Gap is predicted, decreasing to zero by the end of 2016. For the “wet” climactic scenario, a decrease in flows to Coppin Gap is also predicted, decreasing from 120kL/d to 115 kL/d at the end of mining.

4.6 SENSITIVITY ANALYSIS

In any modelling exercise, there always remains uncertainty in adopted parameters. A sensitivity analysis was performed to assess the potential variability in groundwater inflows to the pit under a range of conditions that may be expected but not necessarily supported by the calibrated model. The sensitivity analysis can be used to provide some confidence limits about the predictions.

The following sensitivity runs were carried out for predicted groundwater inflows assuming the base case recharge conditions:

- ***Sensitivity Run 1:*** Horizontal hydraulic conductivity of all units in layers 3 to 8 (except in the granite) increased by an order of magnitude.
- ***Sensitivity Run 2:*** Horizontal hydraulic conductivity of all units in layer 2 (except in the granite) increased by an order of magnitude.
- ***Sensitivity Run 3:*** Specific yield of all units in layers 3 to 8 increased to 0.005 from 0.001.
- ***Sensitivity Run 4:*** Specific yield of all units in layer 2 increased from 0.005 to 0.01.

The results of the sensitivity analysis are presented in Figures 4.14 and 4.15. Increasing the horizontal hydraulic conductivity of all units by an order of magnitude (Sensitivity Run 1) is only predicted to have a significant impact on predicted dewatering volumes, after 2009 onwards, once water levels are drawn down into the fresh rock units (Figure 4.14). Dewatering rates are initially unchanged from the base case, but after 2009 dewatering rates of around 10 L/s (for the base case) are predicted to increase to around 20 L/s for the remainder of the mine life.

Increasing the horizontal hydraulic conductivity of the layer 2 (Sensitivity Run 2) is predicted to result in an increase in dewatering rates as water levels are drawn down (via dewatering) through the weathered material (Figure 4.14). Dewatering rates are predicted to peak at around 30L/s, but return to rates similar to the base case once water levels are drawn down further into the fresh basement rocks.

Increasing the aquifer specific yield in both the shallow and deeper aquifer units (Sensitivity Runs 3 and 4) is not predicted to have a significant impact on predicted dewatering rates (Figure 4.14 and 4.15).

Predicted flows at Coppin Gap for the sensitivity runs, for both the non-mining and mining case are presented in Figure 4.16. For the non-mining cases, the assumed changes in aquifer parameters are predicted to result in some differences in predicted flows at Coppin Gap of the order of 5 to 10 kL/d. The following observations are made regarding the sensitivity of predicted flows at Coppin Gap when dewatering of the mine is included.

- For Sensitivity Run 1 (hydraulic conductivity of the basement rocks is increased by a factor of 10) the drawdown impact from dewatering spreads further upstream and a much greater reduction in flows at Coppin Gap is predicted when compared to the base case (reduction of 100 kL/d to 97 kL/d for the base case and 117 kL/d to 72 kL/d for Sensitivity Run 1).
- For Sensitivity Run 2 (horizontal hydraulic conductivity of layer 2 is increased by a factor of 10) there is a reduction in predicted flows at Coppin Gap from the end of 2009. This is because the impacts of drawdown spread further upstream through the upper aquifer horizon when it is modelled as being more permeable. Once dewatering has progressed below the base of the weathered material, by the end of 2011, the predicted flows at Coppin Gap increase and the reduction in flows at Coppin Gap is comparable to those predicted by the base case scenario.
- There is no significant impact on predicted flows for Sensitivity Runs 3 and 4 as aquifer storage does not impact the drawdown from dewatering.

4.7 PIT VOID PREDICTIONS

4.7.1 Background

Once mining is complete and dewatering ceases, groundwater levels will recover from at or below the base of mining. Over time a balance will develop between groundwater inflow into the open void mine void, recharge from rainfall and evaporation from the open water body or "lake" that will develop in the mine void. The elevation of the final lake level will continue to rise with time until eventually a recovered or equilibrium water level will be reached.

The Coppin Gap groundwater model was modified to represent post-mining conditions, as outlined below to predict the final recovered water levels that may develop within the mine void and the time taken for recovery.

4.7.2 Setup

The location and depth of the final mine void, which at this time is proposed to be left empty, was specified in the model according to mine plans provided for the Spinifex Ridge open cut mine. As the model was set up with layers consistent with the final mine void geometry, no modifications to mine void geometry were required. Model parameters in layers 1 to 7 were adjusted to reflect the empty final void. Aquifer parameters used for the pit void simulated are summarised in Table 4.7

Table 4.7
Mine Void Aquifer Properties

Horizontal and Vertical Hydraulic Conductivity (m/d)	Specific Yield
1000	0.99

The modified representation of aquifer units is presented schematically in Figure 4.18.

Water at the base of the pit may accumulate and form a lake within the mine void as a result of incident rainfall to the mine void and run off from the pit walls, in additional to groundwater inflow from the surrounding rocks. Recharge to the void was assigned as follows:

- 100% of average annual rainfall to the mine void lake or wetted area
- 70% of rainfall reporting to the immediate pit catchment above the mine lake recharge the mine lake
- 20% of rainfall reporting to the final pit catchment (as defined by abandonment bunds) also recharges the mine lake

Evaporation from the final void lake was assumed at a rate of either 50% or 75% of average pan evaporation. The reduction in potential evaporation from the void is due to the reduced hours of sunlight within the void (due to shadow of pit walls) and the reduced evaporative loss generally observed with large open water bodies (eg. lakes and pit voids).

Additionally, the recharge and stream flow conditions (specified in the Recharge and River Package in Modflow) were modified to reflect average conditions to allow the model to run on a much longer time scale than the predictions runs. Initial conditions for the model run were derived from the end of the dewatering prediction assuming base case recharge conditions.

4.7.3 Results

The water levels within the void are expected to rise very slowly and stabilise within the pit void between -100 and -30 mAHD over a period of up to 1000 yrs depending on climatic variation. The void water quality will, with time, increase in salinity but is not expected to acidify (Campbell, 2007). Metals such as molybdenum and arsenic are mobile in neutral and alkaline waters and are likely to be present at levels that exceed quality guidelines for some uses. High levels of dissolved Mo and As currently occur in the groundwater between the Spinifex Ridge Deposit and Coppin Gap.

Water levels at Coppin Gap are expected to fluctuate throughout the year and are determined primarily by seasonal surface water flows during the wet season and a combination of near-surface alluvial and bedrock flow during the drier months.

The water levels at Coppin Gap are expected to quickly stabilise after mining stops and then gradually recover to pre-mining levels. During the wet season the water levels are not expected to change, as the water level is largely determined by surface water flow. During the drier months a minor decrease in the water level is possible due to lower water levels in the basement rock as a result of the mine void. It is expected that there will be a minor change in water levels that is well within the range of pre-mining natural variability.

Upon mining, it is plausible that permeable structures or units that have not been identified by current work may be encountered. It is proposed that should these structures exist, and if they allow water at greater than expected to flow back into the mine void, a system of insitu barriers be installed to restrict the flow, effectively isolate the mine void from the regional groundwater system.

To understand the sensitivity of the current groundwater system to the presence of barriers in the more permeable units model runs were conducted that included barriers across the weathered felsic rocks (layer 2) and calcrete (layer 1). The results of these runs showed no change in the water levels at Coppin Gap due to the presence of the barriers. This demonstrates that there is no advantage to installing barriers, unless significant zones of higher than expected permeability are encountered.

Figures 4.19 and 4.20 show the modelled water levels at Coppin Gap post closure.

SECTION 5 - MINE DEWATERING AND DEPRESSURISATION

5.1 DEWATERING

The Spinifex Ridge Mine is planned for development as an open-cut operation, utilising conventional drill and blast, load and haul mining techniques. To maintain a safe and efficient operation, dewatering (or lowering of the groundwater level), will be required in advance of the working mine floor. In particular, maintenance of dry mining conditions is required to:

- Minimise haul truck tyre wear.
- Minimise drill and blast costs by reducing the requirement for slurry type explosive.
- Minimise the development of NOX gases during blasting (a common problem with wet blasting).
- Improve blast hole drilling and explosive loading conditions which significantly reduce the requirement for secondary breakage.

Combined, these savings significantly reduce the operating expense of the mine and the energy and effort required to mine a given volume of material (Orica, 1998). In many respects the dewatering requirements are the first consideration in the mine planning process.

5.1.1 Dewatering Method

The dewatering of open-cut mines is commonly achieved by lowering the groundwater table from within or outside the excavation. The dewatering method is tailored to suit the requirements of the operation. There are two common techniques that are utilised in most below-water-table (bwt) mines, namely in-pit sumps or water bores.

In-pit Sumps

Dewatering via in-pit sumps involves the creation of a dry zone below the mining floor. The sump aims to drawdown the groundwater table by draining water to a convenient point within the mine where it is pumped out-of-the-pit. The location of the sump is determined by considering the planned mine development and locating the most significant flows. The creation of a sumping system involves:

- Advance blasting to a level below the active floor using an explosive capable of being immersed in water.
- Mining out the wet material to form a void (sump).
- Abstraction water from the sump to lower the groundwater, thereby draining the surrounding rock-mass.
- Pump the water to a point that is not in hydraulic connection with groundwater being abstracted. This can take the form of discharge to a disconnected aquifer or surface water system or utilising the water in a process such as mineral processing or dust suppression.

The main consideration for a mining operation employing this method is to allow adequate area for the development of the system, sufficient lead-time for the development, and pumping to draw the water table down a sufficient level to allow mining of the next bench.

In-pit or Out-of-pit Bores

Dewatering with in or out-of-pit bores involves completion of a water bore(s) designed and equipped to abstract water over a large range of water levels in such a way that allows mining in dry conditions with a minimal volume of water abstracted. The design of a dewatering bore differs from a water supply bore in that it is designed to remove maximum volumes of water from the subsurface, rather than abstract water in a sustainable and cost effective way. To this end the criteria for a successful dewatering bore are very different to those of a water supply bore.

The location and design of a dewatering bore system is dependent on the mine hydrogeology. Out-of-pit dewatering systems are a preferred, non-intrusive dewatering system that can be managed with minimal impact on the day to day operation of the mine. However, due to their location they will often involve greater overall volumes of abstraction, a larger number of installations and a higher amount of initial capital expenditure. In-pit bores can be considered as a deeper sump and a more cost effective option to both sumps and out-pit-bores, if they can be located and managed practically within the mine.

5.1.2 Dewatering System

The current hydrogeological understanding of the Spinifex Ridge deposit expects that the highest groundwater flows will be encountered within in the upper 80 m of the mine (160 - 80 mAHD). The units that are likely to yield the highest flows are the creek alluvium, calcretised zones associated with the creek and ultramafic units, weathered felsic zones and large fault zones. All other rock types are expected to be of low permeability. The location of zones that are expected to have higher inflow into the pit are shown in Figure 5.1. Below 80 mAHD all rock types are fresh and of low permeability. Theoretically large scale fault zones should have the potential to yield high inflows to the pit. However no fault zones of high permeability have been encountered to date, despite the large quantity of resource drilling.

The mine dewatering system is a critical part of the mining process. It must be robust and incorporate a high level of contingency. The results of the groundwater modelling demonstrate that the overall volumes of groundwater that are required to be abstracted are low. The highest volumes and flows are likely to be encountered:

- between 170 and 150 mAHD, with the intersection of the creek alluvium and calcrete zones and,
- from approximately 170 to 80 mAHD on the eastern and western walls of the mine where fractured, moderately weathered felsic units are intersected.

Once these more transmissive zones are dewatered, low rates of inflow are expected for the remainder of the mine life. Initially flow rates of approximately 20 L/s are expected and these will drop with time to approximately 5 L/s.

It is important to note that during periods of heavy rain (wet season), previously dewatered zones may be recharged and could continue to flow into the mine. These flows can be managed with a combination of surface water management and run-off management within the pit. The in-pit pumping system will need to allow for these seasonal volumes. The ability for the mine to accommodate these inflows will depend on the mine schedule. The capacity required will be a function of the bench level to volume ratio at the base of the mine and the requirement to mine that ore. Ideally lower benches will be mined during the drier months with sufficient material scheduled on higher benches for periods where lower benches could be inundated (wet season).

Given the low volumes of dewatering required it is proposed that the mine dewatering be initially performed with an in-pit sumping method that utilises a system of sumps and centrifugal pumps as the primary means of abstraction. Once the mine is operational and a more comprehensive structural model is developed, targeted bores may be useful to intercept significant flows either out-of-pit or within the mine in areas that can be more easily managed.

The scheduling of mine development will need to consider the requirement for “wet blasting”. Although the inflow rates are expected to be low, the low permeabilities will also impede the flow of water into the sump(s). As a consequence, groundwater may fill blast holes and desensitise a “dry” blast product. Provision for a blast product capable of being loaded and fired in wet blast holes is recommended.

A table of expected inflow rates averaged for each mining period (1 year) is provided in Figure 4.12. The values in this table do not consider run-off from areas outside the immediate pit catchment.

5.2 DEPRESSURISATION

Depressurisation or lowering the hydrostatic pressure within and behind a pit wall is primarily required to improve stability of the pit slope. In hard rock open-cut mining, depressurisation of a slope is typically tackled on a batter slope scale and an inter-ramp slope scale. Batter scale depressurisation deals with instantaneous hydraulic loading of a batter due to collection of water on pit wall berms during high rainfall periods. It is a problem typically encountered in sub-tropical or tropical areas that are subject to rainfall events of high intensity. Inter-ramp scale depressurisation is more often a groundwater related problem whereby the mechanism of slope failure is sensitive to the pressure exerted by groundwater on the defects within the rock mass.

5.2.1 Batters and Benches

Spinifex Ridge receives most of its rainfall in the summer months between December and March. Rainfall events are typically short intense thunderstorms or heavy falls from tropical lows associated with cyclonic activity. Due to the rainfall pattern, run-off control measures are recommended to prevent excessive ponding of water on the pit crest and berms, thereby limiting localised wall instability due to hydraulic loading.

5.2.2 Inter-Ramp

Due to the low hydraulic conductivities measured in all of the fresh rock types, it is expected that the slopes of the Spinifex Ridge Pit be subject to increasingly (as the mine deepens) high hydraulic pressures as the pit develops. Horizontal drainholes may be required in areas of geotechnical sensitivity. The scope of any horizontal drainage programme will need to be determined with the completion of field trials, as experience is gained with each rock-type and geotechnical domain. Groundwater contours for each layer at the end 12 years are shown in Figure 4.13.

It is important to note that the contours presented serve as an indication of the overall head distribution for an individual layer, which in the case of the fresh rock and majority of the final wall show the overall head. The actual hydraulic pressure distribution within the slope will be related to the structural features of the rockmass and may display higher pressures on some structures than is inferred from the groundwater contours.

5.3 GROUNDWATER RESPONSE TO DEWATERING

The groundwater drawdown as described in Section 4.5.1 predicts average and extreme cases for climatic variation based on a 12 year mine schedule and is founded on the current understanding of the groundwater system. The modelling seeks to define upper and lower case bounds to the groundwater response, to give an appreciation of aquifer behaviour. It is not intended as a tool to define measures for determination of impact or performance criteria. The modelling does however, allow determination of areas that are sensitive to the groundwater abstraction and facilitate examination and conceptual testing of possible remedial measures.

5.3.1 Groundwater Drawdown

The groundwater response to dewatering is predicted to develop as a steep cone of depression surrounding the immediate pit boundary. The water table may, in many places be coincident with the pit wall and visually appear as damp patches or minor seeps emanating from defects (joints or faults) on the wall.

It is expected that larger flows may be encountered from the weathered Felsic units on the east and west walls, to an approximate level of 80 mAHD. The flows at this stage will be higher initially (~20 L/s) and are expected to diminish with depth as the mine is developed.

A “perched” water table may develop within the calcrete and creek alluvials in close proximity to the pit as the fresh rock is depressurised below. The development of this aquifer condition is likely as the calcrete overlies an ultramafic sequence of particularly low permeability. While the mine is operating, the calcrete and creek aquifers are expected to respond to seasonal water level variation (i.e. due to rainfall recharge), within the range currently observed during average conditions or wet conditions.

5.3.2 Seasonal Variation

Rainfall records demonstrate, and future predictions (BoM, 2006) indicate that the climatic variation within the East Pilbara area is and will remain highly variable, with lengthy periods of both dry and wet weather possible. As described in Section 4.5.1, dewatering predictions for three climatic cases were undertaken to determine the sensitivity of the ease of mine development to possible climatic variation.

For both the “average” and “wet” cases the predictions indicate that the influence of the mine development will be within expected natural variations for Coppins Gap. However, during extended periods of dry climatic conditions, water levels may fall below levels that may otherwise naturally occur while the mine is operational. There is some difficulty in defining the natural variations in the water levels for Coppins Gap waterbody, since no monitoring has taken place; but there are anecdotal comments that the waterbody has dried up in the past. Artificial methods to supplement water levels should be considered if ecological stress, attributed to mine dewatering is observed or at risk.

5.4 MANAGEMENT OF DEWATERING AND DEPRESSURISATION

The Spinifex Ridge dewatering system is designed to meet the follow objectives:

- Effective dewatering of the mine workings to minimise schedule delays and drill and blast costs.
- Minimise the impact of dewatering infrastructure on mine development.
- Ensure that slope groundwater pressures are managed within slope design criteria.
- Minimise the impact of dewatering on the natural variation of water levels outside the mine and in particular at Coppin Gap.
- Eliminate dewatering discharge or manage the quality and quantity of any discharge to be ecologically sustainable.

The successful management of these objectives is one of balancing the operational requirements of the mine with the requirements of the natural system. Given that low dewatering rates are anticipated and steep groundwater gradients are likely to be developed around the open-cut, the management of dewatering volumes is expected to be relatively straightforward.

If excessive drawdown (greater than natural variation) within the upper alluvial or calcrete aquifers is monitored during mining, artificial recharge of the aquifer(s) with water of equivalent quality could be initiated. Given that the water volumes required for dewatering are expected to be modest (5 to 20 L/s) it follows that the rates required to manage water levels within a required range, will not be excessive and well within the surplus capacity of the mine water supply. The mode of discharge should be directly into an existing drainage line at a point that maximises infiltration and does not create an area of accelerated vegetative growth or change in the type of vegetation preferentially supported.

5.5 MINE SITE GROUNDWATER MONITORING PROGRAMME

Effective management of the groundwater system relies upon the ability to assess the predicted outcomes against actual performance in a timely way that enables corrective measures to be planned and implemented. To monitor the effectiveness of mine dewatering and the groundwater response of the surrounding environment, a monitoring programme consisting of groundwater levels and pressures, abstraction and chemistry has been proposed and is discussed below and in Tables 5.1 – 5.3. The monitoring programme is designed to incorporate collection of the required data for completion of a detailed closure plan within 5 years of commencement of operations.

5.5.1 Groundwater Levels and Pressures

Monitoring groundwater level and pressures is necessary to:

- Assess the performance of the dewatering effort, a key performance indicator for the development of each mining bench.
- Assess the depressurisation of pit slopes in areas where the slope design is sensitive to pore pressures.
- Assess the influence of dewatering on water levels in the natural system, including;
    - Coppin Gap surface water features,
    - Groundwater Dependent Ecosystems.
- Assess the influence of dewatering on the regional water system.

These objectives and the proposed monitoring programme are captured in Table 5.1 and graphically displayed in Figure 5.2.

5.5.2 Groundwater Abstraction

To accurately calibrate the groundwater model, the mine water balance will need to be assessed and measured. During mining, water is abstracted from the groundwater system by:

- Abstraction of "free" water via the mine dewatering system;
- Evaporation off the pit walls and floor;
- Vaporisation during blasting of the in-situ rockmass; and,
- Added moisture to the run-of-mine (ROM) rock via dust suppression systems.

Of these, dewatering abstraction is the easiest to measure and the highest contributor to the overall abstraction. However, the majority of the rockmass at Spinifex Ridge is anticipated to be of low permeability with low inflow rates. It can be expected therefore that a high groundwater table will be maintained, with evaporative losses via the pit wall surface(s) contributing to a significant proportion of the mine dewatering effort.

To measure the net abstraction from the pit, the following monitoring programme is outlined in Table 5.2.

It is expected that evaporative loss will form a large component of any total groundwater loss from the mining system and as such will need to be quantified with on-site data monitoring with an integrated meteorological monitoring station that includes the ability to measure daily evaporation.

5.5.3 Groundwater Chemistry

The groundwater chemistry monitoring programme is designed to monitor the seasonal aquifer recharge and influence of the mining activity on the surrounding environment. The programme aims to achieve this by monitoring:

- the surrounding environment (regional bores), to establish a regional baseline;
- the water abstracted via mine dewatering, to understand the influence of the mine on the groundwater system;
- the current receiving environment from the mine towards Coppin Gap, via bores within the system between Coppin Gap and the Mine and the surface water expressions at Coppin Gap; and,
- The alluvial and fractured rock system north of Coppin Gap, to monitor the only identified ground and surface water discharge from the Spinifex Mine to the receiving environment.

Table 5.1
Water Level Monitoring Programme

Area	Monitoring Installation Type		Target Aquifer / Aquitard	Monitoring Frequency (operational)[1]	Installation Status (commenced)	Management Trigger Tool	Possible Action to Correct Impact[2]	Comments
	Water Level	Pressure Profile						
Spinifex Ridge Regional	X		Fractured Rock (fresh and weathered)	Monthly	Yet to commence	Groundwater Model	Make good any decrease in water supply to pastoral bores.	Monitoring of Pastoral and to be installed additional bores.
Coppin Gap	X		Fractured Rock	Monthly	Current (Dec 2006)	Groundwater Model	Artificially manage water levels within natural variation, develop and demonstrate closure solution while operating.	A detailed understanding of the Hydrogeological interaction of the mine and Coppin Gap is to be developed during operation of the mine and a closure plan demonstrated within 5 years of operation.
Coppin Gap North	X		Alluvial and Fractured Rock (weathered)	Monthly	Yet to commence	Groundwater Model	Make good any decrease in water supply to pastoral bores.	Monitoring of Pastoral and to be installed additional bores.
Mine East	X	X	Alluvial, Calcrete, Fractured Rock (Weathered & Fresh)	Bimonthly	Current (Dec 2006)	Groundwater Model	Artificially manage water levels to sustain GDE's while operating.	A detailed understanding of the Hydrogeological interaction of the mine and area to the east of the mine is to be developed during operation of the mine and a closure plan demonstrated within 5 years of operation.
Mine West	X		Fractured rock (Weathered & Fresh)	Bimonthly	Current (Dec 2005)	Groundwater Model	N/A	The hydrology and hydrogeology will be altered by the mine infrastructure.
Mine Walls		X	Fractured Rock (Fresh)	Bimonthly	Current (Dec 2005)	Slope Design	Horizontal drainholes.	The requirement to install horizontal drainholes may increase the area of influence the mine void has on the surrounding environment. This increase is not expected to significantly alter dewatering predictions.
Open Cut Pit	X		Fractured Rock (Fresh)	Monthly	Current (Dec 2005)	Mining Schedule	Increased dewatering	A change (increase) in the mining rate may increase the vertical advance and therefore dewatering rate. This is not expected to significantly alter the groundwater profile.

1. Recommended monitoring frequency for reporting, higher frequencies may be required for operational management.
2. Suggested remedial measures to possible outcomes. The remedial measures are not limited to these suggestions.

Table 5.2
Dewatering Volume Monitoring Programme

Abstractive Source	Measure	Method	Frequency
Direct Abstraction (Sumps or Bores)	KL	Direct measurement	Weekly
Blasting (vaporisation)	Insitu storage estimate (m^3)	Calibrated measurement from test work	Monthly total of wet blasts
Evaporation	mm/day	Onsite measure of pan evaporation	Daily
In-pit Dust Suppression	KL	Direct measurement	Daily

Table 5.3 describes the monitoring frequency and constituents to be analysed to allow assessment of the aims of the programme.

Table 5.3
Groundwater Chemistry Monitoring Programme

Area	Sample Frequency	Analytes	Purpose
Coppin Gap	Monthly	pH, Ec, TDS, Na, K, Ca, Mg, Fe, Cl, SO_4, NO_3, HCO_3, CO_3	Influence of mining activities
	Monthly	Al, As, Mn, Si, Pb, Cd, Cr(VI), NH_3, Sb, Ba, Br, Cu, Hg, Ni, Se, Ag, Zn	
Mine East	Quarterly	pH, Ec, TDS, Na, K, Ca, Mg, Fe, Cl, SO_4, NO_3, HCO_3, CO_3	Influence of mining activities
	Quarterly	Al, As, Mn, Si, Pb, Cd, Cr(VI), NH_3, Sb, Ba, Br, Cu, Hg, Ni, Se, Ag, Zn	
Regional Monitoring and Coppin Gap North	Biannually	pH, Ec, TDS, Na, K, Ca, Mg, Fe, Cl, SO_4, NO_3, HCO_3, CO_3	Influence of mine dewatering
Dewatering abstraction	Monthly	pH, Ec, TDS, Na, K, Ca, Mg, Fe, Cl, SO_4, NO_3, HCO_3, CO_3	Influence of mining activities
		Al, As, Mn, Si, Pb, Cd, Cr(VI), NH_3, Sb, Ba, Br, Cu, Hg, Ni, Se, Ag, Zn	
Remedial discharge/Injection	Monthly	pH, Ec, TDS, Na, K, Ca, Mg, Fe, Cl, SO_4, NO_3, HCO_3, CO_3	Influence of mining activities
		Al, As, Mn, Si, Pb, Cd, Cr(VI), NH_3, Sb, Ba, Br, Cu, Hg, Ni, Se, Ag, Zn	

5.5.4 Groundwater Dependent Ecosystems

The identified groundwater dependent ecosystems within the project area are:

- Phreatophytic and vadophytic vegetation closely associated with current drainage lines;
- Subterranean fauna generically known as Stygofauna and Troglofauna; and,
- Ecosystems that rely on the seasonal presence of surface water expressions.

The threat to the health of these systems from groundwater abstraction is closely linked to groundwater table level within the Calcrete and Alluvial Aquifers (Figure 4.13). Monitoring of these systems can be achieved by periodic baseline surveys of ecosystem health (tree health, fauna surveys, etc) with more intensive monitoring intervals triggered if groundwater levels exceed the natural variation. Determination of the range of natural variation can be set initially set using the numerical groundwater model and updated with measured data as the understanding of the groundwater system improves during the operation of the mine.

Actual monitoring points for all of the above monitoring will be formulated at the detailed design phase of mine development.

6.1 CLOSURE CRITERIA

The acceptable closure of a below water table open-cut mine must be developed on a case by case basis that considers all relevant post mining aspects related to the void. The recommended closure objectives developed by the Department of Water for abandonment of final voids are (WRC, 2003):

- Render the site acceptable and safe over the long-term;
- Minimise environmental and health risks in the vicinity of the site;
- Maximise to the practicable extent any potential future usage of the site; and
- Develop a “walkaway solution”.

6.2 MINE VOID CLOSURE

There are broadly three generic models (WRC, 2003) for open-cut mine closure:

- Open Void;
- Waste Storage (mine spoil or tailings); and,
- Water Storage.

Of these options the preferred option for rehabilitation of most mine voids is to use mine waste rock to backfill the void completely or to above the water level. Where this option is economically and practically possible, it is often employed. However the Spinifex Ridge Mine consists of a single large open-cut mine, and as such, the backfill option is not economically practical. In addition, the mineralisation extends beneath the current mine design and backfilling the mine would economically sterilize any future resource.

The two fundamental scenarios available for closure of the Spinifex Ridge Open-cut are:

- An open void; whereby the void is permanently isolated, hydraulically, from the surface water system and allowed to develop as a groundwater sink where evaporation from the void exceeds the rate of groundwater inflow in to the void; or as,
- A water storage “reservoir”; whereby surface water is diverted into the void and the void is filled. The lake that develops may have a beneficial use as a water supply or natural water feature.

There are a number of issues to address when considering how to manage void closure. The main factors that need to be considered for Spinifex Ridge are summarised in Table 6.1 and Table 6.2. The tables demonstrate that of the two prospective closure scenarios, only an open, hydraulically isolated void can be considered practical and satisfactorily demonstrated as a viable option with the information currently available. For a water storage “reservoir”, the lack of data on stream hydraulics (as an example) results in high risks and high uncertainties related to proving that the system will operate sustainably and without impacts, after closure. If, during the mine operating life, more data becomes available and allows for a detailed understanding of the hydrology, hydrogeology and void geochemistry, this option could be reconsidered.

Since the risks related to a storage reservoir are currently too high, only the option of a sink was investigated in further detail (Section 6.2.1).

Table 6.1
Open Void – Sink

	Issue	Item	Description	Issues	Chance of error in prediction
Open Void Sink	Environmental	Change in Groundwater system	The mine void becomes a groundwater sink that draws water from the surrounding system with evaporative loss from the void acting as a "pump" to continually discharge water to the atmosphere.	Changes in water levels or fluxes that exceed natural variation may change the character of some surface water expressions.	LOW
		Change in Habitat for Groundwater Dependant Ecosystems	Due to a permanent change in groundwater conditions surrounding the mine, groundwater dependent ecosystems may be impacted as a result of either a permanent or transient change in groundwater conditions.	Groundwater dependant systems may suffer as a result of larger than natural changes in groundwater levels.	LOW
		Void water quality	Due to continual evaporative "pumping" from the void, a gradual increase in salinity will occur until a chemical equilibrium is established. This may take the form of a chemical and density driven stratification within the mine void.	The pit void will contain water of poor quality for both salinity and heavy metals. The water source may attract wildlife during dry periods, although water holes at Coppin Gap will be more convenient and attractive sources.	LOW
		Water resource	The presence of a continual pumping source (mine void) will deplete and degrade the former groundwater resource	Low permeabilities and previously degraded water quality the pre-existing groundwater resource is limited to an industrial purpose.	LOW
	Social	Aesthetic appearance	The open-cut will support a variable water level at a significant depth below the surface. The colour and quality of the water may be of "unnatural" appearance.	Visually the water in the void may appear as a salt lake. Currently, surface water expressions in the area appear as fresh water pools or soaks.	LOW
		Safety	The stability of the mine wall and ramp surfaces will change with time. The water quality within the void may be hypersaline and have high heavy metal loadings.	With a deep, variable water level within the void and slopes that are continually changing, the void will be unsuitable as a place of recreation for the general public.	LOW
		Beneficial land use	The mine void cannot be used for purposes other than future mining.	The mine will not add additional value to the area.	LOW
	Economic	Monitoring – post mining	Monitoring post closure will be required until closure predictions are demonstrated.	Funds will need to be set aside to manage closure requirements and any potential remedial measures.	LOW
		Further utilisation of the resource	The resource is mined to economic conditions. Future economic conditions may allow mining to greater depths.	The preservation of a void allows reestablishment of the mine with minimal effort. Preserving the mineral asset for future opportunities.	LOW
		Beneficial land use	The presence of the void will detract from any other beneficial use (other than mining).	Presently the land is used for low intensity pastoral grazing. The actual area and quality of the land occupied by the void does not reduce the value land.	LOW

Table 6.2
Open Void – Storage

	Issue	Major Items	Description	Issues	Chance of error in prediction (now)
Open Void Storage	Environmental	Change in Groundwater system	The void is flooded by diverting all drainage from the former catchment into the void. Once filled the void may act as a both a stratified water body and a throughflow system.	The hydrogeological understanding required to understand and model this strategy will only be possible with accurate data collected from the operating mine. In addition, modelling of the groundwater chemistry will require additional chemical modelling and a through understanding of the mine rock chemistry.	HIGH
		Change in Habitat for Groundwater Dependant Ecosystems	The groundwater system will change, a filling time of the void and subsequent change in the seasonal response will require existing groundwater dependent ecosystems to adapt or change. In addition a "new" type of environment will be created in association with the void.	A high level of uncertainty exists with any prediction of ecological response.	HIGH
		Void water quality	The water quality of the void will be variable. Seasonal addition of fresh water from run-off will recharge the system. During periods of low rainfall a groundwater depression may develop around the void as evaporative losses exceed inflow. The void may develop a stratified water body of variable quality, sustaining both fresh and saline waters within the void.	The water quality within the void will be variable and require a detailed understanding of the chemical evolution of both surface and groundwater interacting with the void and the mine rocks. The information required to perform this analysis can only be practically acquired during the operation of the mine.	HIGH
		Water resource	The filled final void may provide a source of water for other purposes. The water quality within the void may limit the resource quantities available for some intended purposes.	Seasonal variation and stratification of the water chemistry with the void will limit the volume of water for purposes that require good quality water.	HIGH
	Social	Aesthetic appearance	The void will develop into a large, seasonally replenished lake. This may support a "wet land" style ecosystem on the fringe and within the lake.	The nature and management of the pit lakes' ecosystem during development of the lake will be an important part of ensuring an sustainable environmental system is established.	MODERATE TO LOW
		Safety	The lake will present an attractive recreational facility. Rehabilitation of the upper slopes may be required to ensure a geotechnically safe lake fringe.	Consideration will be required for a stable geotechnical slope design that exceeds the design life of the mine.	LOW
		Beneficial Land use	A pit lake will offer alternative land uses (to mining) that may include; a water supply and recreational facility.	Any alternative land use will require detailed assessment utilising data gathered during the development of the mine.	LOW
	Economic	Monitoring – post mining	Monitoring post closure will be required until closure predictions are demonstrated.	Funds will need to be set aside to manage closure requirements and any potential remedial measures.	LOW
		Further utilisation of the resource	Dewatering of the void and removal of any sediment infill will be required to recommence mining.	Treatment of large volumes of contaminated water may be required. This will incur a long development leadtime.	MODERATE
		Beneficial land use	A pit lake will offer alternative land uses (to mining) that may include; a water supply and recreational facility.	Any alternative land use will require detailed assessment utilising data gathered during the development of the mine.	LOW

6.2.1 Void Hydraulics

The Spinifex Ridge open-pit is expected to behave as a sink, where evaporative loss from the void will exceed surface and groundwater inflow. The void water balance can be defined by:

Net groundwater inflow + net surface water inflow – evaporative loss

Potential evaporative loss from within the void can be determined by using measured values of pan evaporation and adjusting for:

- the surface area of free water exposed in the void increases as the water level in the void rises;
- reduced solar radiation, due to the position of the open-cut (south of the Talga Range) the mine will often be shaded, especially in the winter months;
- the reduced evaporative loss from a water body; and,
- reduced evaporative loss as salinity increases within the void.

The percentage of rainfall reporting to run-off can be calculated from catchment area and rainfall volumes. Standardised methods exist for calculating the percentage of rainfall that reports to surface water run-off (IEA, 2001) however, the mine void will differ from the natural system with a higher run-off coefficient due to hard rock mine walls and bench surfaces.

The rate of groundwater entering the void post closure, will be a function of the hydraulic gradient surrounding the void. It is expected that the groundwater system will maintain a steep gradient and therefore relatively consistent inflow rate, due to the low hydraulic conductivity of the rock mass surrounding the void.

The distribution of water table levels surrounding the void upon closure will be dynamic, influenced by the permeability of the material, the gradient towards the pit and rates of recharge. Permeable zones around the pit will have shallower gradients than adjacent low permeability zones. If the drawdown in permeable zones is greater than expected, due to drainage to the pit, engineered solutions such hydraulic cut-off barriers may be required to mitigate excessive drawdowns (see Section 6.3). The location and extent of any barriers required will need to be determined once detailed geological and hydrogeological data can be gathered and physically demonstrated with trials performed during operation of the mine.

6.2.2 Void Chemistry

As a groundwater “sink” the final void water chemistry will continually degrade, with the concentration of salts increasing due to constant evaporative loss from the void. Due to the low permeability of the surrounding rock and the water level of the void being significantly lower than any aquifer (weathered felsic), poor quality water will remain within the immediate vicinity of the void and cannot migrate to any identified aquifer of beneficial use (environmental or economic).

Subsurface material characterised as regolith, unmineralised waste or low-grade-ore is expected to form the majority of final slope exposures of the mine void. None of these materials were identified as potentially acid forming (Campbell, 2007) and it can therefore be expected that the water quality within the final void will not be dominated by acid-mine-drainage processes and is likely to be pH neutral to alkaline. While the processes of acid-mine-drainage are not considered probable, the mobilisation of metals such as molybdenum and arsenic can occur in neutral and alkaline waters and are expected to be elevated in the final void water to levels that exceed guidelines for uses other than industrial purposes (eg. mineral processing).

6.3 RISK AND POSSIBLE REMEDIAL MEASURES

The primary aims of the closure strategy from a groundwater perspective are to ensure that:

- the groundwater systems away from the mine can continue to support the ecosystems that currently rely on it;
- the surface water expression that exists at Coppin Gap can be maintained within its currently observed and predicted (for extreme events) natural variation;
- the groundwater quality surrounding the mine void is not degraded beyond its current beneficial use (low grade stock water); and,
- the system does not require ongoing artificial maintenance (i.e. walk-away).

To achieve all these goals, water levels and the flow direction need to be maintained within the alluvial and calcrete units to replicate pre-mining conditions, while groundwater from within the void must not interact with these aquifers.

The main risk to successfully achieving this outcome, is if drainage back takes place into the mine void via permeable aquifers that intersect the void and are also in connection with the calcrete and alluvial aquifers (Figure 5.1). If the mine adversely impacts the calcrete and alluvial aquifer groundwater system, an engineered solution may be required to sufficiently reduce the flow into the void and thereby isolate the void from the system, ensuring that water levels (in the aquifers and thus also within Coppin Gap) can be maintained within natural variation.

The requirements of such a solution are that it is:

- a proven technology;
- suits the hydrogeological setting; and,
- physically and chemically stable for the life of the application (i.e. permanent).

An approach that satisfies all these conditions and ensures a successful outcome is the installation of a cut-off wall(s) or subsurface hydraulic barrier(s) in the form of an in-situ grout curtain. This approach is commonly used in civil works applications such as the construction of dam and retaining walls. A conceptual study was completed by Coffey Geotechnics Pty Ltd (Coffey, 2007) that considered the feasibility of installing grout curtains across the known areas of higher permeability at Spinifex Ridge. The effectiveness of the installations to manage the groundwater response upon closure has been estimated using a numerical model (see Section 4) with favourable results. In practice, a detailed design will need to be developed and demonstrated with field trails during the development of the mine. Appendix F contains the results of the conceptual study performed by Coffey Geotechnics.

SECTION 7 - CONCLUSIONS

The hydrogeology of the Spinifex Ridge Mine is characterised by shallow alluvial and calcrete units overlying a weakly weathered rock mass with rocks of low permeability. It is expected that upon excavation, moderate inflows up to 20 L/s will be encountered in the upper benches to a depth of 80 mAHD. Subsequent benches can expect inflows in the vicinity of 4 to 5 L/s. For a mine of this size these inflows are considered low. To achieve adequate dewatering of the mine, it is recommended that a sump pumping system is utilised. After a more detailed understanding of where inflows occur, in-pit bores may assist in the dewatering effort.

In addition to managing groundwater inflows, significant pumping capacity will be required to manage seasonal surface-water inflows. The ability for the mine to accommodate these inflows will depend on the mine schedule. The total pumping capacity required needs to be determined in conjunction with the mine schedule and an assessment of the risk to ore supply due to storm water inundation.

The regional groundwater response to dewatering is expected to be relatively localised with development of a steep hydraulic gradient surrounding the Spinifex open-cut mine, due to the low permeability of the surrounding fresh rock mass. Potential exists for drawdown, in excess of natural variation to occur within the calcrete and alluvial aquifers adjacent to the pit, particularly in the vicinity of drainage lines between the mine and Coppin Gap. The impact on water levels at Coppin Gap is expected to be minor and within natural variation.

While the mine is operating, any excessive drawdown can be adequately mitigated with artificial supplementation by either recirculating mine dewatering water (if of acceptable quality) or using surplus capacity from the mine water supply system.

Upon mine closure it is proposed that the surface water diversion bunds will remain in place and the mine void will behave as a ground water sink, with evaporative loss exceeding surface and groundwater inflow. The water levels within the void are expected to rise to equilibrium levels of between -90 and -30 mAHD over a period of up to 1000 yrs, depending on climatic variation. The impact on water levels at Coppin Gap post closure is expected to minor and within natural variation. The void water quality will, with time, increase in salinity but is not expected to acidify (Campbell, 2007). Metals such as molybdenum and arsenic are mobile in neutral and alkaline waters and are likely to be present at levels that exceed guidelines for some uses; this is currently the case with natural Coppin Gap water.

It may be possible to develop a sustainable lake system upon closure, however without a detailed and demonstrated understanding of the subsurface hydrogeology and geochemistry, the environmental impact of this closure strategy is difficult to predict with sufficient confidence at this stage.

SECTION 8 - RECOMMENDATIONS

8.1 DEWATERING SYSTEM

The mine dewatering system will need to accommodate both surface water inundation and groundwater inflow. The main areas of contribution from groundwater inflow will be from the calcrete zones associated with current drainage systems where they overly ultramafic rocks and from the weathered felsic volcanics. Significant flows of short duration (days to weeks) may also be associated with faulted zones that have yet to be identified. To manage all aspects of dewatering, it is recommended that an in-pit sump pumping system be installed. When a detailed understanding of the hydrogeology is developed during the operation phase, a targeted approach with either in-pit or out of pit bores may be beneficial.

To manage dewatering from groundwater, a system capable of pumping a peak of 30 L/s at 400m vertical head is recommended. Additional capacity will also be required to manage surface water inundation. The required capacity will be function of mine schedule flexibility and the level of acceptable risk to ore supply due to cyclonic rain events.

To augment any impact that dewatering may have on the environmental systems surrounding the mine, an artificial aquifer recharge system should be installed. The system should be designed to supplement the upper aquifer system at volumes similar to those abstracted during dewatering. The point of supplementation should be beyond mine bunds or cut-off walls at a point where recirculation is minimised and environmental flow maximised. The exact point(s) of recharge will need to be determined from monitoring data and if necessary may extend to the surface water expressions at Coppin Gap. The water used for this activity will need to be of suitable quality which may need to be sourced from the mine water supply system, if the dewatered water is not suitable.

8.2 MONITORING PROGRAMME

The groundwater monitoring programme is the foundation for effective management of groundwater at the mine. Installation of the monitoring system should take place before mine dewatering commences to establish baseline monitoring. At Spinifex Ridge the monitoring programme commenced in December 2005. Additional regional monitoring is required and permanent installations will need to be established once construction commences to replace monitoring points that are destroyed during construction and mine development.

Trigger criteria for the management of both operational and environmental requirements can be developed and incorporated into the management plan.

8.3 CLOSURE PLANNING

It is recommended that a detailed mine closure plan be developed within the first five years of operation and that a final mine closure plan be finalised within five years of closure. To achieve this goal from a hydrogeological perspective, the following outcomes must be achieved:

- the groundwater model must be upgraded based on any new data collected, so that more accurate predictions related to mine closure can be made;
- a waste rock model that incorporates the potential of the rock exposed within the final walls to interact with the chemical composition of the groundwater needs to be determined and quantified;
- an understanding of the Groundwater Dependent Ecosystems must be established to a level that allows accurate determination of their sustainability post closure; and,
- research into alternative closure strategies that will allow the mine void/site to be used for other purposes post closure must be investigated (eg. void storage).

SECTION 9 - REFERENCES

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