4.5.3 Woodie Woodie

4.5.3.1 Regional Hydrogeology

The Woodie Woodie mine is located in a large synclinal basin known regionally as the Oakover Syncline. The Oakover Syncline is a platform carbonate unit that disconformably overlies the Jeerinah Formation. The Oakover Syncline hosts the two major aquifer units namely the Pinjian Chert Breccia and the Upper Carawine Dolomite, forming a major regional scale aquifer.

Regional groundwater flow in the Woodie Woodie area is thought to be from east to west across the site, away from the topographic high areas (normally coincident with outcropping Jeerinah Formation, locally referred to as the Gregory Ranges) towards the Oakover River (GRM, 2006). The river is considered to be the major natural discharge area within the region.

The most common range of pre-mining groundwater levels is between 254 and 255 mAHD (as measured in Bells, Chris D and Big Mack pits).

4.5.3.2 Local Aquifer Characteristics

The Pinjian Chert Breccia and the Upper Carawine Dolomite are the major aquifer units present in the vicinity of Woodie Woodie. **Table 4-8** provides a summary of the reported hydraulic test results and derived aquifer parameters for the Woodie Woodie area. The data shows a highly transmissive aquifer, capable of delivering high bore yields.

Pinjian Chert Breccia Aquifer

The Pinjian Chert Breccia forms a major aquifer that is commonly confined by the Patterson Formation where it is present, but is otherwise unconfined.

The transmissivity of the Pinjian Chert Breccia is estimated to range from 500 m²/day to 2500 m²/day (Mackie Martin PPK 1994, Golder Associates 2000 & 2003 and GRM 2004 & 2005). The Pinjian Chert Breccia is often vuggy, with voids that could be either open, or in-filled with clay or other fine grained sediments. The vuggy Pinjian Chert Breccia often surrounds the manganese ore zones (e.g. Lewis and Chris D); although it is uncertain whether these vughs are ubiquitous throughout the unit.

The specific yield for the Pinjian Chert Aquifers are likely to be low, because of the low primary porosity, although values of up to 10% for the Pinjian Chert Breccia have been quoted (Mackie Martin PPK, 1993) and may be appropriate at localities with the greatest development of vughs. The confined storage (storativity) is likely to range between 1×10^{-4} and 1×10^{-6}.

Upper Carawine Dolomite Aquifer

The Upper Carawine Dolomite, defined as the dolomite near the contact with the Pinjian Chert Breccia and/or manganese, forms another unconfined aquifer within the region. The transmissivity of the Upper Carawine Dolomite is highly variable, ranging from <100 m²/day to 2000 m²/day. The higher permeability is controlled by dissolution of discontinuities (bedding planes, fractures, etc) and vughs.

The specific yield for the Upper Carawine Dolomite aquifers are likely to be low, because of the low primary porosity. However, values of up to 20% for the Carawine Dolomite have been quoted (Dames and Moore, 1996) and may be appropriate at localities with the greatest development of vughs. The confined storage (storativity) is likely to range between 1×10^{-4} and 1×10^{-6}.

Other Minor Aquifers

The Lower Carawine Dolomite, defined as the dolomite zone furthest from the contact with the Pinjian Chert Breccia, is thought to be of lower permeability. Recent logging of RC samples collected during exploration and resource drilling show that samples further from the contact with the Pinjian Chert Breccia are generally drier than samples collected close to the contact, which supports this interpretation (GRM, 2006).

The Woodie Woodie manganese deposits are highly heterogeneous and may either be of a lower or similar permeability to the main aquifers. Two examples of areas where the manganese ore zones are of a lower permeability are the Lewis and Double 8 pits. In some areas (e.g. the pits of Cracker, Big Mack and Radio Hill South), manganese ore zones have been associated with major groundwater inflows, indicating higher permeability. This higher permeability appears to be associated with a zone of significant faulting, which extends between Cracker and Big Mack and possibly towards Radio Hill. In addition, there is some evidence that inflow rates at Cracker and Big Mack may have been exacerbated by drill holes left un-grouted, possibly linking the pits to the highly permeable manganese ore zones at depth and to the highly permeable Upper Carawine Dolomite.

- **Table 4-8 Summary of Hydraulic Test Results for the Woodie Woodie Area**

Area / Pits	Lithology	Type of Test	Analysis Method	T (m^2/day)	K (m/day)	Storage (Sy or S)
Bells		48 Hr Constant Rate Test Pumping (Q = 110 L/sec)	Cooper - Jacob	5,000	100	
Lewis		48 Hr Constant Rate Test Pumping (Q = 100 L/sec)	Cooper - Jacob	2,000	40	
Chris D		48 Hr Constant Rate Test Pumping (Q = 95 L/sec)	Cooper - Jacob	1900 - 2,750	27 - 40	
Radio Hill Chert	Breccia + Manganese	48 Hr Constant Rate Test Pumping (Q = 100 L/sec)	Cooper - Jacob	2,100	40	
Radio Hill Pumping (Q = 40 & 100 L/sec)	Upper Carawine Dolomite	48 Hr Constant Rate Tests	Cooper - Jacob	150 - 550	3 - 11	
Greensnake	Upper Carawine Dolomite & Chert Breccia	48 Hr Constant Rate Tests Pumping (Q = 40 to 50 L/sec)	Cooper - Jacob	60 – 2,600	1 - 40	
Mike	Carawine Dolomite	na	na	2,000		0.2
Mike	Chert Breccia	na	na	1,500 – 2,000		0.1

NOTES: T – Transmissivity, K – Hydraulic Conductivity, Sy – Specific yield, S – Storativity, na – not available

4.5.3.3 Groundwater Chemistry

Groundwater quality is available for six water sources in the Woodie Woodie area. Three of these are mine pits and three are bores. For some sources, the results presented in **Table 4-9**, are a composite of values taken for that water source, due to the suite of analyses not having been completed for all parameters at one sampling event.

- **Table 4-9 Groundwater Quality from Sources from the Woodie Woodie Area.**

Analyte	Symbol	Units	Area 1 Bore	Bell Pit Overflow	Camp Bore	Chris D Overflow	Double 8 Overflow	Tooma Stockyards
pH	-	none	7.09	8.11	7.77	8.36	7.90	8.92
Electrical conductivity (at 25ºC)	EC	uS/cm	135	125	185	100	125	135
Total Dissolved Solids (at 180ºC)	TDS	mg/L	780	700	1050	--	--	820
Sodium	Na^+	mg/L	180	165	210	155	150	210
Potassium	K^+	mg/L	6	7	2.2	2.6	4.6	8.5
Calcium	Ca^{2+}	mg/L	46	54	47	31	49	26
Magnesium	Mg^{2+}	mg/L	47	55	67	40	48	59
Chloride	Cl^-	mg/L	190	170	240	--	--	215
Bicarbonate	HCO_3^-	mg/L	425	380	409	450	425	319
Carbonate	CO_3^{2-}	mg/L	--	--	--	--	--	--
Sulphate	SO_4^{2-}	mg/L	94	94	165	38	72	110
Nitrate	NO_3^-	mg/L	1.9	3.9	5	--	--	1.9
Iron	Fe	mg/L	0.008	0.065	<0.003	0.106	0.26	0.055
Hardness	-	--	308	360	395	244	322	310

-- No Information Available

The chemistry of the groundwater is generally host rock dependant. The ground water for the Woodie Woodie area would be classified as ranging from very hard to hard. The high bicarbonate values, high pH (7.09-8.92) and high Ca^{2+} and Mg^{2+} are characteristic of groundwater derived from dolomites.

The TDS values provide an indication of water salinity. Four TDS values are available for the Woodie Woodie area, with Area 1, Bell pit and Tooma stockyards being classified as fresh water (<1000 mg/L) and the camp bore falling into the moderately saline/brackish field (1000 – 10,000 mg/L).

On the Expanded Durov Diagram (**Figure 4-18**), the Chris D pit and Double 8 pit analyses indicate groundwater dominated by bicarbonate (HCO_3^-) and sodium (Na^+). This indicates ion exchanged water. The Bell Pit Overflow, Tooma Stockyards, Area 1 Bore and Camp Bore show sulphate (SO42-) (or anions indiscriminate) and sodium (Na+) dominant water types, a water type not frequently found and which may be due to mixing influences.

4.5.3.4 Other Groundwater Users

The WINSITES database of monitoring sites indicates that there are 37 recorded groundwater sites in or adjacent to the area of interest. These vary from bores, wells, mine pits and shafts. **Figure 4-20** shows the locality of the sites.

The operational status of the groundwater sites is not recorded for the majority of the water sources. However, according to the WINSITES database, one bore is operational, fourteen bores are abandoned, one bore is non-operational and the status of the remaining groundwater sources is not recorded. The majority of the bores are shown as being used for livestock watering.

The livestock bores are fairly shallow, varying from 6.67 mAHD to 26.86 mAHD. It appears that a number of these livestock bores are shallow hand-dug wells.

Two of the deepest bores (22A and 22) are drilled by Main Roads Western Australia to provide production water to the Carawine Dolomites. These bores are drilled 46 m and 82 m respectively with an airlift yield of 528 m^3 and 490 m^3 and are artesian. This suggests at least in this area, the deeper dolomite aquifers are confined.

4.5.4 De Grey River

4.5.4.1 Regional Hydrogeology

Groundwater across the northern Pilbara region (inland of the Canning Basin aquifer system) is largely associated with the following main aquifer types:

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

These aquifers are recharged by the direct infiltration of rainfall and run-off where outcrop occurs. In addition, alluvial aquifers are recharged by the leakage of surface water flow within the drainage channel; and to a lesser extent, by groundwater seepage or through-flow from the underlying basement units (depending on the degree of fracturing, mineralisation and secondary permeability).

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

Groundwater within the alluvial aquifer systems typically flows down the 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.

4.5.4.2 Local Aquifer Characteristics

Two main aquifer systems were identified in this area during the groundwater exploration programme undertaken in support of the Preliminary Feasibility Study (PFS) (Rockwater, 2006). These include a shallow alluvial aquifer system associated with the active drainage network and a deeper basal aquifer system associated with a buried palaeo-channel. These aquifer units are separated by a potentially leaky aquitard unit. The properties of these aquifers are summarised in **Table 4-10** and outlined below.

- **Table 4-10 Summary of Aquifer Parameters**

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

1 Derived from Rockwater, 2006

2 Based on typical values for alluvial systems elsewhere.

The shallow aquifer comprises a laterally extensive sequence of coarse sands and gravels, 6 - 10 m thick, associated with the active river drainage channel. The water table is typically between 3 - 7 mbgl (see **Table 4-11**); and is likely to be in hydraulic continuity with the natural pools in the river bed. The aquifer is regularly recharged via direct infiltration of rainfall, run-off and river flow. Groundwater levels are expected to rise close to ground level during high flow events. Groundwater levels recede during dry periods as a result of evaporation, groundwater through flow and abstraction (natural and local abstraction). The aquifer provides baseflow to the river and thus sustains river flows and pool water levels during low flow conditions.

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

The deeper semi-confined basal aquifer system comprises very coarse sand to very coarse gravel deposits associated with the infill of the palaeo-channel feature. The lateral extent of the aquifer is constrained to the palaeo-channel. Groundwater levels are confined and typically between 4 - 7 mbgl (see **Table 4-11**) and approximately 45 m above the top of the basal aquifer system. The transmissivity of this aquifer was interpreted to be between 180 and 885 m^2/d - based on standard analysis of aquifer test data from three bores tested by Rockwater (2006). The range of values observed is likely to reflect the different positions of the test bore sites relative to the palaeo-channel axis. For example, site MMDG04 exhibited the highest values (800-885 m^2/d) and is situated towards the centre of the palaeo-channel near the confluence with the Kookenyia Creek (based on interpreted TEM data) and shows a well developed sequence of coarse alluvial sediments (approximately 23 m thick).

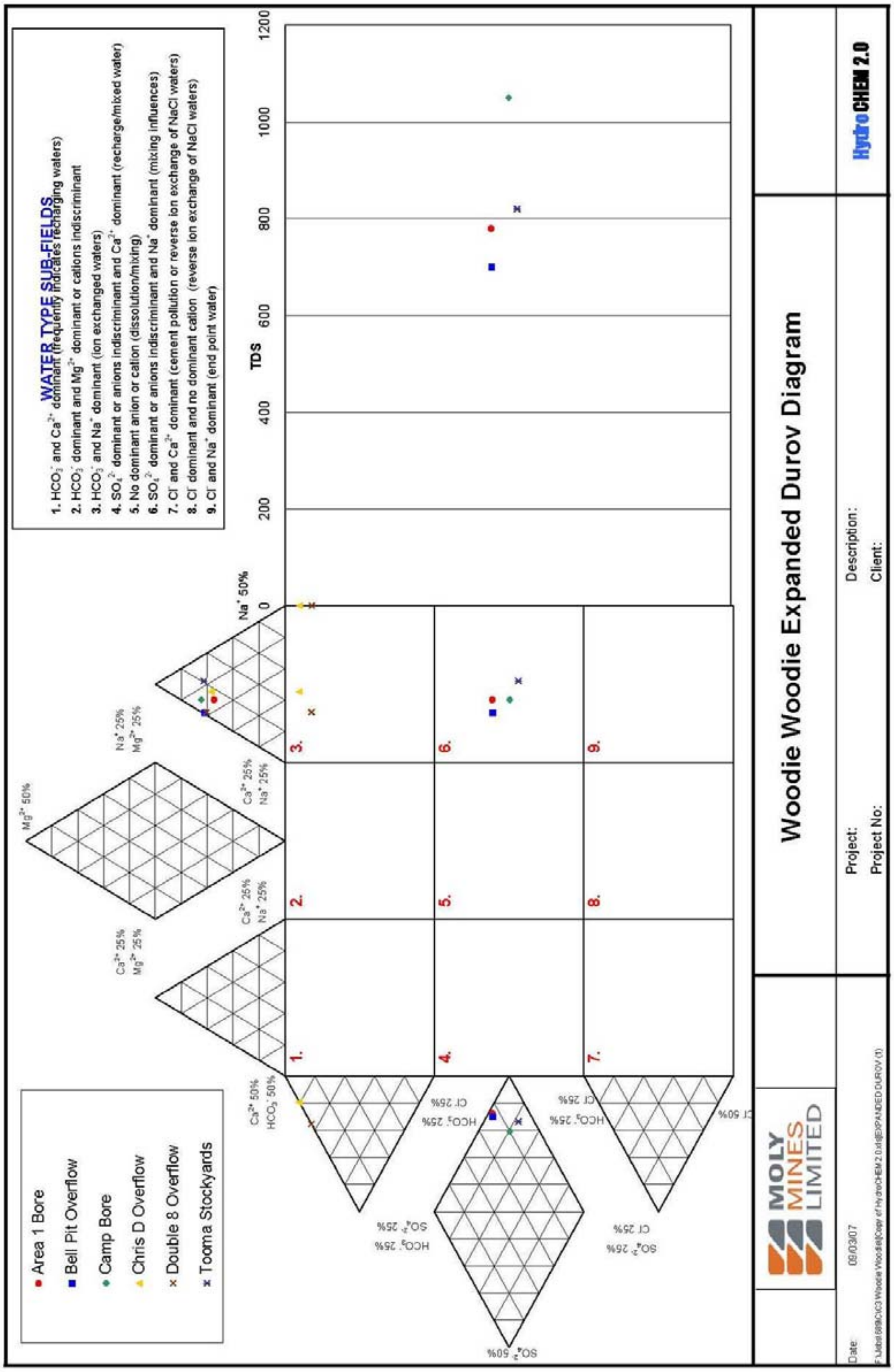
In contrast, site MMDG09 exhibited the lowest transmissivity values (180 - 395 m^2/d) and is situated on the margin of the palaeo-channel and shows a more clayey sequence with only minor stratified horizons of coarse sediments. Evidence of boundary effects were observed in the aquifer test data at all sites and are likely to represent the margins of the palaeo-channel. For the purposes of water resource estimation and associated impact assessment, the effective transmissivity of the basal aquifer should be taken from the mid to lower end of the interpreted range. Evidence of leakage was also observed in the aquifer test data at site MMDG09 and may reflect delayed release of water from the more clayey alluvial sequence at this site, or the contribution of water from the adjacent basement. The storage values for the basal aquifer range from 3.4×10^{-3} to 5×10^{-4}, and are consistent with a semi-confined aquifer. The full DeGrey River groundwater assessment is located in **Appendix J.**

- **Table 4-11 Representative Groundwater Levels**

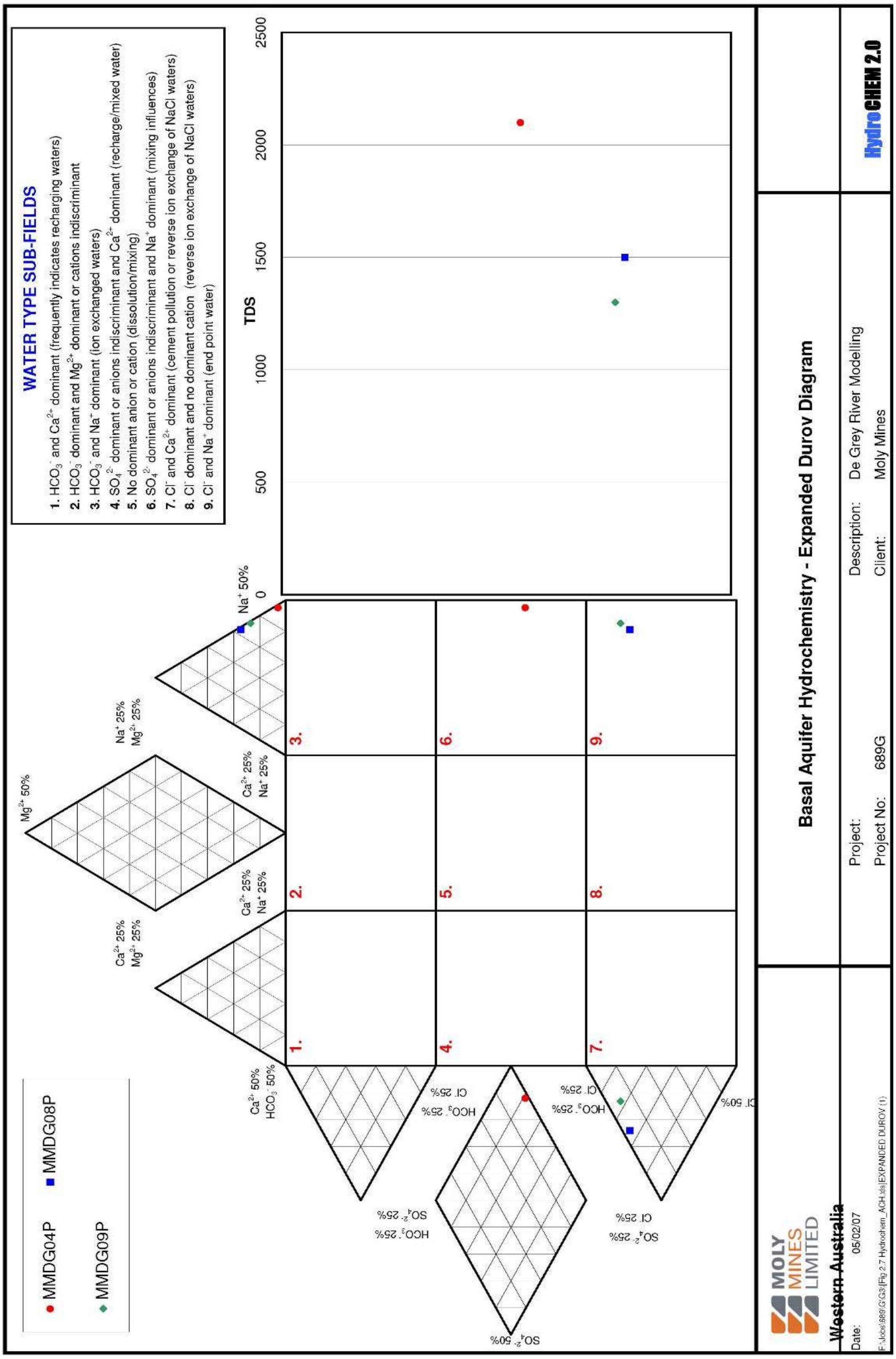
Bore	Aquifer	Water Level (m bgl)	
		December 2005	October 2006
MMDG04A	basal aquifer		4.63
MMDG04P	basal aquifer	4.85	4.67
MMDG04S	upper aquifer	3.87	3.37
MMDG08A	basal aquifer		7.20
MMDG08P	basal aquifer	6.83	pumping
MMDG08S	upper aquifer	7.13	6.83
MMDG09A	basal aquifer		6.83
MMDG09P	basal aquifer	7.22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

4.5.4.3 Groundwater Chemistry

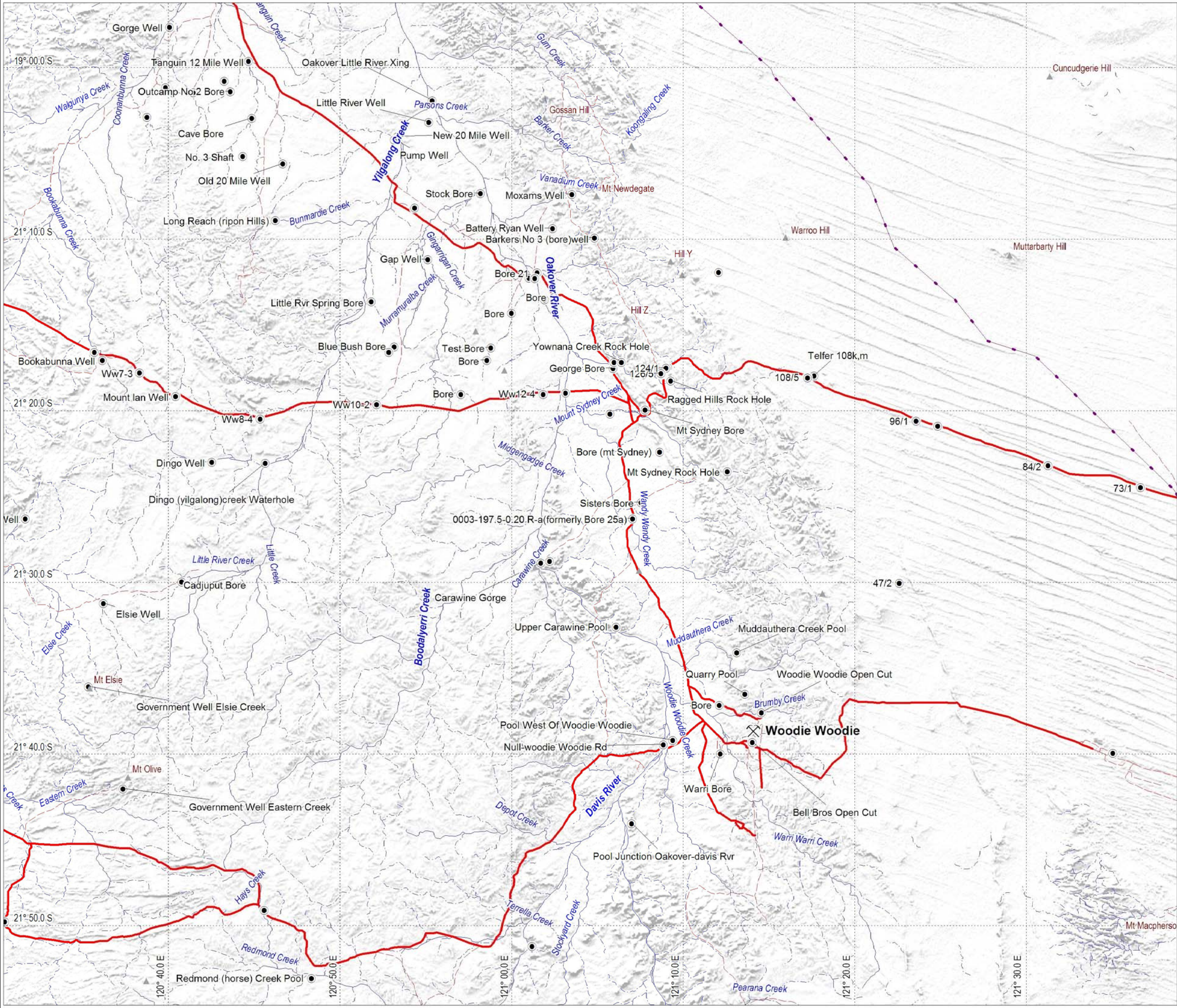
Groundwater associated with the alluvial aquifer systems in this area is typically of good quality. Field electrical conductivity values of 1,900 - 6,220 µS/cm and pH 7.4 - 7.7 were recorded for the basal aquifer system (see **Table 4-12**), while the shallow aquifer system is likely to show similar water quality to the overlying river system. Groundwater sampled from the basal system at sites MMDG08 and MMDG09 during December 2005 was hard to moderately hard and displayed sodium and chloride ion dominant end-member fluid compositions, which suggests little evidence of recent recharge (see **Figure 4-19**). Groundwater sampled from the basal system at site MMDG04, near the confluence with Kookenyia Creek, was moderately soft and displayed a sulphate ion dominant fluid composition (or sodium ion dominant composition with indiscriminate anions) consistent with groundwater mixing (see **Figure 4-19**). The data are provided in **Table 4-13**.



■ **Figure 4-18 Woodie Woodie Expanded Durov Diagram**



■ **Figure 4-19 Basal Aquifer Hydrochemistry – Expanded Durov Diagram**



MOLY MINES LIMITED

Spinifex Ridge Project
Western Australia

Figure 4-20

WINSITES Groundwater Sources in Woodie Woodie Vicinity

0 — 20km

Map Projection: Longitude / Latitude (Australia GDA94)

Compiled: 5 / 7 / 2007 Compiled by: MOL
Updated : 05 / 07 / 2007 Checked by : MOL
Plan No : Revision No : A

File: j:\3100 spinifex ridge mo\14 gis\user working data\per\per_figure_4.15 - A3.wor

Location Diagram :

Map Legend :

- Road
- 4WD Track
- Main watercourse
- Minor watercourse
- Telfer - Port Hedland Gas Pipeline
- WINSITE Groundwater Source

Table 4-12 Field Groundwater Quality

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

Table 4-13 Groundwater Chemistry

Analyte	Symbol	Units	MMDG04P	MMDG08P	MMDG09P
Date	-	-	10/12/05	13/12/05	17/12/05
Sample taken	-	-	after test pumping program		
pH	-	none	8.1	7.4	7.5
Electrical conductivity (at 25ºC)	EC	uS/cm	4,200	3,100	2,800
Total Dissolved Solids (at 180ºC)	TDS	mg/L	2,100	1,500	1,300
Sodium	Na^+	mg/L	830	460	490
Potassium	K^+	mg/L	1.9	4.8	8.5
Calcium	Ca^{2+}	mg/L	7.2	4.7	3.4
Magnesium	Mg^{2+}	mg/L	13	51	41
Chloride	Cl^-	mg/L	600	500	460
Bicarbonate	HCO_3^-	mg/L	830	380	460
Carbonate	CO_3^{2-}	mg/L	<1.0	<1.0	<1.0
Sulphate	SO_4^{2-}	mg/L	200	310	150
Nitrate	NO_3^-	mg/L	4.5	<0.2	24
Iron	Fe	mg/L	<0.05	<0.05	<0.05
Ionic balance	-	%	3.96	-4.42	2.24
Hardness	-	-	moderately soft	Hard	moderately hard
Water type[1]	-	-	SO_4^{2-} dominant[2]	Na^+ and Cl^- dominant	

1 Expanded Durov plot classification.

2 Sodium dominant with indiscriminant anions.

4.5.4.4 Other Groundwater Users

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

Table 4-14 Existing Water Supplies

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

1 MGA94 Zone 51

4.6 Surface Water and Drainage

4.6.1 Surface Water Catchments

The project is located within the De Grey River catchment, which is the main drainage system in the northeast Pilbara area, as shown on **Figure 4-5**. 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 50km southeast of Shay Gap to form the De Grey River. Further downstream near the mouth of the De Grey River (located about 70km northeast from 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 Talga River and then the Coongan River.

The Pilbara region is set in a rugged landscape, where gorges are cut into hill ranges and form water holes with sheer ancient rock faces. In the study area, a ridge 100 to 150m high, known as Spinifex Ridge, is the dominant feature in the landscape. Two breaks in Spinifex Ridge known as Coppin Gap and Kitty's Gap, concentrate flow from the upstream catchment 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 79km^2), so any changes in the hydrology of the Coppin and Kitty's Gap catchments due to mining activities are unlikely to impact on the De Grey River.

The drainage 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 76km^2, as illustrated on **Figure 4-5**. 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 meander 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 has a rocky terrain with high relief and a rapid response to rainfall. In addition, the vegetation is similar with low scrub (predominately spinifex) with sparse tree coverage.

The second of the Coppin Gap catchments to the south and west of Coppin Gap has an area of 54km^2. This catchment predominately has a relatively low relief and hence a slower response to rainfall. The main waterway which consists mainly of pebbles, gravels and sands, with dense tree growth, meanders along the 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. The "venturi" effect that occurs results in increased 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. This zone of sediment deposition just downstream of Coppin Gap was confirmed during a site inspection by Aquaterra on 3 to 5 May 2006, whereby a sandbar was observed just downstream of Coppin Gap. As a result of the scouring and sandbar, a permanent depression has been formed in Coppin Gap that creates the semi-permanent pool.

At Kitty's Gap, the waterway is also confined to the narrow gap in the ridge, so 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 (2.9km^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 no sandbar has formed at Kitty's Gap.

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. Further details of the surface water assessment undertaken for the project are in **Appendix H**.

4.6.2 Hydrological Regimes and Climatic Variables

In the general Pilbara region, the climate is described as arid with wet summers, and waterways are typically ephemeral, generally flowing only a few times a year. The climatic features of the region have been described in more detail in **Section 4.1**.

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, regional techniques are typically relied upon to produce flow estimates in this area.

4.6.3 Coppin Creek and Coppin Gap Pool

Two surveys of the aquatic ecosystem of the project area in 2005 and 2006 included Coppin Creek, Coppin Gap pool and associated drainage lines (OES, 2005a; 2006c). Survey locations are shown in **Figure 4-21** and biological results are presented in **Section 4.9**. Both sampling events occurred soon after rainfall, when the creekline was made up of small, disconnected pools.

The project area is arid, with lotic systems that are predominantly ephemeral. The upper reaches of major rivers in the Pilbara Bioregion typically traverse through deep gorges with intermittent flows that can transport large volumes of water, often forming river pools and waterholes (Karanovic, 2006).

Coppin Creek is a tributary of Kookenyia Creek, and drains the Coppin Gap Catchment (**Figure 4-5**). . During heavy rainfall events it flows northward through Coppin Gap to the De Grey River (**Figure 4-5**). Coppin Creek is a temporary, inland, dryland creek, similar to other creeks in the region.

Coppin Gap pool is a semi-permanent water body located where Coppin Creek intersects the Talga Range, with a calcrete basement (Williams, 1998). Two catchments flow into Coppin Gap; the Coppin Gap East Catchment and the Coppin Gap West Catchment (**Figure 4-5**). Water flow through Coppin Gap is directed northward to the De Grey River. Coppin Gap pool has minimal fringing (riparian) vegetation due to steep rocky inclines, with only a small section of creek bank supporting eucalypt and melaleuca species.

Creekline Morphology and Condition

The morphology of Coppin Creek within the project area varies considerably, with the soil profile and texture of soil materials reflecting a dynamic system that undergoes constant change through cycles of deposition and erosion. Sediments in Coppin Creek generally ranged from coarse sands to large cobble.

The creek is classed as having an integrated, convergent channel network in a tributary channel pattern (McDonald *et al.*, 1998). The depth of the major channel is classed as shallow to very shallow, with moderately deep sub-channels. The banks of the major drainage channel were typically gently inclined (3° – 10°).

Under the classification system of the Australian and New Zealand Environment and Conservation Council (ANZECC/ARMCANZ, 2000) for the protection of aquatic ecosytems, Coppin Creek is a ‘slightly to moderately disturbed’ ecosystem. The classification is based on Coppin Creek being mostly undisturbed, apart from intermittent human activity, primarily in the form of tourist visitation (four-wheel drive access), and pastoral management activities, cattle grazing, frequent fire and weeds as a result of human activities.

Existing Sedimentation Transport and Deposition

In most waterway systems, during a flood, sediments are mobilised (erosion), transported downstream and then deposited. In the Coppin Creek catchment upstream of Coppin Gap, the source of most sediment is likely to be from silts, sands and gravels found in low relief areas in the middle to upstream reaches of the western catchment. The lower areas of the western catchment and the eastern catchment are typically rock, so are likely to mobilise only small amounts of sediment from erosion. The mobilised sediments are likely to be deposited in sections of the waterway with low velocities. In the Coppin Creek catchment, this is likely to be just upstream and just downstream of Coppin Gap.

Flow through Coppin Gap is confined to a narrow cross section so during a flood, water will back-up just upstream of Coppin Gap. This increased flood depth just upstream of the gap results in reduced velocities so there is the potential for sediment deposition in this area. As velocities are high through the gap, significant sediment deposition in this area is unlikely. This was confirmed during the biological surveys of 2005 and 2006 where no true sediment layer was observed in Coppin Gap pool, as was found at other sites in the project area. Instead, a layer of organic material (referred to here as 'sediment') had accumulated along the littoral zone over a lithic base, with the area appearing to act as a compensation basin for the entering water

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. This zone of sediment deposition was confirmed during a site inspection by Aquaterra on 3 to 5 May 2006, whereby a sandbar was observed just downstream of Coppin Gap.

Water Quality

The water quality parameters assessed during the biological surveys of Coppin Creek and through a monthly surface water monitoring program, include basic components (pH, EC), major ions, dissolved metals and nutrients. In line with recommendations in ANZECC/ARMCANZ (2000), baseline data has been collated to serve as a reference for typical water quality ranges, for Coppin Creek and Coppin Gap pool (**Table 4-15**). The concentrations of some baseline water quality parameters for Coppin Creek exceeded the ANZECC trigger values for freshwater, indicating the limited relevance of these guidelines to Coppin Creek.

Surface water in Coppin Creek is typically fresh and alkaline, with an electrical conductivity of approximately 3,540 µS/cm and a pH of 8.1 – 8.9. Coppin Gap pool is a fresh, semi-permanent water body with an electrical conductivity less than 4,800 µS/cm and a pH of 8.2 **-** 8.3 (**Table 4-15**). The dominant ions in surface water generally follow the normal sequence for inland rivers of Australia, that is; bicarbonate > chloride > sulphate for the anions, and sodium > magnesium > calcium > potassium for the cations. Slight variations from the sequences were noted between 2005 and 2006 at some sites where salinity was lower, as is commonly reported in inland waters of Australia (Hart and McKelvie, 1986).

Concentrations of dissolved metals are variable throughout Coppin Creek, reflecting variability in local geology. Concentrations of beryllium, cadmium, selenium, lead and mercury were below detection at all sites, in both baseline surveys of the creek. Arsenic, barium, copper, manganese, molybdenum, nickel and zinc were detected at one or more sites (**Table 4-15**).

At Coppin Creek, concentrations of nutrients such as total nitrogen and total phosphorus ranged from below detection to concentrations similar to that recorded in fertiliser-impacted agricultural areas of the south west of Western Australia, which are atypical of the Pilbara region. However, concentrations of both nutrients remained below 2 mg/L. Concentrations of *chlorophyll a*, an indicator of primary productivity and organic pollution, were variable between sites and sampling events, ranging from 5 to 41 mg/m^3. Similarly, concentrations of total suspended solids (TSS) were variable (10 to 1,030 mg/L) between sites and sampling events.

At Coppin Gap pool concentrations of nutrients such as total nitrogen and total phosphorus were below 1mg/L. The TSS values (**Table 4-15**) from monthly sampling events were within the range of values from published data for the De Grey River (<5 – 400 mg/L) (OES, 2006a).

The available data shows that Coppin Creek reports a high degree of variability in water quality between sites, due to the disrupted and non-continuous nature of the creek system, and between sampling events, depending on the season and the phase of the hydric cycle in which the creek was sampled.

Sediment Quality

Sediment quality was assessed during the biological surveys in 2005 and 2006. In line with recommendations in ANZECC/ARMCANZ (2000), preliminary sediment quality data was collated to serve as a reference for typical sediment quality ranges for Coppin Creek and Coppin Gap pool (**Table 4-16**). The concentrations of some baseline sediment quality parameters for Coppin Creek exceeded the ANZECC interim sediment quality guidelines (high trigger value), indicating the limited relevance of these guidelines to Coppin Creek.

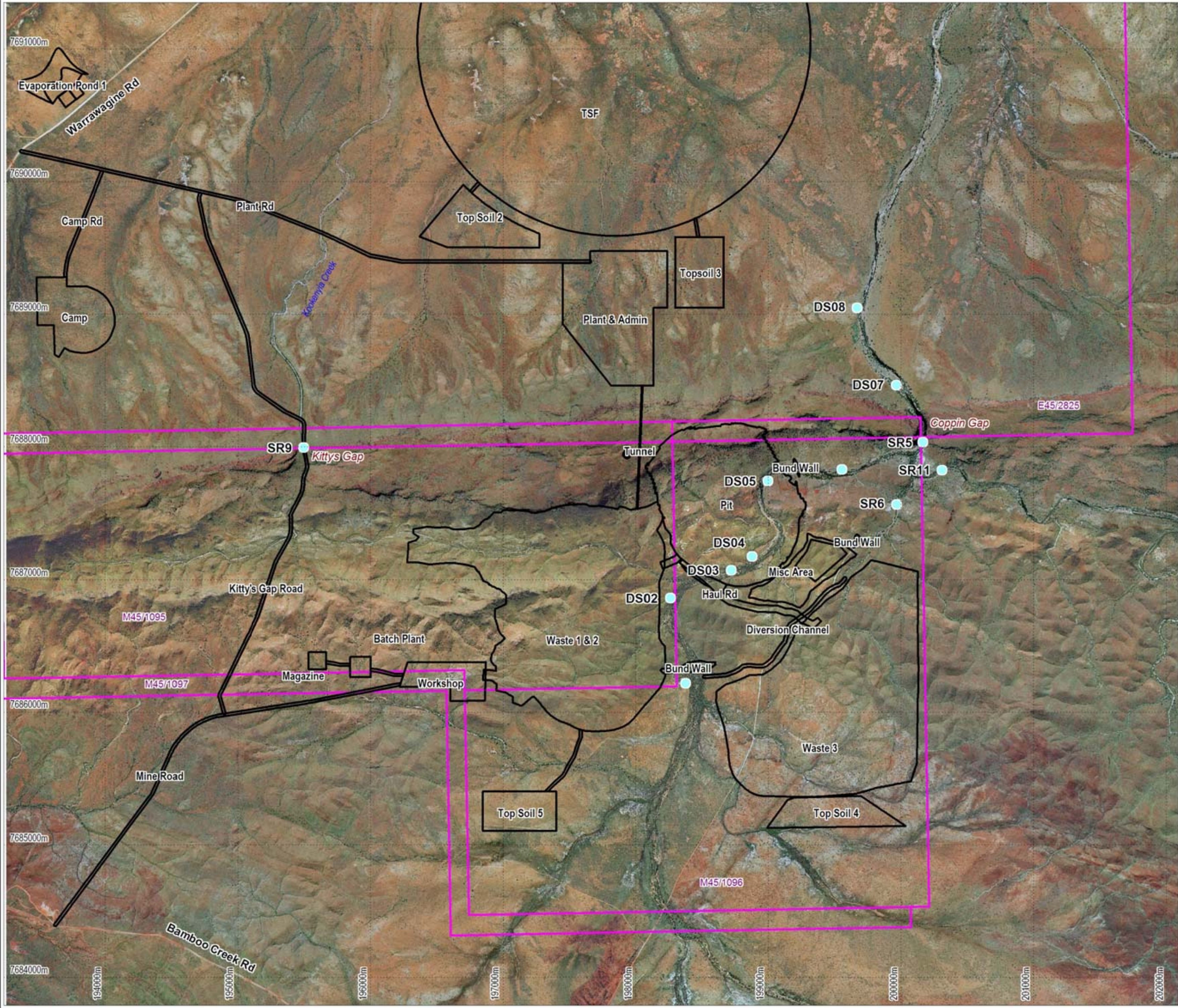
As with water quality, sediment quality is variable between sites in Coppin Creek, related to the disconnected nature of pooled surface water in the creek. In general, the pH of the sediments is alkaline and the salinity (in terms of total soluble salts) is low. Major ions were variable between sites and sampling events.

Beryllium, cadmium, selenium and mercury were below detection in all samples collected. Arsenic, barium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, vanadium and zinc ranged from below detection to detectable levels in all samples collected from Coppin Creek (**Table 4-16**). Regarding total metal concentrations in the sediment at Coppin Gap pool, beryllium, cadmium, lead, molybdenum, selenium and mercury were below detection in all samples collected. Conversely, arsenic, barium, chromium, cobalt, copper, copper, iron, manganese, nickel, vanadium and zinc were above the detection limits in two samples collected from Coppin Gap pool.

In terms of nutrients, total nitrogen remained below 20mg/kg while total phosphorus was comparatively elevated in Coppin Creek. Total nitrogen and total phosphorus concentrations in the sediment at Coppin Gap pool were greater than at all other sites in the project area (**Table 4-16**).

In comparison to other sites within the project area but outside of Coppin Creek, the concentrations of most parameters were lower in Coppin Creek. This was probably a reflection of the coarse, rocky sediments in Coppin Creek, which have little affinity for retaining metals, nutrients or salts due to their physical properties.

Multi-seasonal surveys have acquired sediment quality from the project area. However, due to the lack of true sediment at Coppin Gap pool and the limited natural fluctuations in the system to date, data for Coppin Gap pool should be considered indicative at this stage.



MOLY MINES LIMITED

Spinifex Ridge Project
Western Australia

Figure 4-21
Location of aquatic survey sites at Spinifex Ridge, sampled in 2005 and 2006

0 — 1500m

Map Projection: MGA Zone 51 (GDA 94)

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Updated : 4 / 7 / 2007
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Compiled by:
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Revision No : A

Location Diagram :

Legend

Aquatic Survey Site Location

- **Table 4-15 Range of Values for Water Quality Parameters in 2005 and 2006.**

(n = number of data records. All metals are reported as dissolved concentrations, in mg/L unless otherwise stated).

Parameter and units of measurement (mg/L unless specified otherwise)	Coppin Creek		Coppin Gap pool	
	Range	n	Range	n
Laboratory pH (pH unit)	8.1 -8.9	12	8.2 – 8.3	2
Electrical Conductivity (µS/cm)	226 -3540	12	2350 - 2610	2
Total Dissolved Solids	124 -2240	12	540 – 2530	13
Dissolved Oxygen	10 -15	5	7.2	1
Hydroxide Alkalinity	<1	12	<1	13
Carbonate Alkalinity	<1 -134	12	<1 – 130	13
Bicarbonate Alkalinity	113 -669	12	183 – 679	13
Sulphate	4 -309	12	47 – 201	13
Sulphur	1 -103	12	16 – 67	13
Chloride	3.2 -730	12	128 – 789	13
Calcium	20 -67	12	28 – 69	13
Magnesium	2 -84	12	29 – 175	13
Sodium	19 -640	12	108 – 494	13
Potassium	<1 -7	11	3 - 6	2
Silicon			29	1
Arsenic	0.003 -0.016	12	0.007 – 0.025	13
Beryllium	<0.01	12	<0.01	13
Barium	0.092 -0.151	12	0.041 – 0.096	13
Cadmium	<0.0001	12	<0.0001	13
Chromium	<0.001 -0.002	12	<0.001 – 0.006	13
Cobalt	<0.001 -0.001	12	<0.001 – 0.002	13
Copper	0.001 -0.011	12	<0.001 – 0.007	13
Lead	<0.001	12	<0.001 – 1.42	13
Manganese	0.003 -0.607	12	0.017 – 0.171	13
Molybdenum	0.003 -0.131	12	0.068 – 0.154	13
Nickel	<0.001 -0.002	12	<0.001 – 0.004	13
Selenium	<0.001	7	<0.01	1
Vanadium	<0.05 -0.11	12	<0.01 – 0.05	13
Zinc	0.01 -0.029	12	<0.005 – 0.021	13
Iron	<0.05 -0.05	7	<0.05	1
Mercury	<0.001	7	<0.0001	11
Total Nitrogen	<0.1 -1.9	7	<0.1	1
Total Phosphorus	<0.010 -0.64	12	<0.01 – 0.09	11
Reactive Phosphorus as P	<0.010 -0.191	7	<0.010	1
Chlorophyll a (mg/m^3)	<5 -41	12	<5 – 5	2
Suspended Solids (SS)	10 -1030	5	<1 – 30	12
Ammonia as N			0.016	1
Nitrite as N	<0.010 -0.149	5	<0.010 – 0.013	10
Nitrate as N	0.092 -5.6	5	<0.010 – 66.8	10
Nitrite + Nitrate as N	0.092 -5.7	5	<0.010 – 66.8	10
Total Kjeldahl Nitrogen as N	0.6 -1.9	5	<0.01 – 0.4	11

- **Table 4-16 Range of Values for Sediment Quality Parameters in 2005 and 2006.**

(n =the number of data records. All metals are reported as total concentrations).

Parameter and units of measurement (mg/L unless specified otherwise)	Coppin Creek		Coppin Gap pool	
	Range	n	Range	n
pH Value (ph unit)	8.2 -9.5	18	8 - 8.7	2
Electrical Conductivity (µS/cm)	54 -269	18	230 - 269	2
Total Soluble Salts	176 -874	18	748 - 874	2
Moisture Content (%)	<1.0 -46.8	18	<22 – 32.3	2
Bicarbonate (meq/kg)	5 -219	18	112 – 120	2
Carbonate (meq/kg)	<1 -8	18	<1	2
Sulphate	<10 -80	18	50 - 90	2
Sulphur	<10 -10	8	20	1
Chloride	<10 -210	18	130 - 180	2
Sodium	20 -230	18	180 - 260	2
Potassium	<10 -440	16	10 - 770	2
Calcium	<10 -4560	18	50 - 8110	2
Magnesium	<10 -7920	18	50 - 14100	2
Arsenic	<5 -11	18	7 - 8	2
Barium	20 -120	18	30 - 40	2
Beryllium	<1	18	<1	2
Cadmium	<1	18	<1	2
Chromium	13 -566	18	113 - 184	2
Cobalt	3 -25	18	15 - 20	2
Copper	7 -81	18	45 - 50	2
Iron	5700 -17000	8	30500	1
Lead	<5 -18	18	<5	2
Manganese	96 -699	18	432 - 466	2
Molybdenum	<2 -4	18	<2	2
Nickel	6 -176	18	55 - 79	2
Selenium	<5	8	<5	1
Vanadium	11 -99	18	47 - 72	2
Zinc	9 -59	18	33 - 41	2
Mercury	<0.1	8	<0.1	1
Total Nitrogen	<20 -20	8	120	1
Total Phosphorus	7 -55	18	36 - 54	2
Total Organic Carbon (%)	<0.5 -2.6	8	<0.5	1
Total Kjeldahl Nitrogen as N	50 -840	10	120 - 360	2
Nitrite as N (Sol.)	<0.1 -0.2	10	0.1 - 0.22	2
Nitrate as N (Sol.)	<0.1 -1.8	10	<0.10 - 0.5	2
Nitrite + Nitrate as N (Sol.)	<0.1 -1.9	10	0.2 - 0.6	2