4.5 Groundwater

4.5.1 Mine Site

4.5.1.1 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.

4.5.1.2 Local Aquifer Characteristics

The groundwater system at the Spinifex Ridge site is broadly defined by three surface water catchments (**Figure 4-5**). Of these three, the two catchments that drain through Coppin Gap also directly influence the groundwater system of the proposed open-cut mine.

The surface water catchment affecting the plant site to the north of the ridge is constrained within the immediate footprint of the site and bounded by the Talga Range to the south. Both the groundwater and surface water flow is to the north.

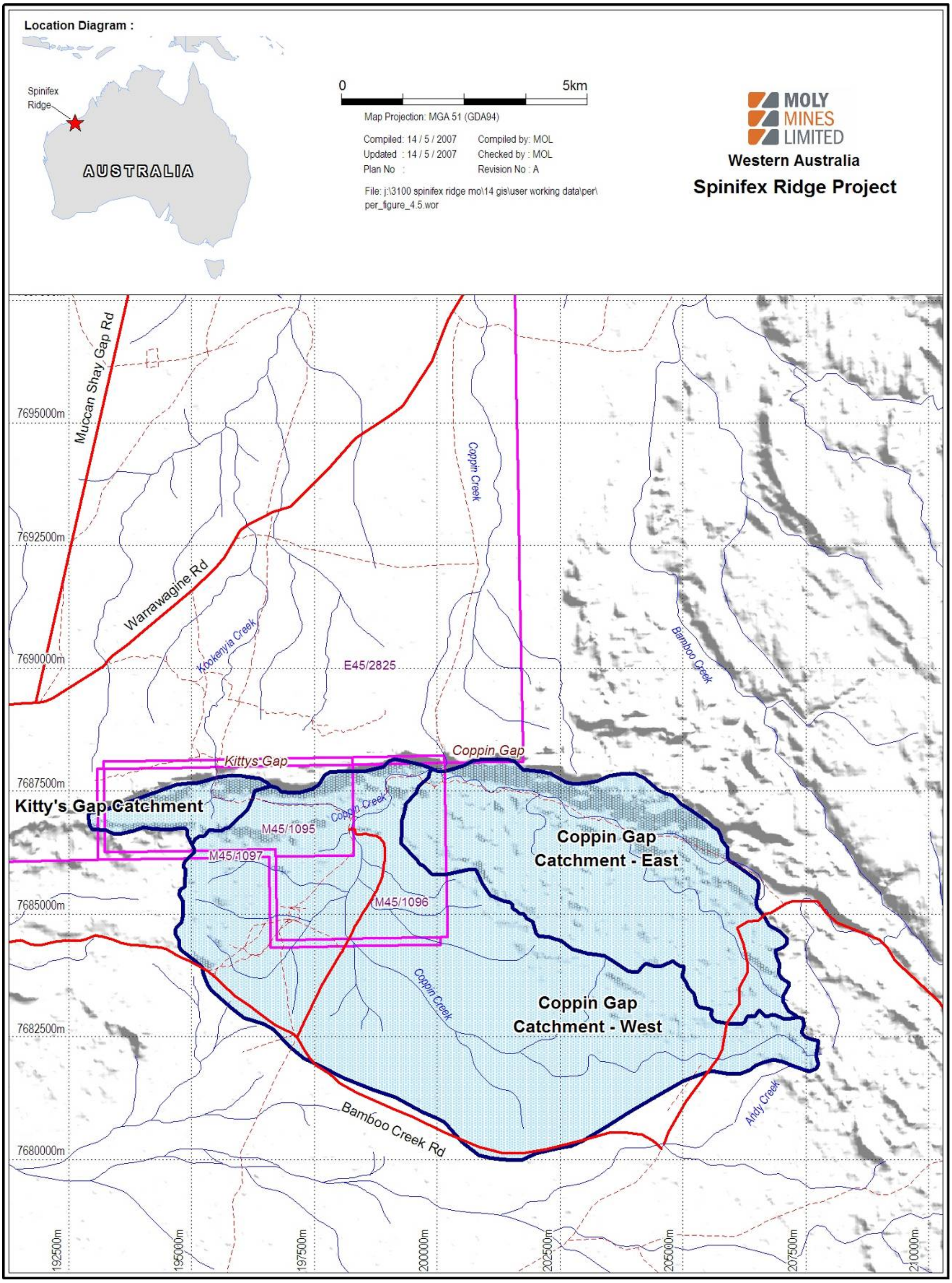
Recharge to groundwater within the catchments is limited to direct infiltration from rainfall within the catchment. There are no identified sources of groundwater inflow from outside the surface water catchment boundaries.

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.

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.



■ **Figure 4-5 Catchments at Spinifex Ridge**

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 (e.g. 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. The hydraulic character of the various rock types encountered at Spinifex Ridge is shown in **Table 4-4**.

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).

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 0.1 to 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.

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 4-6** 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 has 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.

4.5.1.3 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, 2006);
- proposed Tailings Dam (Moly Mines, January 2007);
- creek System between Mine and Coppin Gap (Moly Mines, January 2007); and
- 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.

- **Table 4-4 Mineralogy of Mafic and Felsic Bedrock Waste Units.**

(Source: GCA, 2006)

Felsic (GCA6062)		Felsic (GCA6188)		Mafic (GCA6070)		Mafic (GCA6192)		Mafic (GCA6066)	
Component	**Abundance**	**Component**	**Abundance**	**Component**	**Abundance**	**Component**	**Abundance**	**Component**	**Abundance**
quartz	dominant	quartz	dominant						
				quartz Ca-amphibole	major	quartz hornblende	major	quartz Ca-amphibole	major
plagioclase muscovite	minor			plagioclase	minor	plagioclase	minor	plagioclase	minor
calcite chlorite Ca-ampholite K-Feldspar	accessory	**calcite** chlorite	accessory	**pyrrhotite** chlorite clinzoisute biotite	accessory	chlorite muscovite	accessory	**calcite** chlorite muscovite clinzoisite	accessory
pyrite **chalcophyte** scheelite	trace	**Fe-dolomite** **pyrite** **chalcopyrite** Scheelite muscovite	trace	**pyrite** **chalcopyrite**	trace	**calcite** **pyrrhotite** **chalcopyrite** clinzoisute magnetite titanite	trace	**pyrite** **pyrrhotite** **chalcopyrite**	trace

Table 4-5 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, 2004.

** Vertical Hydraulic Conductivity is assumed to be 10 times less than horizontal conductivity.

Graphical typing of groundwater by aquifer type and location are shown in **Figure 4-7** to **Figure 4-10**. From the graphs the following observations are 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); and
- 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 **Figure 4-7** to **Figure 4-10**, 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/ARMCANZ, 2000). The chemical mobility of both As and 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 magnesium (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.

Water samples taken from the proposed 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).

4.5.1.4 Other Groundwater Users

The WINSITES database of monitoring sites indicates that there are 14 recorded groundwater sites in or adjacent to the Spinifex Ridge minesite. These vary from drillholes, bores, wells and pools. **Figure 4-11** shows the locality of the sites and **Table 4-6** provides the relevant details.

The operational status of the groundwater sites is not recorded for the majority of the water sources. However, a ground survey of the sites has determined that 7 of the listed sites exist or are operational; these are shown as shaded within the table. The majority of the bores and wells are used for livestock watering or road maintenance, while Coppin Gap Pool is used seasonally (dry season) as a recreation area.

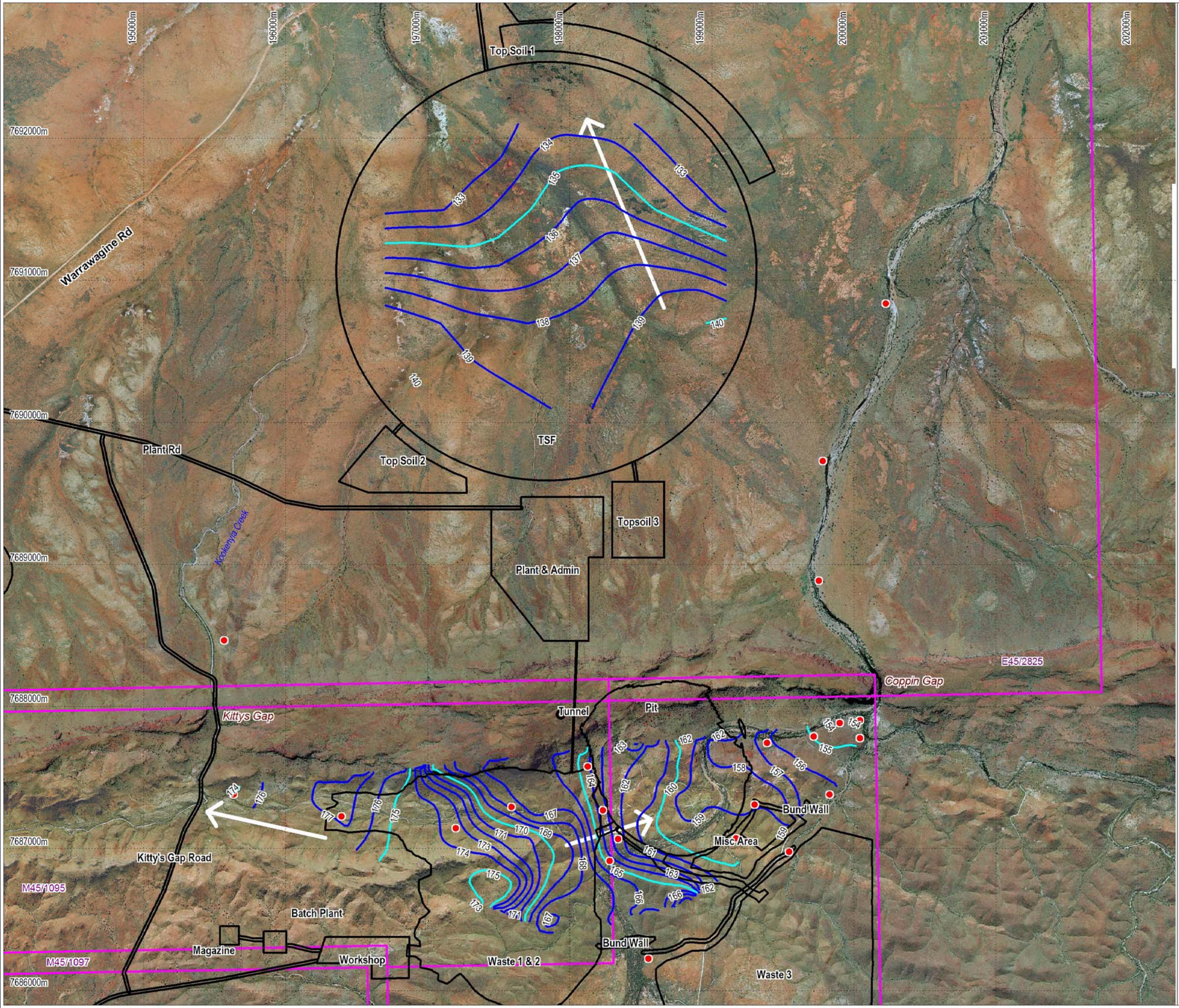
The bores are fairly shallow, varying from 7.4 metres below ground level (mbgl) to 30 mbgl. A number of these livestock bores are shallow hand-dug wells.

4.5.1.5 Coppin Gap Water Balance

Determination of the water balance at Coppin Gap has been undertaken with the use of a numerical model that considered a 12 year mining scenario (Aquaterra, 2007). The groundwater system at Coppin Gap is a dynamic system with large seasonal fluctuation. To simulate the variability, modelling of both average and climatic extremes have been considered Average conditions for flow through Coppin Gap (**Figure 4-12**) and predicted groundwater drawdown (**Figure 4-13** and **Figure 4-14**) are presented.

Flows at Coppin Gap

Predicted flows into Coppin Gap are dwarfed by the contribution from surface water **Figure 4-12**. For the case where average recharge conditions are assumed, the model predicts a decrease in groundwater flows at Coppin Gap from around 110 kL/d to around 95 kL/d over the life of the mine. These flows are below the modelled range of flows for drought conditions when after repeated dry seasons flows drop to less than 50 kL/d without mining.



MOLY MINES LIMITED

Spinifex Ridge Project
Western Australia

Figure 4-6
Groundwater Contours & Flow Direction - January 2007

0 1400m

Map Projection: MGA Zone 51 (GDA 94)

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Compiled: 4 / 7 / 2007
Updated : 4 / 7 / 2007
Plan No :

Compiled by:
Checked by :
Revision No : A

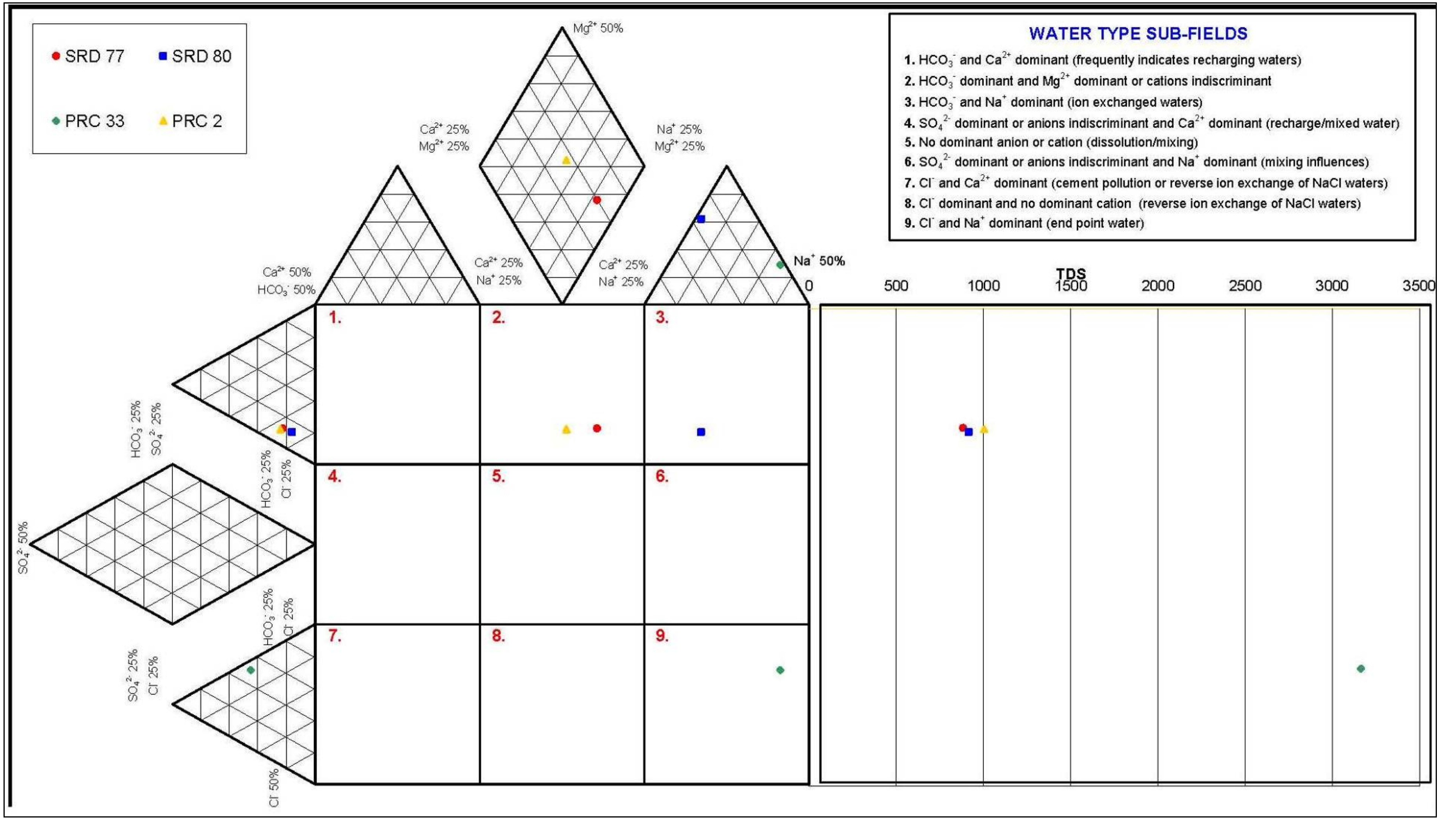
Location Diagram :

Spinifex Ridge

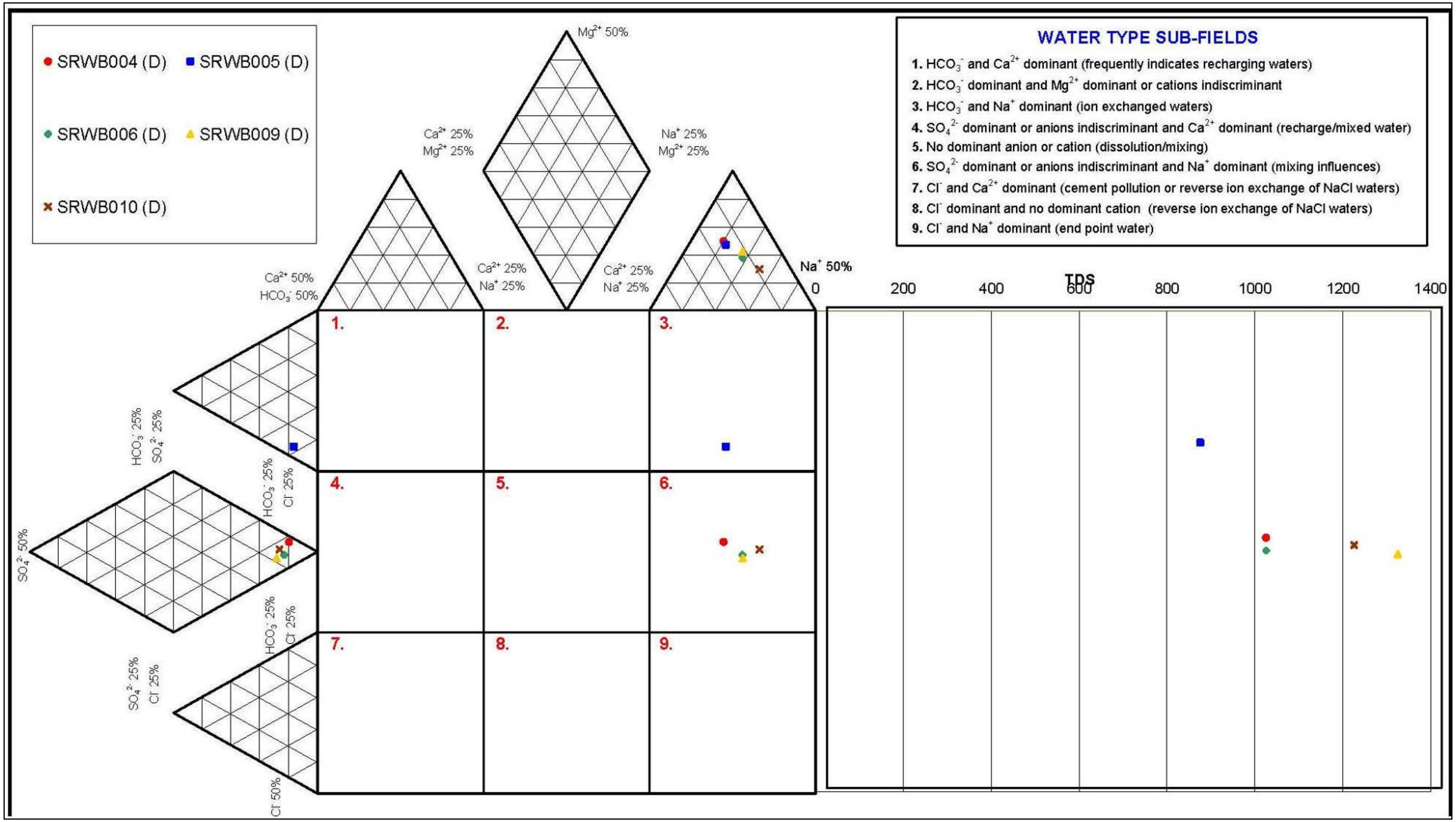
AUSTRALIA

Legend

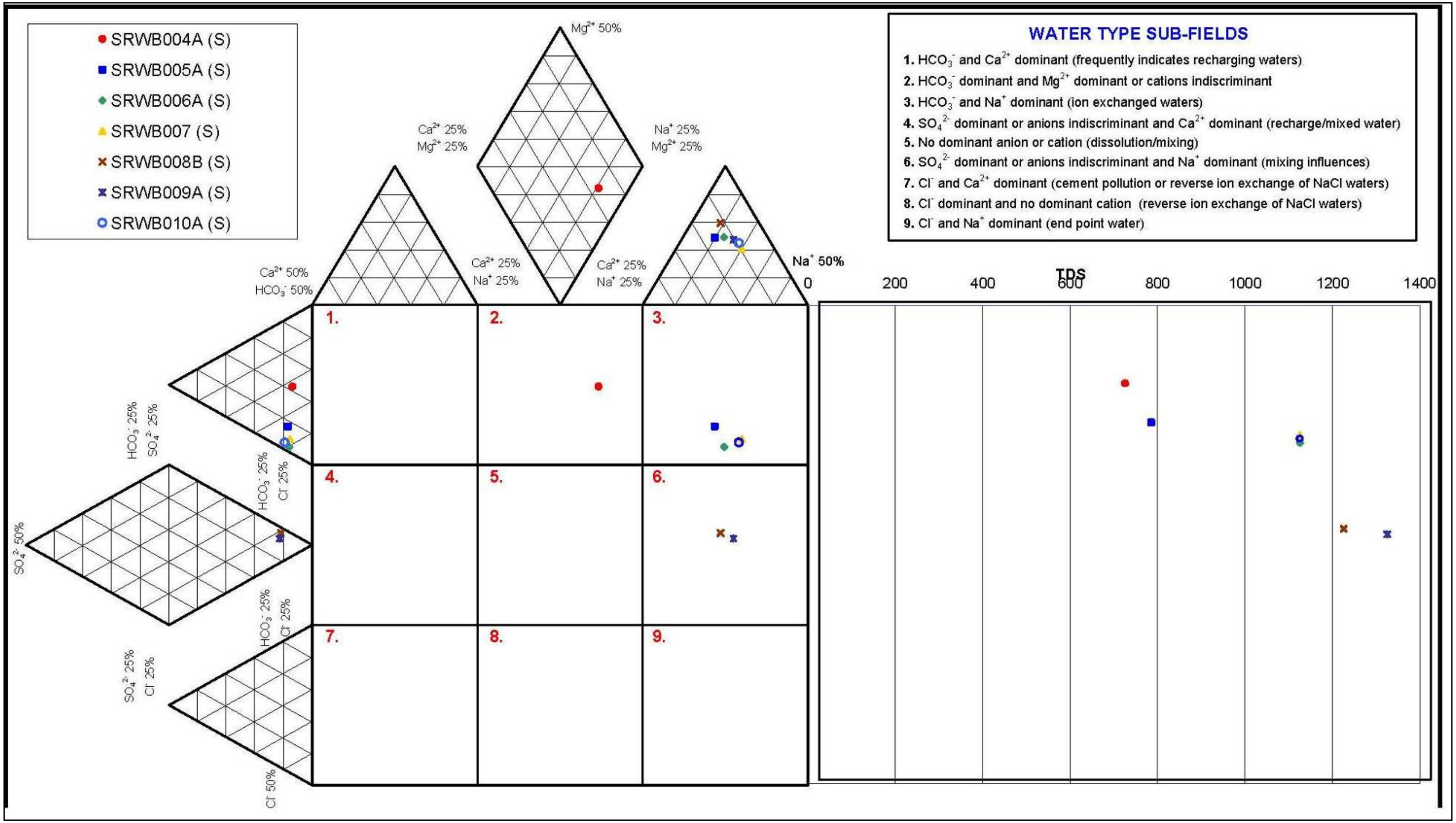
- Bore location
- Groundwater contour
- Groundwater contour (index)
- Flow direction arrow



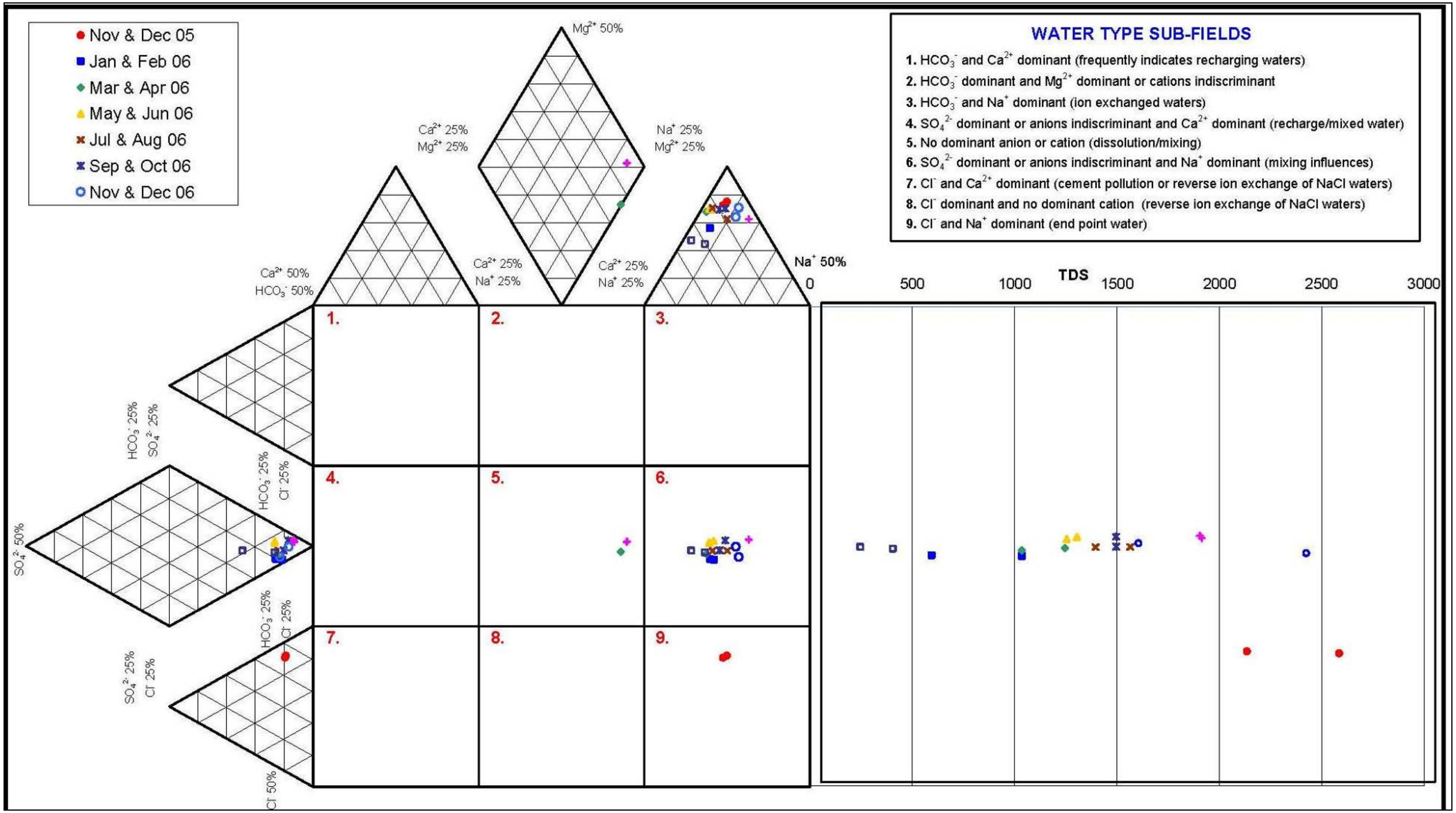
- **Figure 4-7 Spinifex Ridge Pit Expanded Durov Plot**



■ **Figure 4-8 Coppin Gap Deep Bores Expanded Durov Plot**



■ **Figure 4-9 Coppin Gap Shallow Bores Expanded Durov Plot**



■ **Figure 4-10 Coppin Gap Expanded Durov Plot**

MOLY MINES LIMITED

Spinifex Ridge Project
Western Australia

Figure 4-11
Locality of
WINSITES Monitoring Sites

0 3.5km

Map Projection: MGA 51 (GDA94)

Compiled: 14 / 5 / 2007 Compiled by: MOL
Updated : 02 / 07 / 2007 Checked by : MOL
Plan No : Revision No : B

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Location Diagram :

Proposed Site Layout Footprint

Spinifex Ridge Project Mineral Tenements

WINSITE Monitoring Site

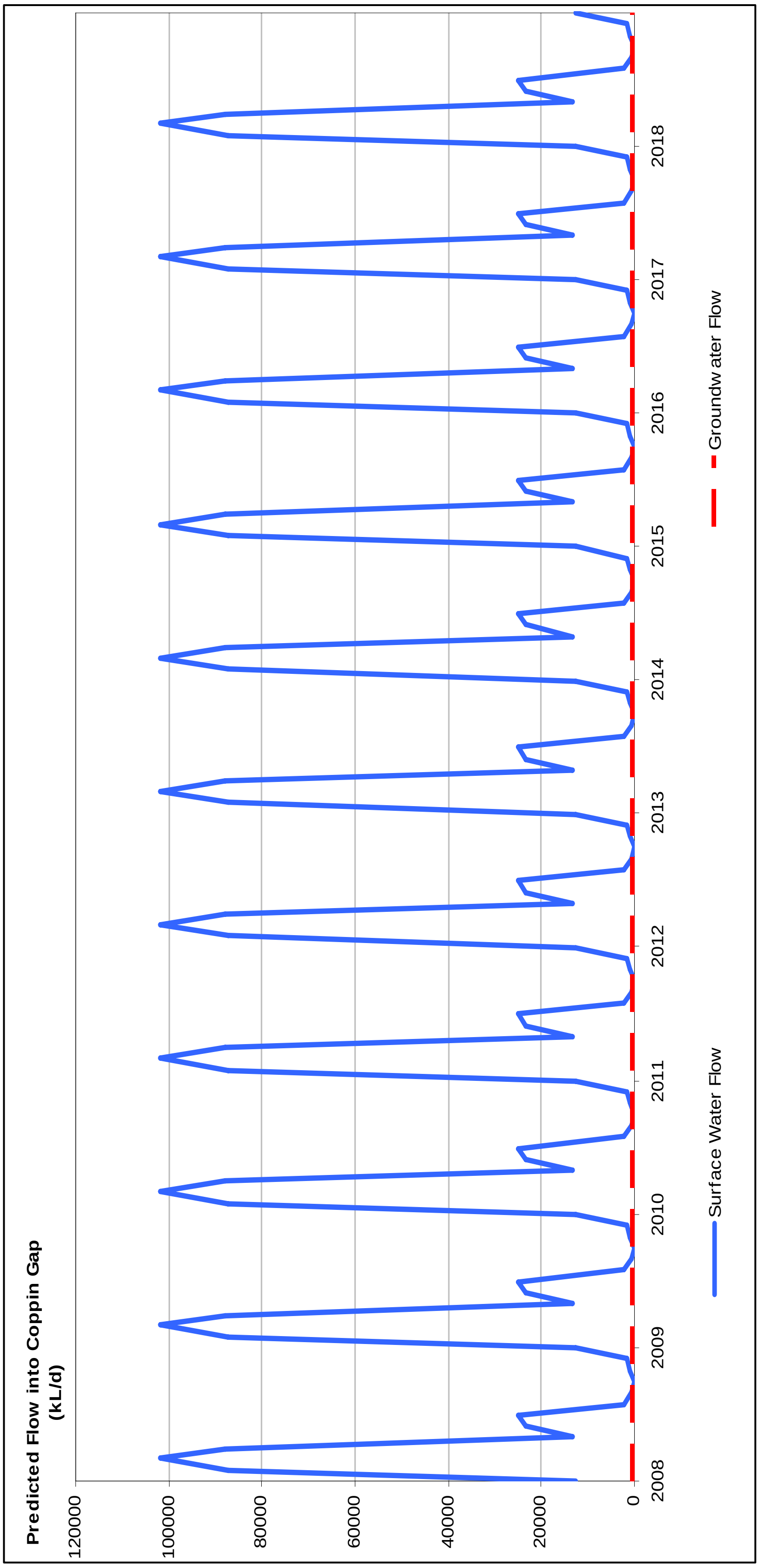
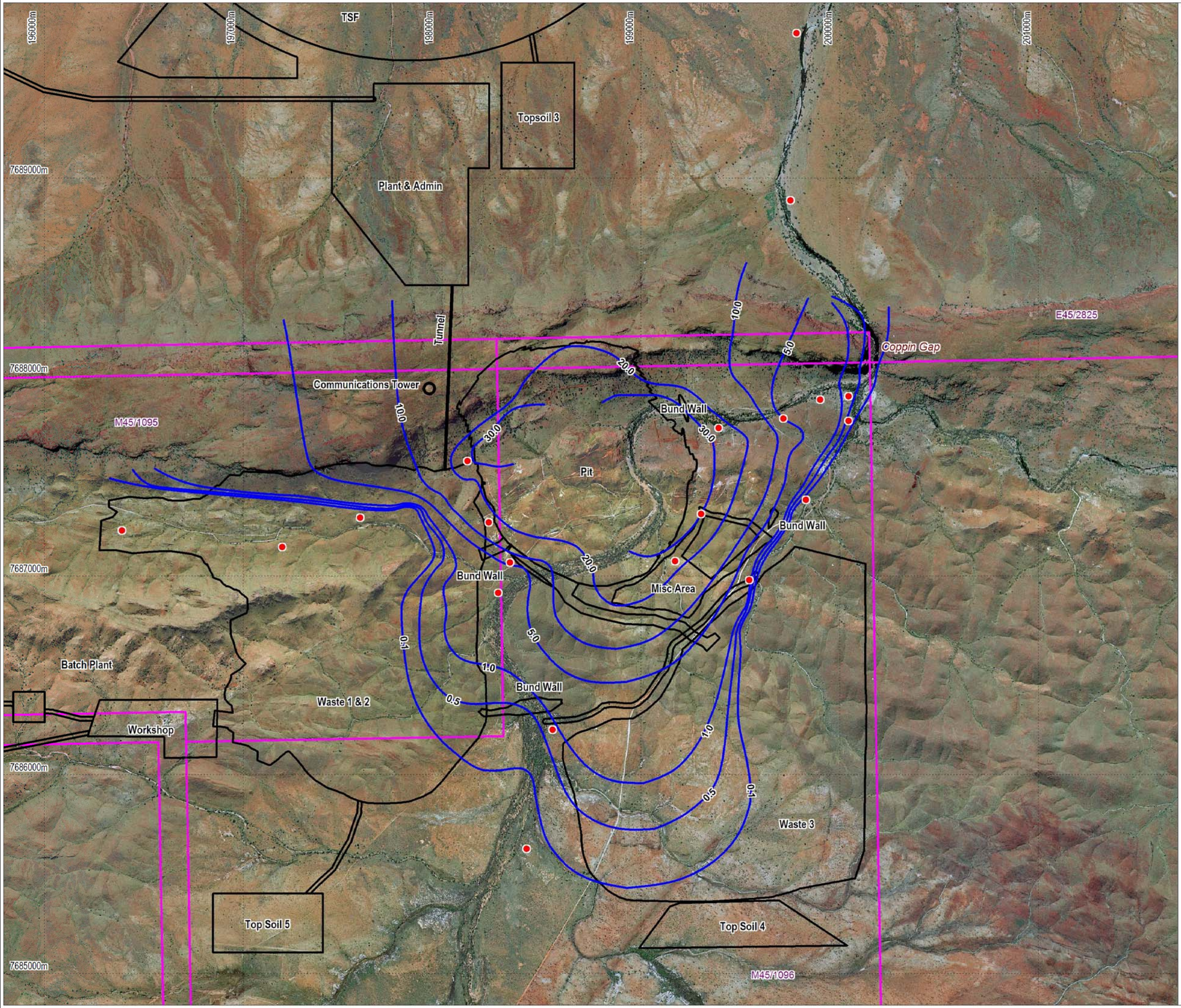


Figure 4-12 Predicted Flows at Coppin Gap

Spinifex Ridge Project
Western Australia

Figure 4-13

Predicted Groundwater Drawdown (this does not reflect change in Coppin Gap Pool).



0 1000m

Map Projection: MGA Zone 51 (GDA 94)

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Compiled: 4 / 7 / 2007
Updated : 10 / 7 / 2007
Plan No :

Compiled by:
Checked by : GK
Revision No : B

Location Diagram :

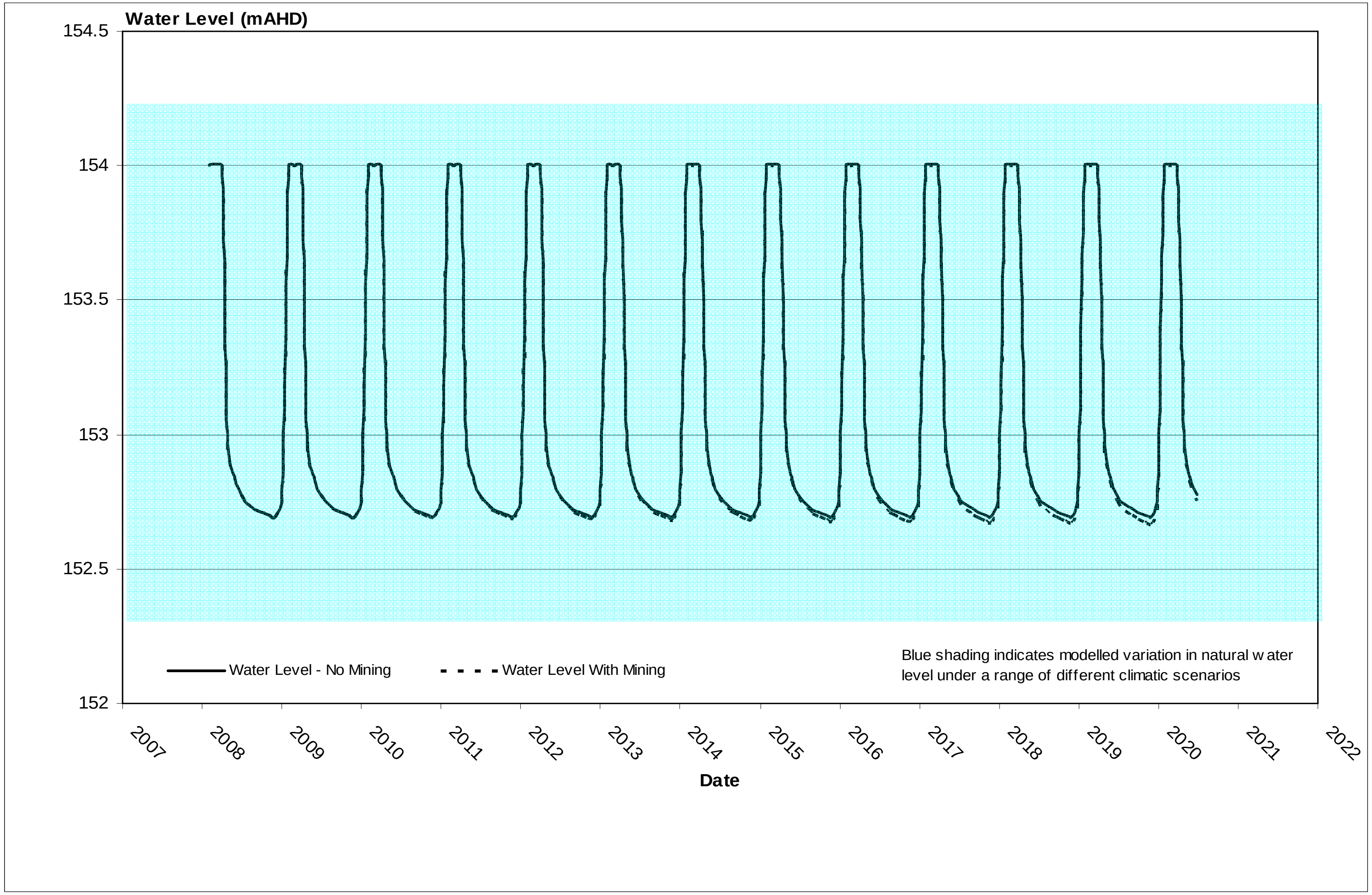
Legend

- Bore location
- Groundwater drawdown contour at end of mining (12 years)

Table 4-6 Water Sites from WINSITES Database

AWRC Reference	AWRC Name	Latitude	Longitude	Listed Purpose	Drilled Depth (mbgl)	Authorised Owner	Static Water Level (mbgl)	Total Dissolved Solids (Estimate from Conductivity)
71010748	Coppins Well	-20.8455	120.124		7.41	Coppin	6.510	580 mg/L
71010749	Kitty's Well	-20.8412	120.08		8.46	Coppin	4.610	550 mg/L
71010754	Bore 5	-20.8434	120.051	Production	16.5	Main Roads	2.700	
71010755	5A	-20.8441	120.063	Production	18	Main Roads	2.600	
71010797	D.D.S. Hole No10	-20.8849	120.11		23.47		10.540	
71010806	Kitty's Gap Well	-20.9115	120.085	Livestock	7.88	Eginbah Station	3.200	1300 uS/cm o
71010809	Borehole	-20.8892	120.119	Domestic Household	7.81	ESSO	3.430	767 mg/L
71010810	Percussion D.H.C.	-20.8873	120.102		30.1	ESSO	28.760	578 mg/L
71010811	Percussion D.H. B.	-20.8873	120.102		30.5	ESSO	6.400	999 mg/L
71010812	Drillhole NO 5	-20.8873	120.102		55	ESSO	2.610	388 mg/L
71010813	Percussion D.H. NO 4	-20.8873	120.102	Investigation	30	ESSO	9.990	1213 mg/L
71010814	Drillhole NO 3	-20.8873	120.102	Investigation	17.32	ESSO	8.770	768 mg/L
71011480	Coppin Gap Pool	-20.883	120.121					1606 mg/L
71011481	Long Year Pool	-20.8892	120.119	Investigation				1329 mg/L

mbgl - metres below ground level



■ **Figure 4-14 Predicted Water Levels at Coppin Gap**