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Chapter 6
Surface and Groundwater

Western Desert Resources Limited
Roper Bar Iron Ore Project



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6 Existing Environment - Surface and Ground Water

6.1 Surface Water

This chapter provides a description of the existing surface water catchments, including their environmental values (significance), hydrology and water quality. The mine project area and proposed haul road route are described under separate headings.

6.1.1 Regional Surface Water Systems and Catchment Context

Regional Catchments

The area potentially affected by the proposed mine site and haul road is located between the Roper and McArthur River drainage divisions, on the western side of the Gulf of Carpentaria (Figure 6-1) and traverses the Towns River, Limmen River and Rosie Creek catchments.

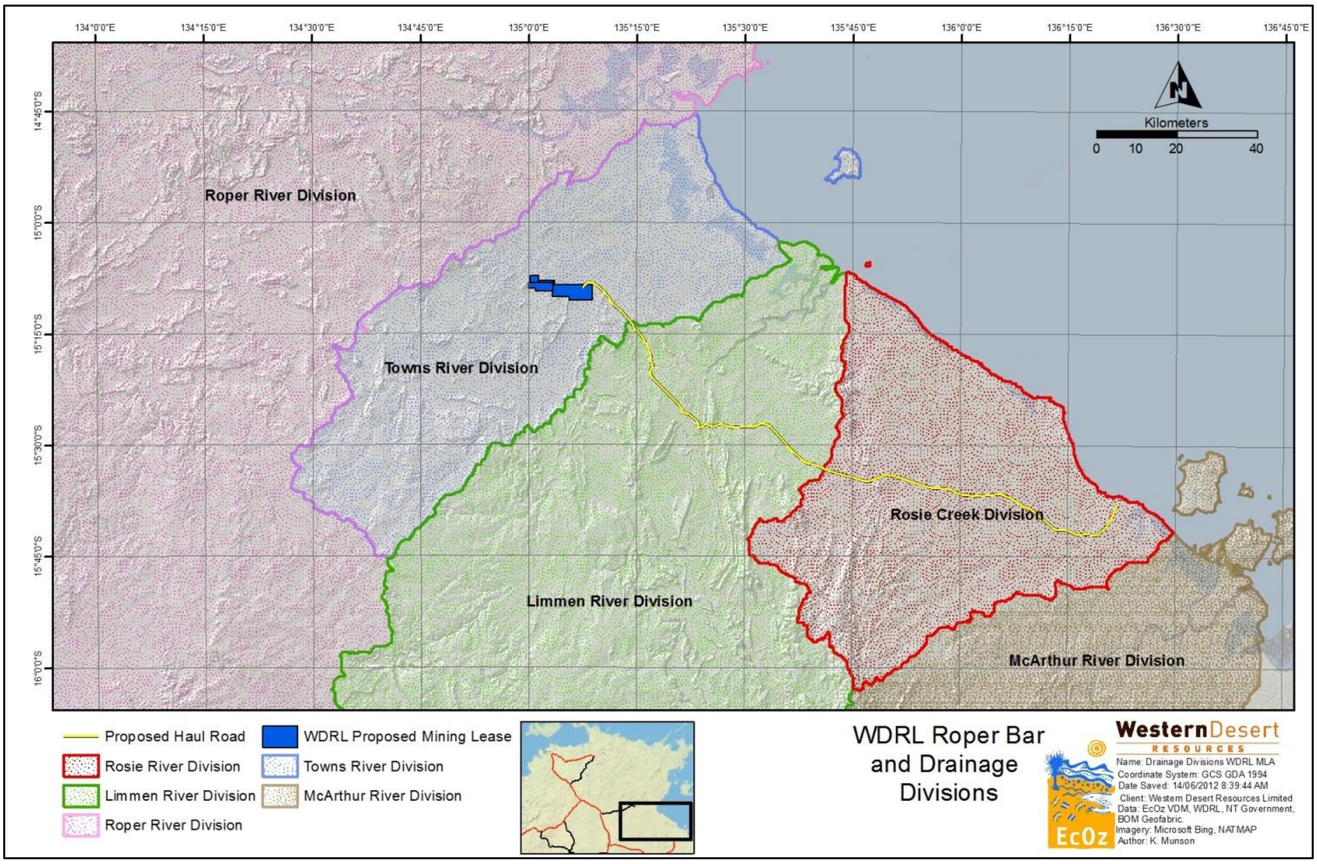


Figure 6-1 Location of mine site, haul road and Bing Bong loading facility in context of regional catchments.

Environmental Values

There are no declared Beneficial Uses under the *NT Water Act (2004)* or Ramsar-listed wetlands in the Towns River catchment, any of the catchments that the proposed Bing Bong haul road crosses, or in the vicinity of the proposed Bing Bong Loadout Facility. Although not considered to be within the potential zone of impact, it is noted that the lower estuarine reaches of the Towns River, together with its associated tidal flats and coastal dunes, are contained within the Limmen Bight and associated coastal floodplains Site of

Conservation Significance (NT). This area is also listed in the Directory of Important Wetlands in Australia as the Limmen Bight (Port Roper) Tidal Wetlands System. The area is significant because it is the second largest area of saline coastal flats in the NT.

Surface water resources in the Towns River catchment are limited to stream flow during the wet season and in-stream and off-stream billabongs during the dry season. Along the proposed Bing Bong haul road route, several rivers appear to flow perennially, fed by springs in their upper catchments. There are no constructed storages of any substantial size in any of the catchments affected by the project. Although there are no specific uses of surface waters within the Towns River catchment, the main economic uses of surface water in the region are for livestock watering and to support the local fishing and tourism industry.

The ecological values in the region are further discussed in Chapter 4 and cultural and recreational values are discussed in Chapter 3 and Chapter 8.

Sensitive Receptors and Species of Conservation Significance

In general, aquatic environments are highly susceptible to significant changes in water quality and disturbance to riparian areas. Mining is one such activity that could result in such outcomes. A desktop study of freshwater ecosystems within the region identified six aquatic species of conservation significance that could potentially be affected by the project (see Chapter 4 and Appendix D). However, none of these species were identified during site surveys within the mine project area or within surveyed downstream habitats. Further discussion of aquatic habitats, species of conservation significance and riparian areas that may be affected by the project is provided in Chapter 4.

Macroinvertebrate sampling has been performed so as to gain a pre disturbance baseline dataset.

6.1.2 Local Surface Water Hydrology

Mine Site

The project area is located within the middle reaches of the Towns River catchment, which is approximately 5441km^2 in extent. From its headwaters (approximately 30m AMSL), the Towns River catchment drains in a north-east direction for a total length of 130km, before it enters the Gulf of Carpentaria. The project area is located approximately 50km from the Towns River mouth and 20km upstream of the tidal influence in the vicinity of the Savannah Way road crossing.

The main Towns River channel passes through the centre of the project area, which is joined by two major tributaries about 20km downstream; Magaranyi River to the south-east and Yumanji Creek (Little Towns River) to the north (Figure 6-2). The catchment area of the main Towns River channel is relatively small (503km^2), compared to that of Magaranyi (2068km^2) and Yumanji (1213km^2) sub-catchments. Stream flows are restricted to during and just after the wet season (November to April) and surface waters are confined to remnant pools during the dry season (May to October). During the wet season, the Towns River has been observed to cease flowing for a week or more during periods of low rainfall. Although hydrographic data is not available for the Towns River or its tributaries, their catchment sizes and observations during baseline water quality surveys suggest that Magaranyi River contributes the highest flows, followed by the Towns River and Yumanji Creek.

The Towns River and its tributaries display a highly sinuous and meandering form, which alternate between well-defined channels and braided channel areas. The low-lying floodplain in the vicinity of the proposed mine is wide and flat and contains many non-active channel features including ox-bow lakes and abandoned pools. The exception is where the streams abut ridgelines, where channels are usually more heavily armoured and straight and likely to have remained stable over time.

Hydraulic modelling of flooding of the Towns River in the vicinity of the proposed mine site indicates that at peak flows for 5, 10 and 100 year average return intervals (ARIs) are 715m^3/s, 946m^3/s and 1847m^3/s, respectively. When stream banks overtop, flood waters may affect areas 1.0 to 1.5km from the stream channel, to a depth of between 2.8m (5-year ARI) and 3.7m (100-year ARI). Maximum stream velocities vary between 0.63m/s and 1.03m/s along the embankments and between 1.47m/s and 1.67m/s in the stream channel (see cross-section 9263.826 in Appendix N).

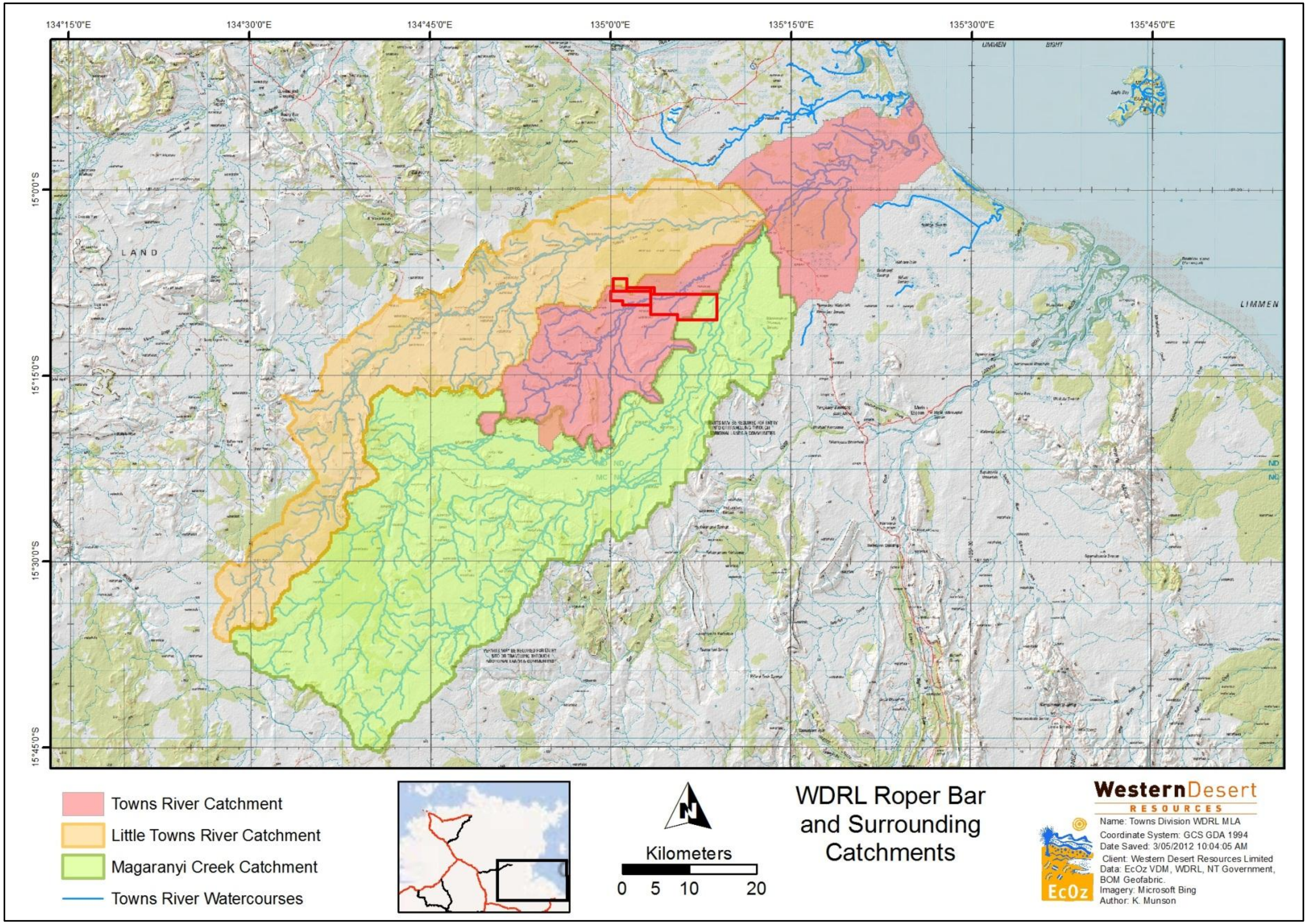


Figure 6-2 Location of project area within Towns River catchment.

Haul Road Route

The proposed haul road route crosses a number of major streams and their tributaries, as detailed in Table 6-1 and illustrated in Figure 6-3. The relatively large catchments crossing the proposed haul road alignment are characterised by flat terrain, in the order of 0.1% grades. Consequently, the catchment response to rainfall is not always predictable and runoff will depend upon the antecedent moisture conditions and the intensity and duration of the rainfall event.

Previous hydrological studies in the Limmen Bight and McArthur Rivers regions reported that the average annual runoff in the Gulf savannah county is less than 12% of mean annual rainfall. Runoff is expected to peak after initial wetting of the catchment, with runoff unlikely until 40mm of rainfall falls over a large proportion of the catchment. This is due to the flat grades and sandy nature of much of the terrain. See Chapter 3 Land Resources.

The nature of rainfall in the region is that it can be patchy and banded, so that with the large (greater than 500km^2) catchments, many rainfall events will not generate runoff.

Table 6-1 Catchment areas and modelled maximum flow rates of major streams crossed by proposed haul road.

Stream	Map Reference (Figure 6-3)	Catchment Area (km^2)	Q $_{1yr}$ (m3/sec)	Q $_{2yr}$ (m3/sec)	Q $_{10yr}$ (m3/sec)	Q $_{20yr}$ (m3/sec)	Q $_{100yr}$ (m3/sec)
Magaranyi River 1A	1A	38	26	100	259	280	450
Magaranyi River 2A	2A	1,917	437	530	900	1060	1760
Cox River	5A	5,365	1047	1474	2809	3435	5250
Piker Creek	6A	141	72	99	171	204	295
Limmen Bight River	7A	8,260	1344	1905	3734	4606	7155
Nathan River	9A	341	145	199	348	415	603
Rosie Creek	12A	1,380	353	492	903	1091	1628
Tributary Rosie Creek	13A	205	71	99	175	210	308
Pine Creek	14A	629	149	208	386	468	703
Bing Bong Creek	16A	300	89	124	223	268	397

Bing Bong

Bing Bong is located on dunes and beach ridges adjacent to tidal mud flats along the coastline of the Gulf of Carpentaria. The site does not intersect any natural drainage lines. The main drainage lines beyond the site are Mule Creek to the east and Bing Bong Creek to the north. The area is subject to storm surges associated with cyclones.

Figure 6-3 Proposed haul road route in relation to major waterways

6.1.3 Existing Surface Water Quality

There is limited pre-existing surface water quality data available for the Towns River catchment, or any of the major catchments along the proposed haul road route. At the time of preparation of this document, 21 sites had been sampled on two occasions as part of a baseline surface water monitoring program during the 2011-12 wet season. Sampling was undertaken at approximately monthly intervals, during periods of flow. This data will be utilised in the operational surface water monitoring program, details of which are provided in Section 6.1.4. Discussion of available water quality data are presented and discussed separately below for the mine project area and proposed haul road route.

Mine Site

Baseline surface water quality data has been collected at 14 sites along the Towns River and its tributaries (Figure 6-4). Sites were selected to ensure that baseline data are available both upstream and downstream of proposed infrastructure on drainage lines that may be affected by construction/mining activities.

In the vicinity of the mine project area, surface waters can be classified into two groups according to their ionic composition (Figure 6-6). The low ionic composition is reflected by very low concentrations of dissolved metals and nutrients, circum-neutral pH and relatively low electrical conductivity (Table 6-3). Site RBSW14, located at the Savannah Way crossing of the Towns River, is affected by the tidal influence of the lower reaches of the system and this is reflected in the relatively high electrical conductivity and dominance of sodium and chloride ions at this location. Dissolved iron has been added to the list of analyses for further baseline sampling.

Turbidity is relatively high at many of the sampling sites for a catchment that is largely undisturbed and samples were collected during periods of base flow (i.e. not affected by storm events). However, total suspended solids are relatively low, suggesting that the turbidity is affected by fine colloidal material dissolved in the water column.

Haul Road Route

Surface water quality data has been collected at 6 sites along the proposed haul road route, between the mine project area and the Bing Bong Loadout Facility (Figure 6-5). Sites were selected at the location of planned river crossings.

Water quality is variable between the rivers, with ionic concentrations generally increasing along the haul road route from the mine project area to the Bing Bong Loadout Facility (Table 6-4). Both the Rosie and Pine Rivers are rich in calcium carbonate, reflecting the dolomitic geology present in their catchments (see Chapter 3). Bing Bong creek is an estuarine system, which is reflected in the very high ionic concentrations (dominated by sodium, chloride and sulfate) in water at the sampling site.

Concentrations of metals and nutrients are generally low, with the exception of relatively high zinc concentrations at two of the sites (i.e. Limmen Bight and Rosie Rivers) and ammonia at one of the sites (Limmen Bight River). It is noted that at the time of compiling this document, only total metal concentration data were available for the haul road monitoring sites, whereas soluble (filtered) metals data are more likely to reflect the fraction that is bioavailable. Soluble metals (including iron) have been added to the list of analyses for further baseline sampling.

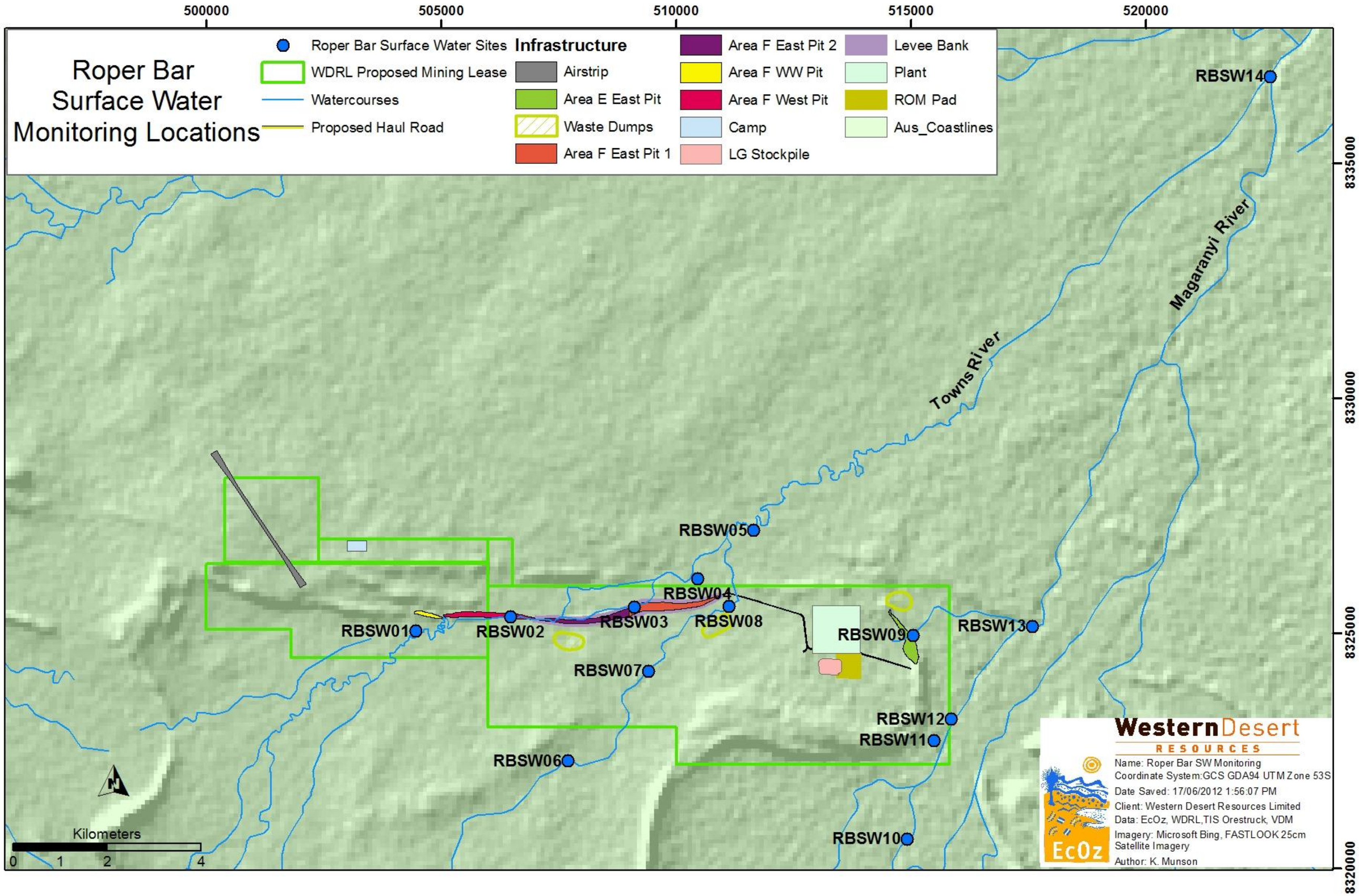


Figure 6-4 Locations of baseline surface water monitoring sites in vicinity of mine project area.

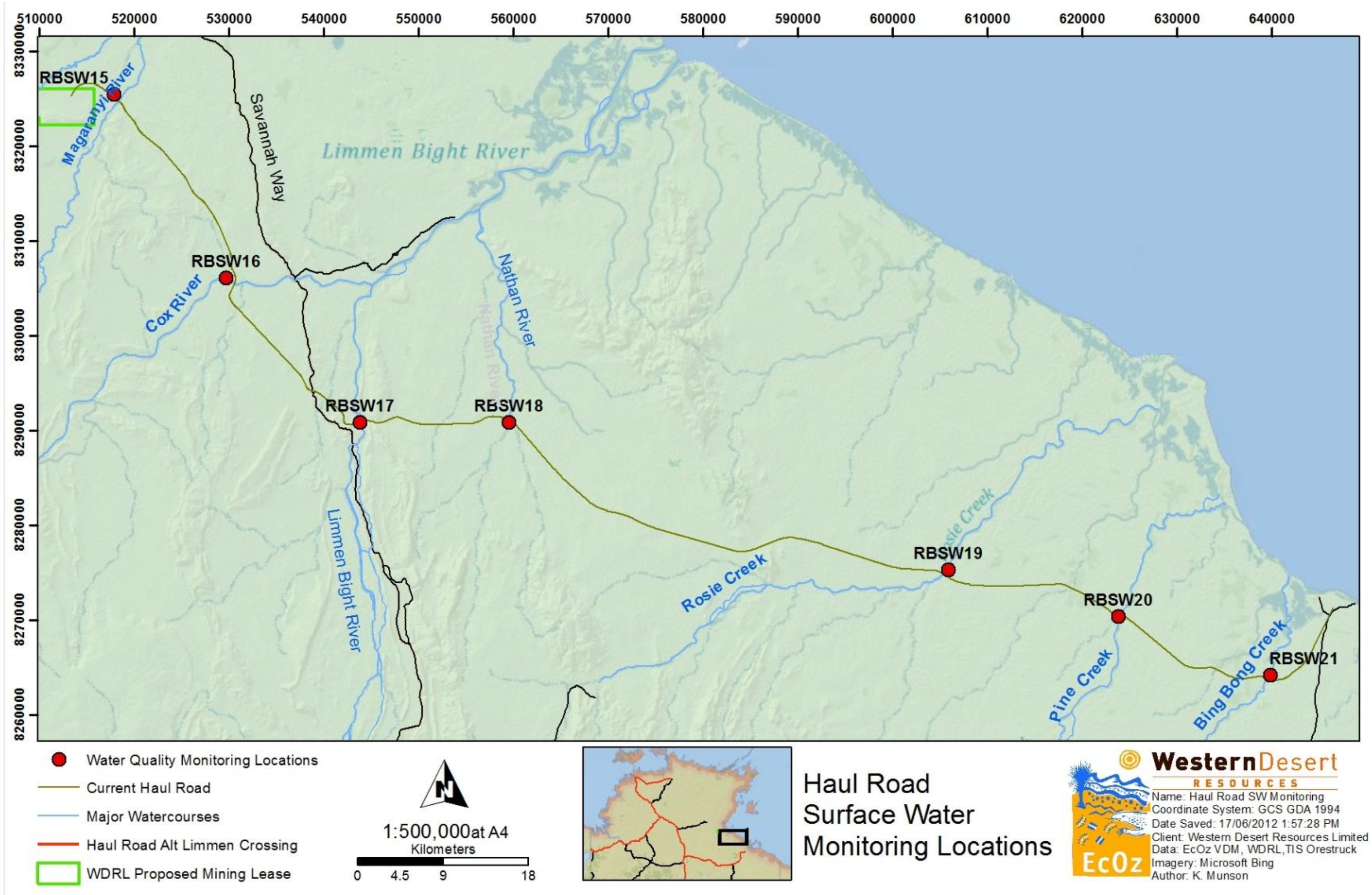


Figure 6-5 Locations of baseline surface water monitoring sites along the proposed haul road route.

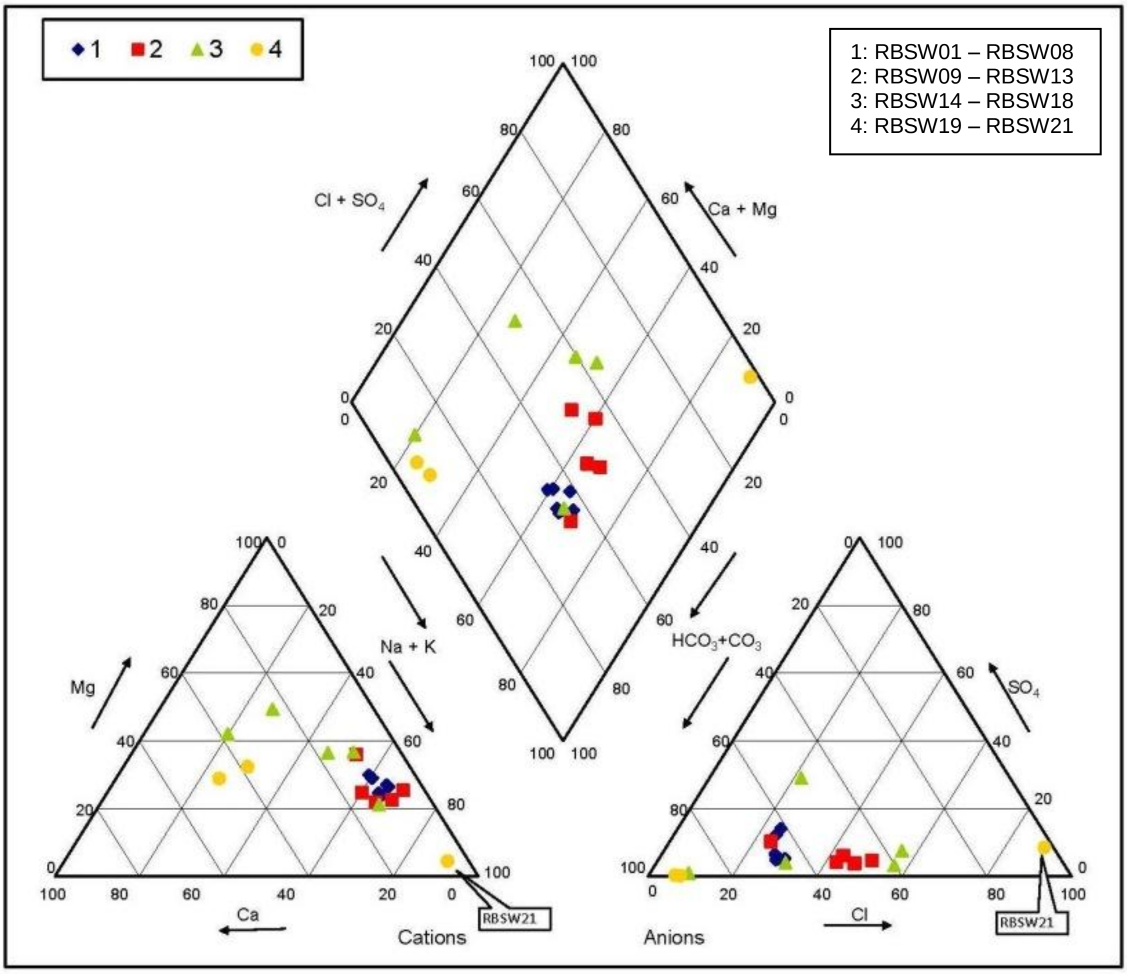


Figure 6-6 Piper Diagram showing ionic composition of surface waters in the mine project area and haul road route.

Table 6-2 Description of ionic composition of surface waters in the mine project area and haul road route.

Category	Sites	Dominant ions
1	RBSW01 – RBSW08	Cations: Na or K type. Anions: HCO_3 type Overall: Na + K, HCO_3 + CO_3 type.
2	RBSW09 – RBSW13	Cations: Na or K type Anions: HCO_3 type. Overall: Na + K, HCO_3 type
3	RBSW14 – RBSW18	Cations: Na or K type. Anions: HCO_3. Overall: No dominant type except for 1 sample; Ca + Mg, HCO_3 + CO_3
4	RBSW19 – RBSW21	Cations: Na + K type for RBSW21. Anions: HCO_3 type or Na-Cl type for RBSW21. Overall: Na and K type, Cl - HCO_3 + CO_3 type

Table 6-3 Water quality of Towns River and its tributaries in vicinity of the mine project area.

Site	In-situ pH	In-situ EC (uS/cm)	In-situ Turbidity (FTU)	Suspended Solids mg/L	As mg/L	Ba mg/L	Be mg/L	Cd mg/L	Co mg/L	Cr mg/L
RBSW01	7.32	92	58	7	<0.001	0.01	<0.001	<0.0001	<0.001	<0.001
RBSW02	7.86	100	61	6	<0.001	0.008	<0.001	<0.0001	<0.001	<0.001
RBSW03	7.13	94	71	6	<0.001	0.009	<0.001	<0.0001	<0.001	<0.001
RBSW04	7.14	93	40	5	<0.001	0.009	<0.001	<0.0001	<0.001	<0.001
RBSW05	7.14	88	33	<5	<0.001	0.008	<0.001	<0.0001	<0.001	<0.001
RBSW06	7.14	70	30	<5	<0.001	0.004	<0.001	<0.0001	<0.001	<0.001
RBSW07	7.15	57	29	<5	<0.001	0.002	<0.001	<0.0001	<0.001	<0.001
RBSW08	7.14	85	48	73	<0.001	0.004	<0.001	<0.0001	<0.001	<0.001
RBSW09	7.09	63	5	-	<0.001	0.011	<0.001	<0.0001	0.001	<0.001
RBSW10	6.82	42	26	<5	<0.001	0.013	<0.001	<0.0001	<0.001	<0.001
RBSW11	8.59	66	10	<5	<0.001	0.002	<0.001	<0.0001	<0.001	<0.001
RBSW12	7.01	42	22	<5	<0.001	0.012	<0.001	<0.0001	<0.001	<0.001
RBSW13	6.8	42	26	<5	<0.001	0.016	<0.001	<0.0001	<0.001	<0.001
RBSW14	7.42	201	18	<5	<0.001	0.025	<0.001	<0.0001	<0.001	<0.001

Notes: Data are averaged from two sampling occasions (May 2011 & January 2012) and metals data are for dissolved fraction, except for RBSW09, which has only been sampled once (May 2011) and metals data are for the total fraction.

Site	Cu mg/L	Mn mg/L	Ni mg/L	Pb mg/L	V mg/L	Zn mg/L	Ammonia mg/L	Total N mg/L	Total P mg/L
RBSW01	<0.001	0.002	<0.001	<0.001	<0.01	<0.005	<0.01	0.5	0.01
RBSW02	<0.001	0.004	<0.001	<0.001	<0.01	<0.005	0.01	0.4	<0.01
RBSW03	<0.001	0.005	<0.001	<0.001	<0.01	<0.005	0.03	0.4	0.02
RBSW04	<0.001	0.003	<0.001	<0.001	<0.01	<0.005	0.02	0.4	<0.01
RBSW05	<0.001	0.003	<0.001	<0.001	<0.01	<0.005	<0.01	0.4	<0.01
RBSW06	<0.001	0.008	<0.001	<0.001	<0.01	<0.005	<0.01	0.3	0.02
RBSW07	<0.001	0.01	<0.001	<0.001	<0.01	<0.005	0.01	0.4	<0.01
RBSW08	<0.001	0.006	<0.001	<0.001	<0.01	<0.005	0.01	0.4	0.01
RBSW09	<0.001	0.169	<0.001	<0.001	<0.01	<0.005	<0.01	0.2	<0.01
RBSW10	<0.001	0.002	<0.001	<0.001	<0.01	<0.005	0.03	0.2	<0.01
RBSW11	<0.001	0.004	<0.001	<0.001	<0.01	<0.005	0.01	<0.1	<0.01
RBSW12	<0.001	0.002	<0.001	<0.001	<0.01	<0.005	<0.01	0.3	<0.01
RBSW13	0.002	0.004	<0.001	<0.001	<0.01	0.016	<0.01	0.3	0.01
RBSW14	<0.001	0.004	<0.001	<0.001	<0.01	<0.005	0.01	0.2	<0.01

Table 6-4 Water quality of major streams along the proposed haul road route.

Site	In-situ pH	In-situ EC (uS/cm)	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L
RBSW15	7.28	36	<0.0001	<0.001	0.001	<0.001
RBSW16	6.68	153	<0.0001	<0.001	0.003	0.002
RBSW17	7.86	277	<0.0001	0.001	0.003	0.003
RBSW18	7.79	143	<0.0001	<0.001	<0.001	<0.001
RBSW19	8.1	358	<0.0001	<0.001	<0.001	<0.001
RBSW20	8.04	451	<0.0001	<0.001	0.001	<0.001
RBSW21	7.87	4780	<0.0001	<0.001	<0.001	0.005

Notes: Data are averaged from two sampling occasions (December 2011 & January 2012) and metals data are for the total fraction.

Site	Mn mg/L	Ni mg/L	Pb mg/L	Zn mg/L	Ammonia mg/L	Total N mg/L	Total P mg/L
RBSW15	0.012	<0.001	<0.001	0.008	0.06	0.4	0.03
RBSW16	0.041	0.001	0.001	0.006	0.07	0.6	0.04
RBSW17	0.061	0.002	0.001	0.027	0.07	0.6	0.04
RBSW18	0.023	<0.001	<0.001	<0.005	0.17	0.2	0.02
RBSW19	0.064	<0.001	<0.001	<0.005	0.03	0.2	0.03
RBSW20	0.025	<0.001	<0.001	0.024	0.02	0.2	0.02
RBSW21	0.026	0.005	<0.001	0.01	0.06	0.3	0.02

6.1.4 Operational Surface Water Monitoring Programs

Surface water quality will be monitored on a regular basis at sites that are located both upstream and downstream of inputs from the mine site, in order to assess potential impacts of mining operations on downstream surface water quality. A preliminary surface water monitoring program is presented in Table 6-5 below, including baseline monitoring locations described in Section 6.1.3 above. The monitoring program will be finalised prior to commencement of mining activities, in consultation with relevant regulatory agencies (i.e. DoR, NRETAS).

It is proposed that initially, the default ANZECC (2000) guidelines for 95% aquatic ecosystem protection (hardness modified) will be adopted as maximum trigger values for surface water monitoring. It is envisaged that site-specific trigger values will be developed when there is sufficient data available from baseline monitoring and upstream reference sites.

6.1.5 Proposed Aquatic Macroinvertebrate Monitoring Program

Baseline surveys of aquatic macroinvertebrates was conducted during the 2012 post-wet season recessional flow period, in accordance with the NT manual for the national AUSRIVAS monitoring methodology (Lamche 2007). Importantly, this sampling was conducted prior to the commencement of any construction/mining activities. Sites were sampled on major streams draining the mine project area (i.e. Towns River, Magaranyi River) and upstream/downstream of proposed haul road crossings. A Draft report is presented as Appendix S.

Table 6-5 Proposed surface water monitoring program.

Monitoring Sites	Frequency	Analytes
Mine Area: RBSW01 – RBSW14	Monthly (during periods of flow)	In-situ pH, electrical conductivity (EC), turbidity. Total dissolved solids (TDS) and total suspended solids (TSS). Total acidity and total alkalinity. Major anions (Cl, SO_4, CO_3/HCO_3, NO_3) and cations (Ca, Mg, Na and K) and fluoride. Dissolved metals: As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, Fe Ammonia and nutrients (total N and total P)
Haul Road: RBSW15 – RBSW21, both upstream and downstream of haul road	Weekly during construction	In-situ pH, electrical conductivity (EC), turbidity. Total suspended solids (TSS).

6.2 Hydrogeology and Groundwater

This section describes the existing groundwater environment at the Roper Bar Project and provides context to the groundwater drilling, sampling, testing and modelling investigations that were undertaken. A detailed report is included in Appendix E.

6.2.1 Geological Setting

The Roper Bar Iron Ore Province is a large intracratonic sedimentary basin with an exposed area of about 180,000km^2. The basin contains thick marine and non-marine sedimentary rocks, whilst some volcanic rocks and related intrusive igneous rocks may also be found occasionally (WDRL 2011). For a detailed description of the regional and local geology, please refer to Chapter 3 (Land Resources).

The dominant stratigraphy comprises relatively un-metamorphosed and un-deformed sediments with iron ore in outcrop and under a shallow cover of oolitic ironstone, referred to as the Sherwin Ironstone Formation (SIF), which hosts all the known iron mineralisation and deposits. North-south striking faults are common, although a major east-west structure referred to as the Hells Gate Hinge Line, transects the area.

Locally, the geological sequence is covered by laterised soils with thicknesses ranging from 2m to approximately 10m. Underlying this is a sequence of siltstones and sandstones, interlayered siltstones and mudstones/shales with minor bands of sandstones. The hematite iron ore of the Sherwin Ironstone is relatively fine grained with layers of fine silicified sandstones, siltstones and mudstone becoming coarse with depth. Interlayered fine to medium grained sandstones and grey to dark grey siltstones with thin layers of mudstones occur below this sequence. Figure 6-7 shows a cross section through the groundwater monitoring bores RBGW09 to RBGW03, which are shown on the map in Figure 6-8. Note that this cross section is not perpendicular to the strike of geological bedding, in fact, it is almost parallel with the strike. For more detailed geological structure of the area see Chapter 3.

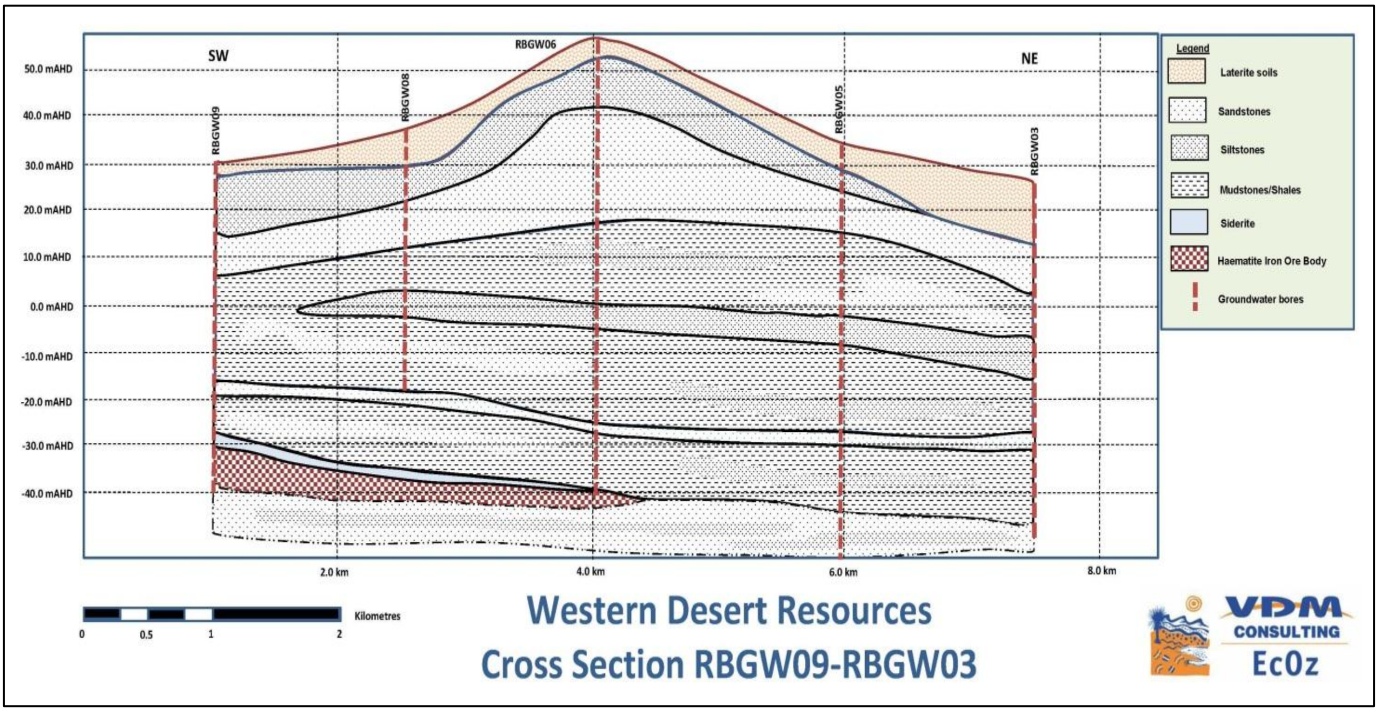


Figure 6-7 Local Geological Cross-Section though several groundwater monitoring bores at the mine site.

Note: this is not perpendicular to the strike of geological bedding but almost parallel. See Figure 6-8 for locations of bores shown in this cross section.

6.2.2 Regional Groundwater Resources

Regional groundwater studies are limited. Recent studies to the north indicate that major aquifers in the Roper region occur in the Tindall Limestone, Dook Creek Formation and Cretaceous sediments (Tickell, 2009). These, particularly the Tindall aquifer, recharge in areas where the aquifer intercepts the surface through karstic conduit systems such as sinkholes and caves resulting from deep weathering (Knapton, 2009).

The mine site is located within the Towns River Catchment whilst the proposed haul road crosses several catchments of which the Limmen Bight is the largest. The Limmen Bight region hosts an aquifer system located in the north-east among shallow calcrete lithotypes (Northern Territory of Australia, 2009) which is a likely source of base flow to the Nathan River.

The Towns River has several waterholes along its course. These water bodies appear to be surface reflections of very shallow localised, and probably perched, groundwater systems which may be fed in some locations from exposed surface fracturing across higher lying ground.

6.2.3 Local Groundwater Resources

A total of eleven investigative bores were constructed to ascertain the hydrogeological characteristics of the local aquifers and their variability around the proposed open pits (Figure 6-8 and Table 6-6). These bores are to be used for ongoing monitoring purposes.

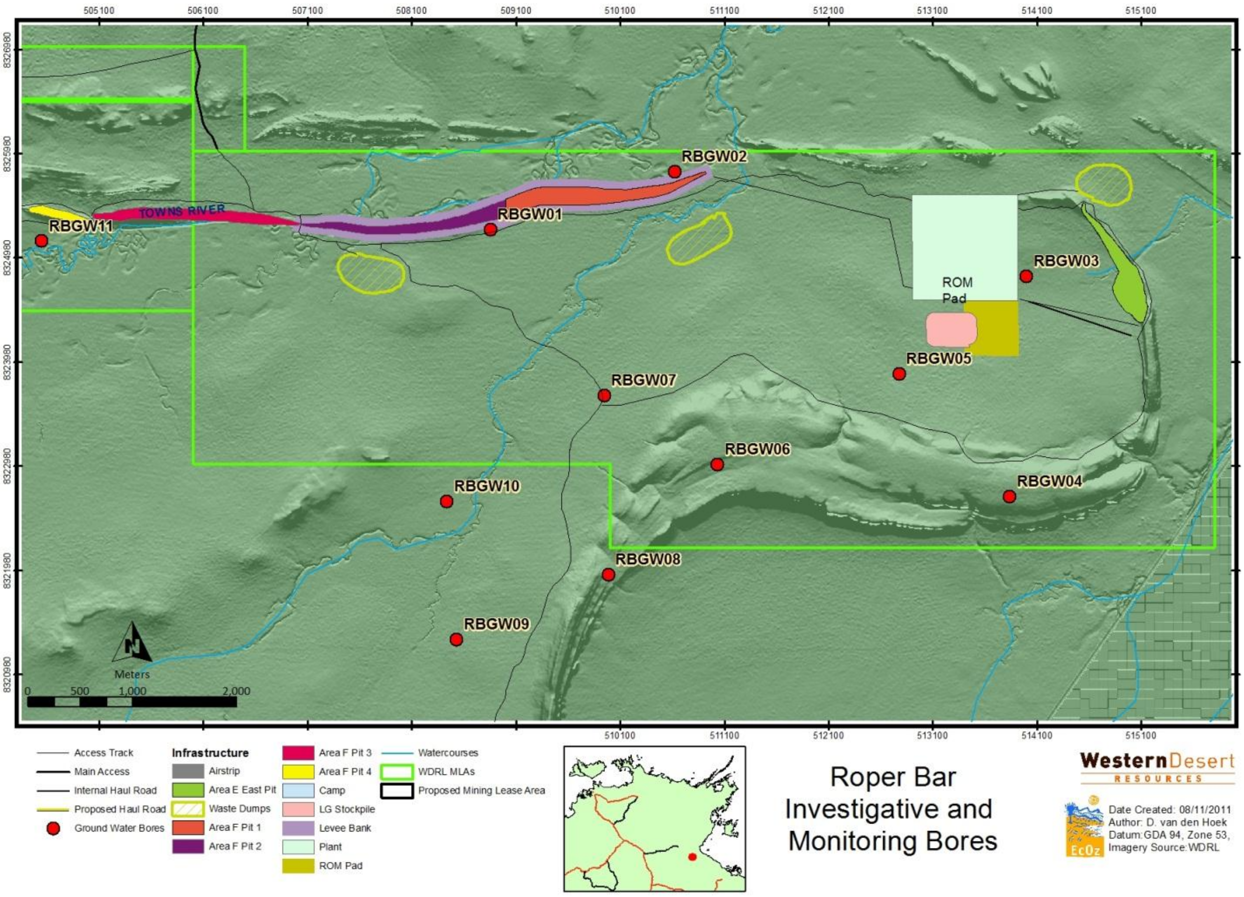


Figure 6-8 Locations of Investigative and Monitoring Bores at the mine site area.

Aquifer Yields

Bore drilling did not encounter any significant water bearing/yielding zones and there is no indication that any of the observed multiple water strikes are interconnected. Water was encountered predominantly in a) sandstones interbedded with siltstones and b) hematitic iron interbedded with silicified sandstones, mudstones and siltstones (Table 6-7).

Table 6-6 Bore Construction Details.

Hole ID	Coordinates		Top of Casing	Bore Depth	Screen Intervals (mAHD)		Groundwater Level (mbTOC)		
	East	North	mAHD	m	from	to	Nov-11	Jan-12	Mar-12
RBGW01	508851	8325252	25.01	79	-24.7	-54.7	10.14	9.57	8.81
RBGW02	510617	8325804	23.80	102	-48.9	-78.9	13.00	12.42	11.68
RBGW03	513995	8324801	25.90	79	-23.8	-53.8	16.18	15.98	15.31
RBGW04	513832	8322687	53.25	71	5.0	-18.5	18.51	16.49	15.43
RBGW05	512772	8323863	30.75	87	-33.0	-57.0	9.37	8.67	7.85
RBGW06	511029	8322996	56.62	56	11.8	-0.2	9.39	8.39	7.58
RBGW07	509942	8323656	27.54	123	-72.2	-96.2	12.32	11.66	10.61
RBGW08	509981	8321938	39.58	56	17.0	-17.0	6.07	3.80	3.08
RBGW09	508527	8321313	32.27	71	-21.7	-39.7	12.12	11.87	11.29
RBGW10	508433	8322638	27.26	72	-33.2	-45.2	9.34	9.17	8.73
RBGW11	504539	8325139	27.96	72	-14.2	-44.2	13.46	13.64	13.10
		Average	33.6	79			11.81	11.06	10.32
		Maximum	56.6	123			18.51	16.49	15.43
		Minimum	23.8	56			6.07	3.80	3.08

Table 6-7 Water-bearing Strata and Airlift Yields.

Hole ID	Water Strikes		Lithology	Airlift Yields
	mbgl	mAHD		(L/s)
RBGW01	33; 62; 70	-9; -37; -4	Sandstone interbedded with siltstone	0.5
RBGW02	33	-9	Contact weathered mudstone/sandstone	<0.1
RBGW03	70	-44	Siltstone interbedded with mudstone	<0.1
RBGW04	9	43	Laterite/Extremely weathered siltstone and sandstone	0.3
RBGW05	61	-31	Red ferruginous sandstone	<0.1
RBGW06	23	32	Quartzite sandstone	0.3
RBGW07	56; 107	-29; -80	Quartz sandstone and siltstone	0.5 - 0.8
RBGW08	18; 21	20; 17	Quartz sandstone interbedded with ferruginous layers	1.0 – 1.5
RBGW09	30	1	Siltstone and shales/mudstones	0.3
	57	-25	Intensely weathered siderite	
	62	-30	Hematitic shale interbedded with silicified sandstones and mudstones	
RBGW10	30	-3	Finely laminated siltstone with shale/mudstones	0.2
	58	-31	Intensely weathered siderite	
	60	-33	Hematitic iron ore body	
RBGW11	30	-2	Siltstone interbedded with sandstone	<0.1

The investigation indicates that:

- Bore yields are low; in the range between 0.1L/s and 1.5L/s and generally less than 0.5L/s.
- Very low yields were encountered at and below the proposed depth of mining at 70.0m below ground level.
- The highest water strike, approximately 1.5L/s after bore development, was encountered at 21.0m below ground level in bore RBGW08, in quartz sandstones interbedded with a ferruginous layer.
- The hematite iron ore body, on average 60m deep and dipping east-west, is interbedded with porous silicified siltstones and sandstones with an average yield of 0.25L/s. Earlier studies (SKM 2010) indicated that this is a shallow semi-confined to confined aquifer controlled by primary porosity.

Observations indicate that bore yields are relatively high initially but that they will not be sustained over the long-term, which is typical of localised weathering and fracturing that do not extend laterally. Relatively slow recovery of water levels after pumping indicates that recharge through the fracture systems and primary porosity is limited and controlled by barrier boundary conditions in a semi-confined to confined aquifer system, with limited areal and vertical extent. The deeper seated waters are within an aquifer system receiving little recharge from overlying and underlying strata and sustainable yields will not be maintained, whilst dewatering rates will decrease steadily with time.

Groundwater Levels

Groundwater levels are relatively deep and imitate the local topography (Figure 6-9 and

Table 6-7). Groundwater levels range from the shallowest of 9.3m (21.4mAHD) to the deepest of 16.1m (34.7mAHD) below ground level. Groundwater flows are preferentially to the north and north-west, with radial flow from the water mound in the sandstone-siltstone ridges located to the south and south-east (Figure 6-12).

In the western portion of the site, near the Towns River, water levels are shallower and follow the gently undulating topography, particularly during the wet season following saturation of the low conductivity overlying lateritic soils. However, the depth to groundwater is generally well below the beds of drainage channels and the Towns River, which implies that these would facilitate vertical infiltration recharge from rainfall runoff into the underlying aquifers. The impermeability of the shallow surficial materials limits the amount of recharge and causes water to pond in streambeds, long after the rain has ceased.

Aquifer Hydraulic Parameters

As a consequence of the low bore yields, a combination of pump and slug testing (Appendix E) was utilised to ascertain the hydraulic properties of the aquifers. Hydraulic testing yielded low hydraulic conductivities (K-values) and transmissivities (T-values; refer Tables 3 and 4) which are indicative of slightly fractured rock aquifers in which permeability is controlled by a combination of the primary porosity of the pore space matrix and the secondary porosity of features such as fractures and bedding plains.

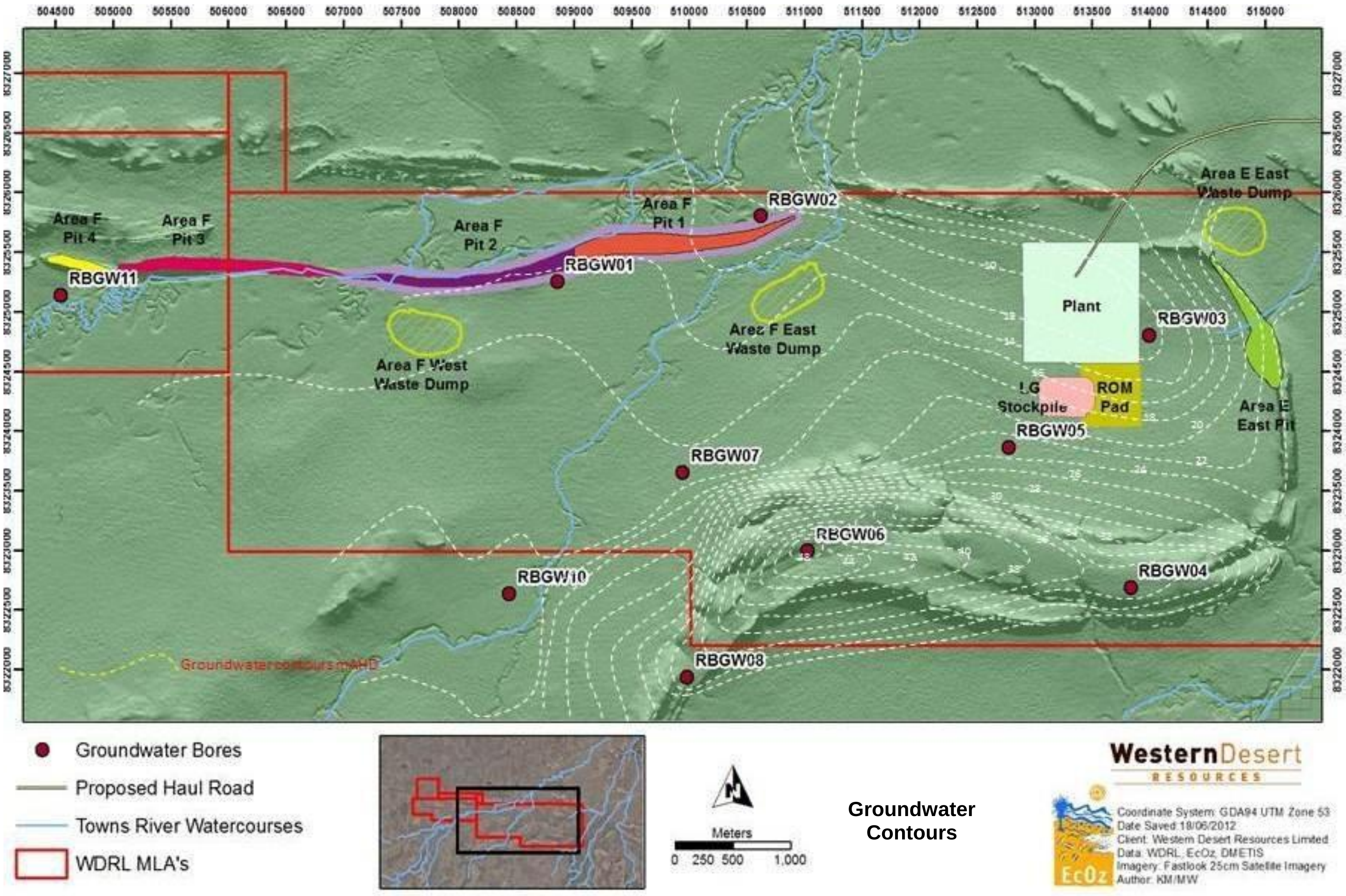


Figure 6-9 Groundwater Contours (mAHD) at the mine site area.

Table 6-8 Hydraulic Parameters.

Slug Testing	Averages		Aquifer Thickness
Bore ID	**K (m/s)**	**T (m^2/s)**	**(m)**
RBGW01	1.40E-07	1.03E-05	73.0
RBGW02	1.12E-08	1.07E-06	96.0
RBGW03	1.27E-07	5.72E-06	73.5
RBGW04	7.55E-08	4.95E-06	65.5
RBGW05	3.69E-08	5.86E-07	81.0
RBGW06	7.53E-08	3.81E-06	50.5
RBGW09	1.30E-08	6.19E-07	47.5
RBGW10	5.50E-08	4.03E-06	47.5
RBGW11	2.31E-08	1.49E-06	64.5
Average	6.20E-08	3.61E-06	66.6
Maximum	1.40E-07	1.03E-05	96.0
Minimum	1.12E-08	5.86E-07	47.5
Bore Testing			
RBGW07	1.89E-08	1.30E-06	69.0
RBGW08	6.50E-07	4.48E-05	49.5
RBGW08A	4.00E-07	1.98E-05	49.5
Average	3.56E-07	2.20E-05	-
Maximum	6.50E-07	4.48E-05	-
Minimum	1.89E-08	1.30E-06	-

Table 6-9 Transmissivity T-Values.

Hole ID	Lithology	Airlift Yields (L/s)	T (m^2/d)
RBGW01	Quartz sandstone interbedded with siltstone	0.5	0.9
RBGW02	Mudstone/Sandstone	<0.1	0.1
RBGW03	Siltstone interbedded with mudstone	<0.1	0.5
RBGW04	Laterite/Siltstone/Sandstone	0.3	0.4
RBGW05	Ferruginous sandstone	<0.1	0.1
RBGW06	Quartzite sandstone	0.3	0.3
RBGW07	Quartz sandstone/Siltstone/Iron ore body	0.2	0.1
RBGW08	Quartz sandstone interbedded with ferruginous layers	1.0	1.7 to 3.9 average 3.0
RBGW09	Siltstone and shales/mudstones Intensely weathered siderite Hematitic iron ore interbedded with silicified sand and mudstones	0.3	0.1
RBGW10	Finely laminated siltstone with shale/mudstones Intensely weathered siderite Hematitic iron ore interbedded with siltstone and mudstone	0.2	0.3
RBGW11	Siltstone interbedded with sandstone	<0.1	0.1

Aquifer hydraulic parameters, particularly transmissivity, in the sandstones/siltstones and the hematite iron ore are low; in the order of 0.1m^2/day to 4.0m^2/day. The lower transmissivity pertains to the dominantly ferruginous sandstone materials and the highest to the quartzite sandstone interbedded with ferruginous sandstones. The hematite iron ore sandstones interbedded with mudstones and siltstones have an average transmissivity of 0.4m^2/d. The higher transmissivities were calculated from short term (less than 100min) data, before the effects of barrier boundaries established. Based on the field observations and slug/drawdown curves, there appears to be:

- A shallow localised unconfined aquitard between 25m and 30m deep in a highly weathered sequence of sandstones interbedded with siltstones.
- A semi-confined to confined aquifer in the Sherwin Ironstone Formation between 50m and 60m below ground level.

The implications for mining are:

- Relatively low influxes into the open pits, with groundwater level drawdowns confined to within close proximity to the open pits.
- Owing to the impermeability of the geological regime, dewatering is unlikely to impact on the shallow soils and surface waters.
- Although a water balance indicates that ground water influxes will meet plant water requirements, low yielding bores and aquifers may necessitate a bore field to the north, along the Hell's Gate Hingeline (a major fault), should additional water be required.

6.2.4 Groundwater Quality

Groundwaters are characterised by circum-neutral pH and high electrical conductivities (Table 6-10). Groundwater contains varying concentrations of all major cations and anions, with saline conditions at some locations near the Towns River:

Table 6-10 Groundwater Quality at the mine site area.

Site	pH	Temp	EC	TDS	Ca	Mg	Na	K	SO_4^{2-}	Cl
	units	°C	uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
RBGW01	7.1	33.3	7,550	4,230	94	239	888	43	2	2,010
RBGW02	6.1	33.2	18,800	10,560	71	688	2,440	120	549	5,680
RBGW03	7.6	33.7	1,580	879	31	37	206	14	62	318
RBGW04	4.6	33.5	83	46.4	<1	2	7	<1	<1	15
RBGW05	6.2	34.6	262	144	2	17	5	5	3	10
RBGW06	5.8	34.3	273	151	6	6	15	12	9	24
RBGW07	6.4	34.3	289	160	4	16	10	6	16	13
RBGW08	5.9	34.0	220	122	1	6	14	8	1	18
RBGW09	7.1	34.4	276	152	9	16	10	7	<1	20
RBGW10	7.5	34.4	446	246	7	15	40	11	2	45
RBGW11	6.7	34.6	30,950	17,010	355	1,430	4,330	120	2,030	8,790
Average	6.5	34.0	5,521	3,064	58	225	724	34	297	1,540
Maximum	7.6	34.6	30,950	17,010	355	1,430	4,330	120	2,030	8,790
Minimum	4.6	33.2	83	46	1	2	5	5	1	10

Filtered trace metals, including beryllium, cadmium, chromium, cobalt, lead and vanadium, were all below their respective laboratory limits of reporting (LoRs). Arsenic, barium, copper, manganese, nickel and zinc are mostly above their LoRs but below their respective NEPM Health Investigation Levels (NHMRC NRMMC 2011). However, barium at bore RBGW01 exceeds its Health Investigation Level (HIL: 2.0mg/L) at a concentration of 9.09mg/L. Concentrations of barium appear to naturally originate within the sandstone rocks. Several investigators (e.g. Gilkenson *et al*. 1983) found that large concentrations of barium are typical of confined aquifers, in which dissolved sulfate concentrations are depleted by anaerobic microbial reactions. This is supported by the low sulfate concentration (2.0mg/L) in bore RBGW01. Owing to natural background conditions, iron concentrations substantially exceed the NEPM Aesthetic Investigation Level (0.3mg/L) for this metal, with an average of 4.1mg/L and ranging from <0.05mg/L to 10.1mg/L.

Hydrogeochemical processes, as expressed by a Piper Diagram (Figure 6-10), were evaluated:

- Groundwaters are of the Cl and SO_4 type.
- Three water samples are reverse ion-exchange $CaCl_2$ water types, with no particularly dominant cation. These waters retain permanent hardness, although it is dependant of their interaction with the lithologies through which they circulate.
- Eight water samples are end-point waters, with dominant NaCl. These waters generally cause salinity.

Short-term groundwater quality behaviour suggests that with time, pH in groundwater within the quartz sandstone/siltstone/mudstone domains may increase to become slightly alkaline. Groundwater in deeper lithologies, particularly those hosted by the hematite ores, may with time remain circum-neutral or decrease to slightly acidic waters. These observations are to be verified during monitoring of groundwater during mining activities.

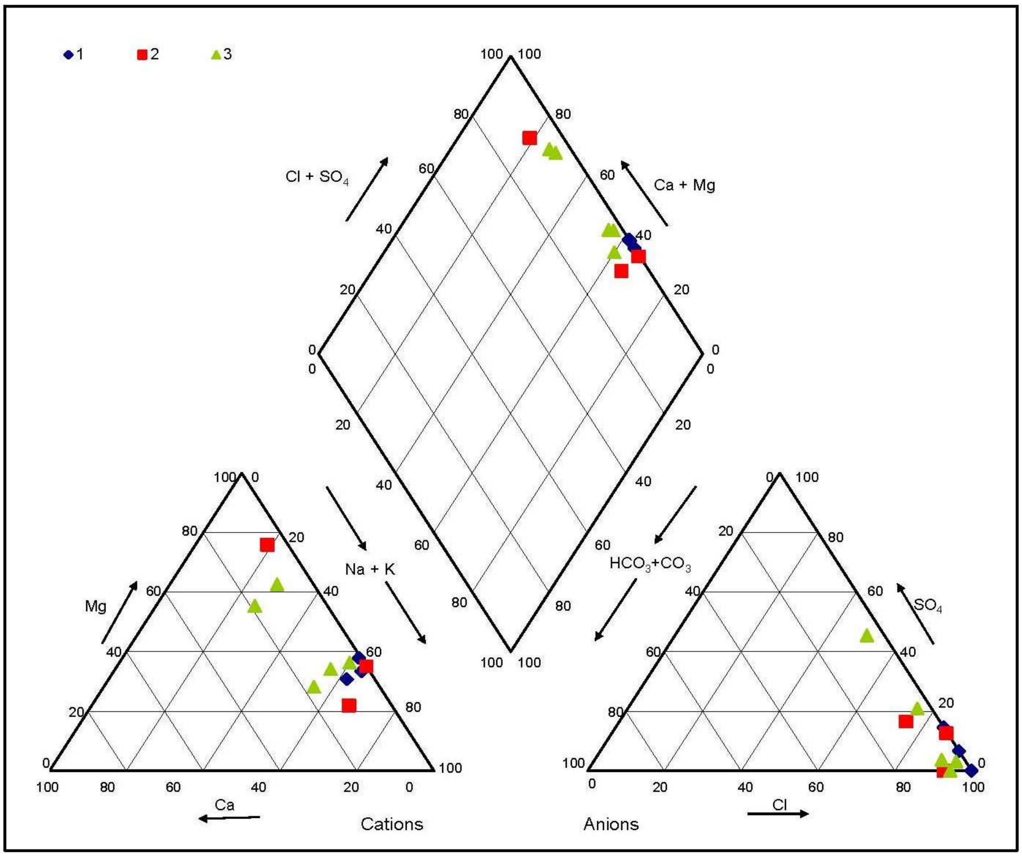


Figure 6-10 Piper Diagram of groundwater samples collected from the 11 groundwater monitoring bores at the mine site.

6.2.5 Groundwater Dependent Ecosystems

Groundwater Dependent Ecosystems (GDEs) are areas where groundwater plays a key role on both vegetation dynamics and soil water balances. These areas are of particular interest for several reasons, including their relatively high richness, both in animal and plant species, and their ability to sequester and store carbon (Mitsch & Gosselink 2000). GDEs here are defined as: *natural ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their ecological functions*.

Six types of GDEs are conventionally recognised in Australia:

- **Terrestrial vegetation** that relies on the availability of shallow groundwater.
- **Wetlands** such as paperbark swamp forests and mound spring ecosystems.
- **River base flow systems** where groundwater discharge provides a base flow component to the river's discharge.
- **Aquifer and cave ecosystems** where life exists independent of sunlight.
- **Terrestrial fauna**, both native and introduced that rely on groundwater as a source of drinking water.
- **Estuarine and near shore marine systems**, such as some coastal mangroves, salt marshes and sea grass beds, which rely on the submarine discharge of groundwater.

Of the types of GDEs described above, the 'terrestrial vegetation' category is the most likely to occur within the project area. Table 6-11 details the criteria for discerning zones and sites which may fit the definition of a GDE.

Table 6-11 Criteria for Defining GDEs.

Environmental Aspect	Criteria	Indicators of Ground Water Dependence
Level 1: Locate zones with potential for groundwater dependence		
Potential for groundwater fed systems	Status of inundation, submergence, seeps and springs, ground water aquifers, geology and topography	Soil and surface/ground water surveys indicate water at (inundation, submergence, seeps, springs) or close (dampness) to the surface which vegetation can readily tap into or there is potential for expression of this water to the surface based on geology and topography.
Level 2: Assess specific areas where ground water dependence potential is high		
Indications of water at inundation, submergence, seeps, springs) or close (dampness) to the surface	Soil moisture Expression of ground water Source of surface water Refer to vegetation criteria	Greater than 15% following at least 7 days of no rain. Shallow ground water levels, extent of ponding or flowing (frequency; rainfall relationship) Drainage/topographic characteristics Surface/ground water quality characteristics Refer to vegetation structure
Vegetation Characteristics	Vegetation structure Plant Species composition	Structure (large trees) suggests reliance on a long term available water source. Species composition suggests a dependence on a shallow ground water table. Presence of species dependent on (near) permanent water.

Whilst there is a potential for GDEs within estuarine areas, the Bing Bong port facilities have not been assessed because groundwater systems are not planned to be disturbed. If production (dust suppression) water requirements exceed the volumes captured and stored on site, then a suitable groundwater source, to the south of the stockyard will be investigated. Appropriate approvals will be required and sought.

Within the proposed mining area, the depth to groundwater (Figure 6-11) is generally deeper than 10m below natural ground level, which suggests that GDEs are unlikely to be present within the mine project area. However, a small spring has been observed in the south-east corner of the project area, to the west of the Magaranyi River and upstream of surface water site RBSW12 (see Surface Water Chapter 3.5). This surface expression of shallow ground water originates from rain infiltration into locally exposed and shallow fractured sandstone ridges and is likely to be a GDE. The limited extent of the sandstone outcrop, coupled with the impermeability or hydraulic disconnection from deeper weathering and/or fracturing causes infiltrated rain to seep out along the lower reaches of the ridge. These seeps are likely to diminish and/or cease during prolonged periods of drought and the impact on a small pocket of a non-distinct vegetation community in the project area is not regarded as regionally significant.

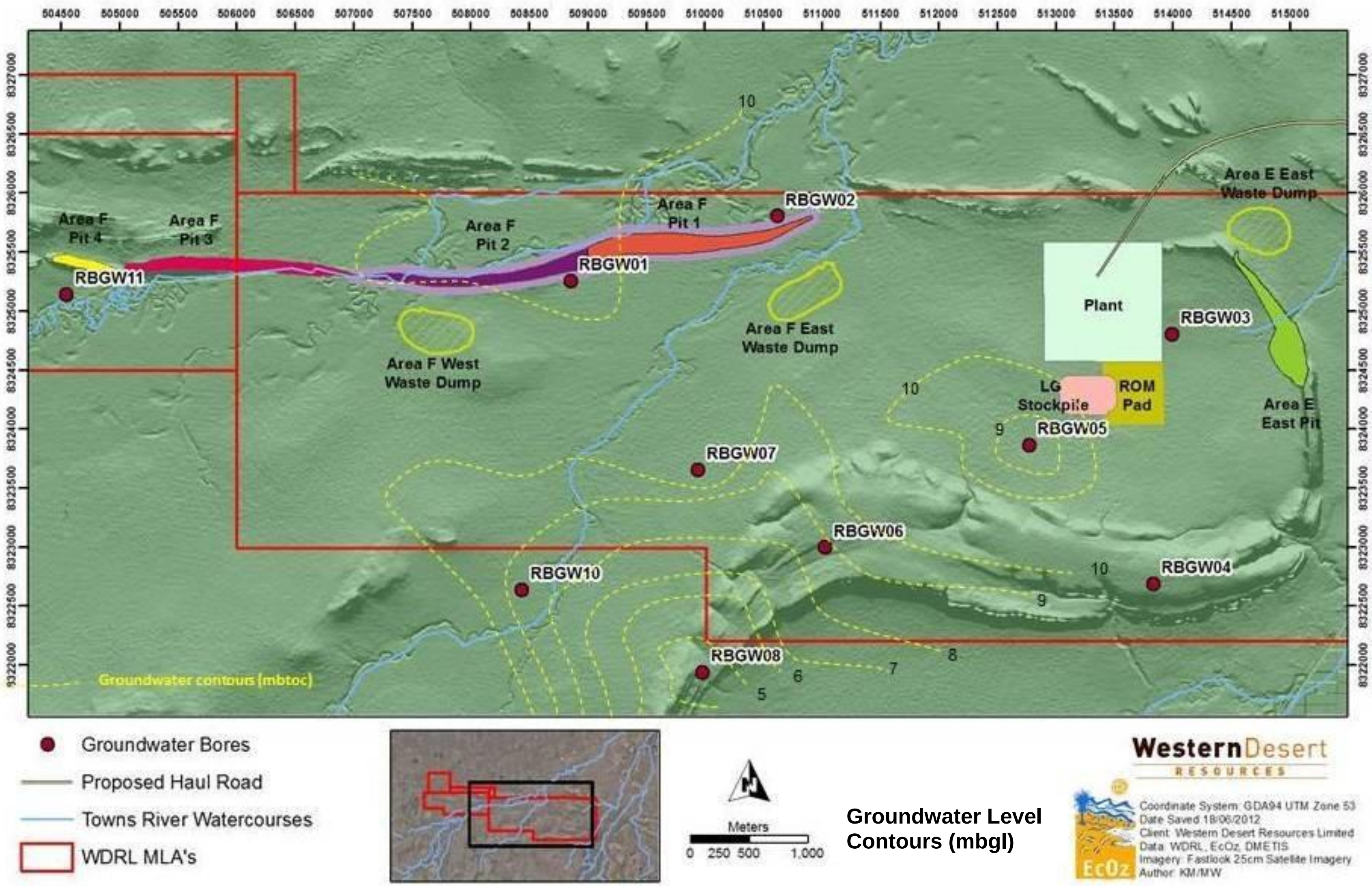


Figure 6-11 Groundwater Level Contours (mbgl) at the mine site area.

6.2.6 Groundwater Modelling

To ascertain influx of groundwater into the proposed open pits, and consequently the impact of such influxes on the surrounding environment, groundwater modeling using MODFLOW-SURFACT (Version 3) was undertaken (Appendix E) based on a conceptual model (Figure 6-12) consistent with the groundwater investigations. In this model, the top layer primarily consists of the weathered zone (up to 28m thick), underlain by the Kyalla Member (up to 160m thick), the Sherwin Ironstone Member (about 25m thick) and the Moroak Sandstone (about 60m thick). The Sherwin Ironstone outcrops near the mine site and dips down towards the west. It is hypothesized that the Hell's Gate Hingeline (a major fault) has moved the Ironstone Formation near the surface in Area F-East.

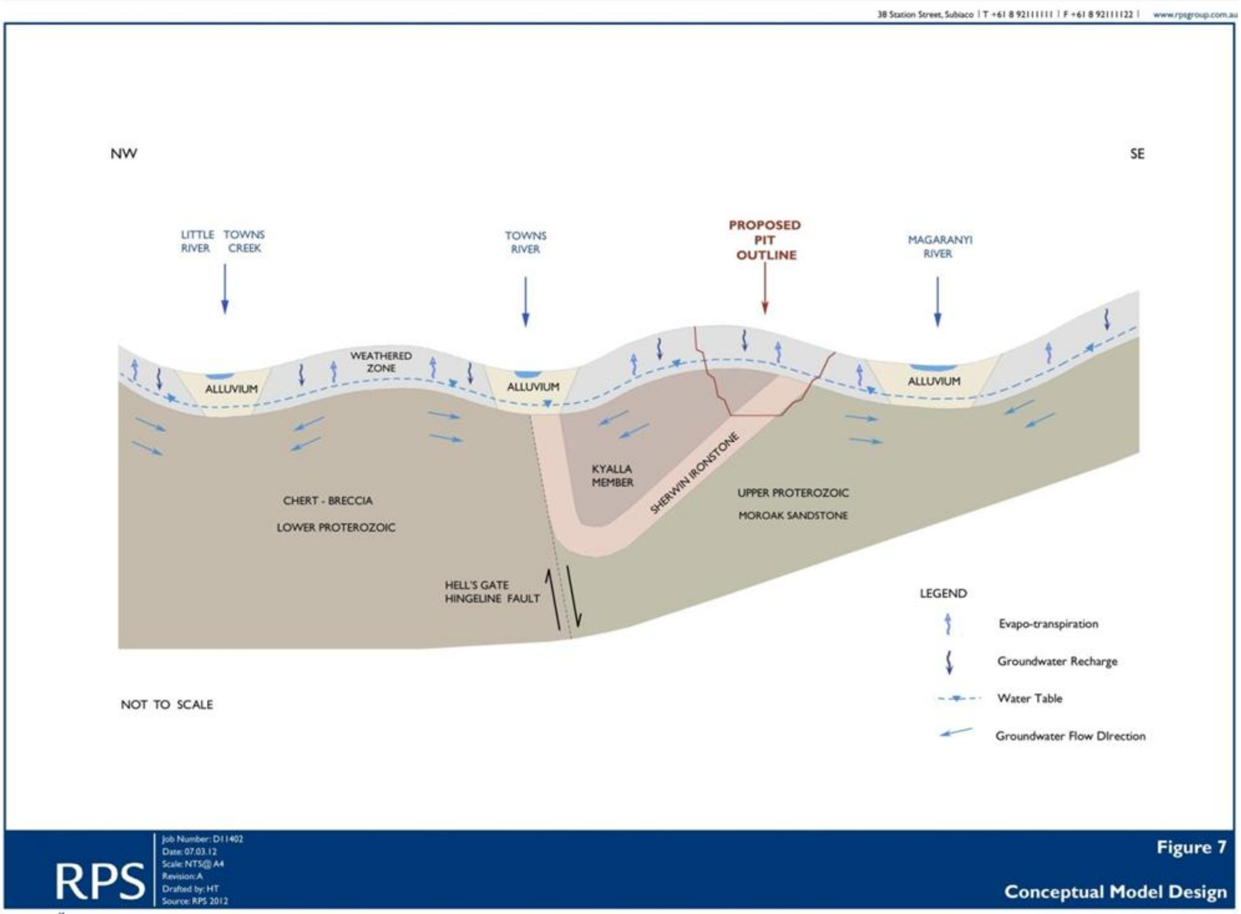


Figure 6-12 Groundwater Conceptual Model for the mine site area.

Input of water in the model is considered to be from rainfall recharge, up-gradient groundwater inflow and from river leakage (where the groundwater table is below the river bed). Output from the model is considered to be via evapotranspiration, groundwater outflow down-gradient and groundwater discharge to the river (where the groundwater table is above the river bed). Across the study area, groundwater is generally expected to be below the river bed, hence the rivers are likely to provide groundwater input rather than receive groundwater output. The groundwater flow model was calibrated by comparing computed groundwater heads with observed groundwater heads from the 11 observation wells within the model domain (Appendix E).

Model Predictions

The steady-state model was used as the basis for transient predictions. The purpose is to estimate the groundwater inflow into the proposed open pits and the extent of groundwater level drawdown during mining associated with pit dewatering (Appendix E).

Predicted Mine Inflow Rate

The base-case prediction shows that total groundwater influx changes from 6,600kL/d for the first year of mining, decreasing to about 3,200kL/d in year four and increasing to about 8,900kL/d in year six. These figures include groundwater that is stored within the rock-mass of the ore body, as well as groundwater entering from the sides and base of the pits.

Groundwater influx from the sides and floors of the open pits commences at 4,000kL/d for the first year of mining, decreasing to about 3,000kL/d in year four and increasing to about 4,500kL/d in year six.

Given the size of the pit voids and evaporation rates in the area, most of the water is expected to evaporate from the pit surface. Owing to low bore yields, dewatering will most likely be undertaken by pumping from in-pit sumps.

Predicted Groundwater Drawdown

The lowering of groundwater levels as a result of pit dewatering is predicted to be 5.0m and 1.0m at distances of 0.9km and 1.2km respectively, from the edge of the mine pits at the end of a seven year period. Hence, the model predicts that the impact of mining on lowering the regional water table is minimal and localised. This is primarily due to the low permeability (K) of the rock material surrounding the mine site.

Predicted Impact on Surface Water Courses

The potential impact on surface water bodies due to pit dewatering is predicted to be minimal or absent. The impact on rivers from mine dewatering has been assessed by comparing the net river leakage rate pre- and post-mining. The pre-mining steady-state net river leakage rate was 3,747kL/d which reduces to 3,642kL/d post-mining. This small reduction (2.8%) in river leakage reflects the removal of the Towns River from the model during mining, as this section is proposed to be re-aligned away from the pit areas during mining. The reduction in net river leakage is considered minor in terms of impact to the river. This is consistent with the conceptual understanding of the site, where the regional water table is located below the river bed and which implies that lowering of the groundwater level by influx does not induce more leakage from the river to the aquifer.

6.2.7 Operational Groundwater Monitoring Program

Groundwater levels and field water quality will be surveyed monthly whilst samples for laboratory analysis of water quality will be obtained quarterly, from all monitoring bores located both upstream and downstream of the mine site. The data and information gathered from these monitoring programs will be used to assess potential impacts of mining operations on downstream water qualities. A preliminary groundwater monitoring program is presented below, including baseline monitoring locations (Table 6-12). The monitoring program will be finalised prior to commencement of mining activities, in consultation with relevant regulatory agencies (i.e. DoR, NRETAS) including additional monitoring locations for shallow and deep groundwater monitoring bores in the vicinity of specific infrastructure locations (i.e. WRDs, plant, ore stockpiles, etc).

It is proposed that site-specific (and possibly individual monitoring location-specific) trigger values be developed using ambient water qualities from baseline monitoring and reference sites.

Table 6-12 Proposed Groundwater Monitoring Program for the mine site.

Monitoring Sites/Action	Frequency	Analytes
RBGW01 to RBGW11 Additional shallow and deep bores up- and downstream of specific infrastructure locations i.e. WRDs, tailings dam, plant, ore stockpiles, etc,	Monthly	Groundwater level. Field water quality: in-situ pH and electrical conductivity (EC).
RBGW01 to RBGW11 Additional shallow and deep bores up- and downstream of specific infrastructure locations i.e. WRDs, tailings dam, plant, ore stockpiles, etc,	Quarterly	Groundwater level. Field water quality: in-situ pH and electrical conductivity (EC). Laboratory: Total acidity and total alkalinity. Major anions (Cl, SO_4, CO_3/HCO_3, NO_3) and cations (Ca, Mg, Na and K) and fluoride. Sulphide S. Dissolved metals: As, Cd, Cr, Cu, Mn, Ni, Pb, Zn, Fe
Reporting	Monthly and quarterly	Tabulations and trend diagrams. Mass transport model.
Response	Monthly and quarterly	Variations by more than 10% trigger further assessment, re-sampling and site investigations to ascertain cause, impact, remediation and preventative action.

6.3 Towns River: Realigned Section

This section describes the part of the Towns River that is to be realigned in the context of morphology, hydrology and stream side vegetation characteristics.

6.3.1 Existing Stream Characteristics

Details of existing stream catchments, hydrology and morphology are provided in Chapter 6 and aquatic/riparian environments and biodiversity are described in Chapter 4. Information specifically relevant to the proposed stream re-alignment from these sections are summarised below.

To illustrate river morphology cross-sections of the river were taken at various points along this section of river (Figure 6-13); the cross-section diagrams and photos are in Figure 6-14.

The stream has little in-stream variability with no woody debris recorded and few long-term pools. These pools are typically in river bends with a base of bedrock.

The Strahler Order of the river section to be realigned was derived using the Geoscience Australia's Geofabric Watercourselines dataset. Using these data the Towns River is considered to be a 5th order river with the diverted section to be 3rd order.

Catchments and Hydrology

The total catchment area of the main Towns River channel is relatively small (503km^2), of which some 344km^2 lies upstream of the proposed re-alignment. Stream flow is restricted to during and just after the wet season (November to April, refer Photo 1) whilst surface waters are confined to remnant pools, if any, during the dry season (May to October, refer Photo 2).

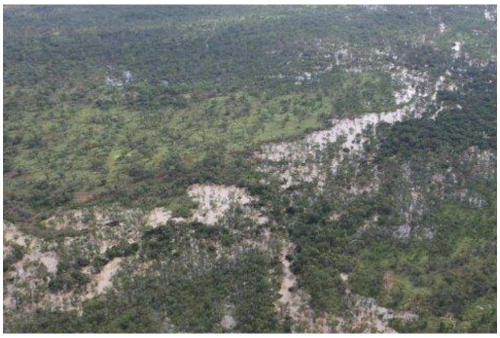


Photo 1: Flooding during February 2012.

Photo 2: Streambed November 2011, Golders, 2012.

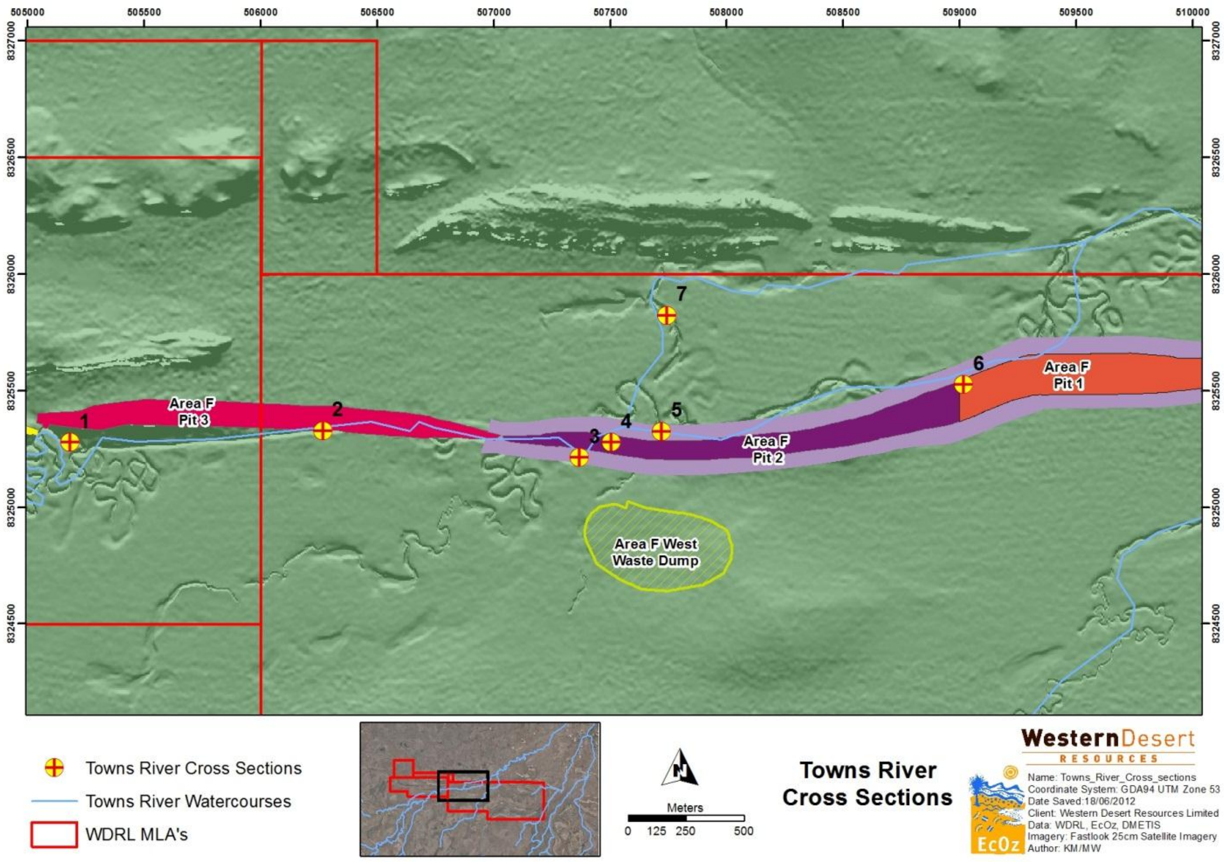


Figure 6-13 Locations of Towns River Cross Sections

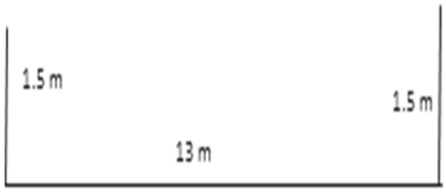
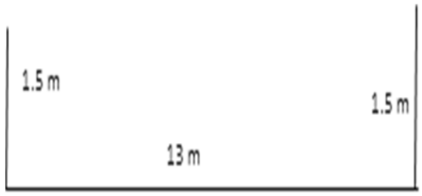
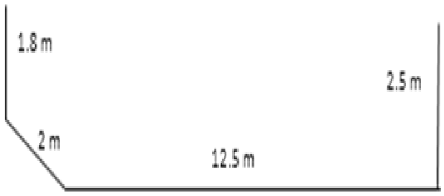
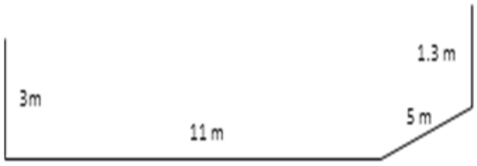
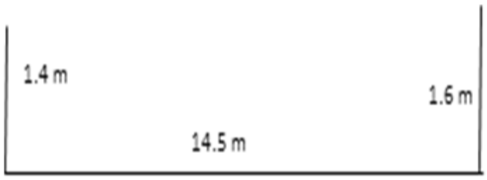
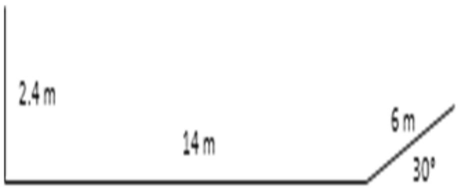
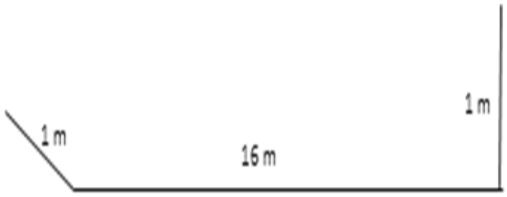
Site/Cross Section Number^	Image	Approximate Channel Dimensions
1		
2		
3		
4		
5		
6		
7		

Figure 6-14 Examples of typical cross-sections of the Towns River in the vicinity of the mine site.

Whilst there is no available existing hydrological data (Spatial Data and Mapping Natural Resources Division, NRETAS) for the Towns River i.e. there are no details pertaining the likelihood and history of flooding, including the extent, levels and frequency of flooding in and around the project site, hydraulic modelling of the Towns River indicates that estimated peak flood discharges for various average return interval (ARI) events are 720 m^3/s (5 ARI), 950 m^3/s (10 ARI) and 1,850 m^3/s (100 ARI). Estimated widths of flooding, depth of flow and peak velocities upstream of Area F are provided in Table 6-13 below.

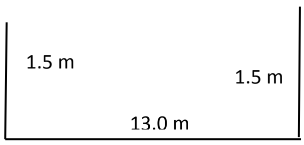
Table 6-13 Details of flooding of the Towns River upstream of Area F.

Cross-Section^	ARI	Peak Flows (m^3/s)	Flooding Width (m)	Channel Depth (m)	Peak Velocity (m/s)		
					Left Bank	Main Channel	Right Bank
9263.826	5	720	1,247	2.8	0.6	1.5	0.8
	10	950	1,271	3.1	0.7	1.5	0.9
	100	1,850	1,339	3.7	0.8	1.7	1.0
Golders 2012; Appendix N1 for relevant details including location of cross-section.							

Stream Channel Morphology

The natural channel in the project area as detailed in Table 6-14 below is relatively uniform:

Table 6-14 Typical Section of the Towns River at Area F (Appendix N1).

Coordinates	Photograph	Approximate Channel Dimensions	Notes
0506268 N 8325326 E			Rocky streambed. Almost vertical banks.

The flow depth in a channel with these dimensions using a longitudinal slope of 0.002 (typical of local conditions) and Manning's n value of 0.035, would be approximately 3.4 m for the 1-year ARI estimated peak flow (at Catchment T: Area F Pit 3) of a 24 hour 1:1 year ARI event at 128 m^3/s. Golders indicated that *it is highly likely the natural channels in this region would only convey the runoff from relatively low magnitude storm events. So, a design event with an ARI of 1 year cannot be fully conveyed through the natural channel capacity and flooding on the overbank regions will occur.* This observation is confirmed by Photo 1 above taken after 16mm of rain on 28 February (BoM, 2012).

The morphology of the Towns River comprises of ox bows and channels that display a highly *old* meandering, sinuous form. Golders (Appendix N1) observed that:

- Given the estimated flood peaks and lack of in-channel capacity, it would be expected that the area would be highly dynamic with erosion and deposition of sediment common during most flood events.

- A significant proportion of the design discharge for events exceeding the 1-year ARI are conveyed in the overbank areas.

Streamside Vegetation

There is no pronounced and distinct riparian zone along this section of the Towns River; the vegetation abutting the stream is typically open eucalypt woodland (where the stream has created a deep channel trough this vegetation type) or is floodplain vegetation dominated by Melaleuca sp. Figure 6 16 shows these relationships. Occasionally, within the channel on sandy substrates, Acacia holosericea forms small thickets. By far the most dominate stream side vegetation is floodplain vegetation dominated by Melaleuca.

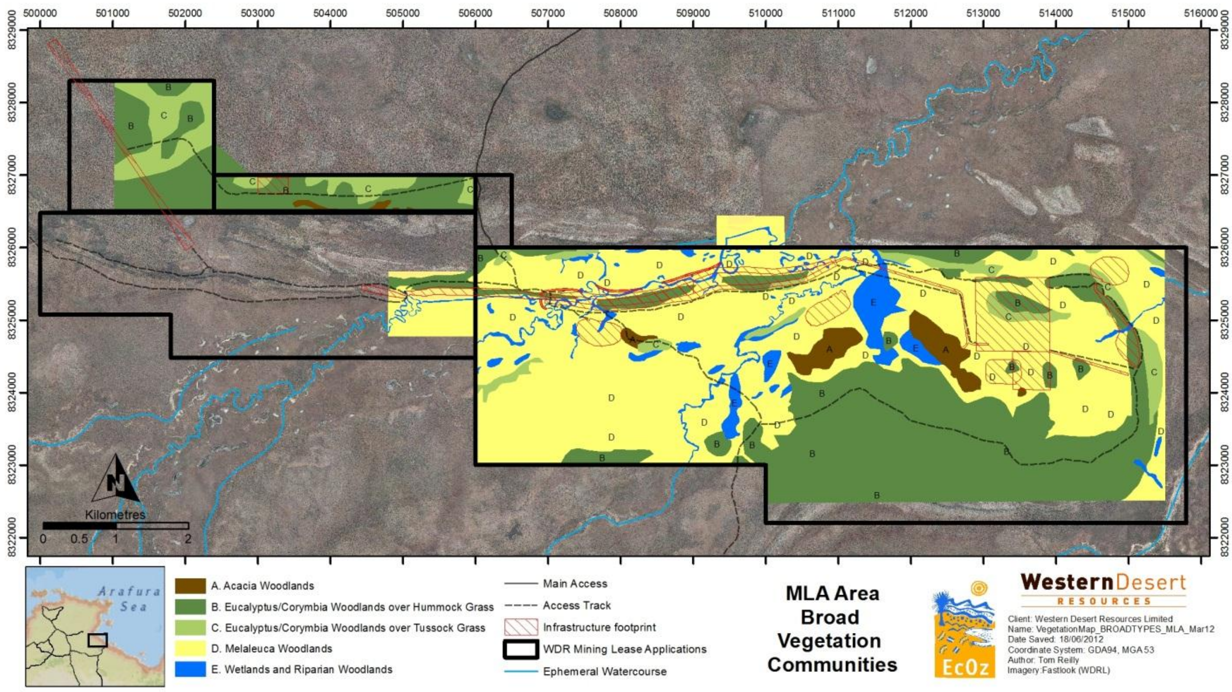


Figure 6-15 Vegetation Communities along the Section of the Towns River to be Realigned

Soils in the areas to be impacted by a realigned channel

The soil profile comprises clay overlying a mixture of soils and rock (Appendix N2). A generalised soil profile appears in Table 6-15.

Groundwater in the areas to be impacted by a realigned channel

Groundwater inflow was observed in two of the 15 geotechnical test pits. Test pits inferred that groundwater source was shallow perched water sitting in stream sediments on top of clay. Both these were close to the existing streambed. Two out of 15 indicates that it is not the norm but rather localised and sporadic.

Drilling at locations RBGW 01, 02 and 11 in proximity to the Towns River encountered ground water at depths greater than 30m below surface (Section 6.2 and refer Appendix E). The groundwater levels at these locations are deeper than 9.5m below surface and well below the level of the streambed. The detailed hydrogeological investigation and subsequent groundwater modelling observed that there is no hydraulic connection between the Towns River and the underlying aquifers and that the Towns River may slowly leak, if any, water into the underlying strata.

Table 6-15 Typical Soil Profile at Realignment (source Appendix N2).

Depth	Description
Surface	Silty Sand and Clayey Sand, fine to medium grained, grey brown.
0.0 – 2.2	Clay, high plasticity, mottled grey, red and orange brown, fine to medium gravel with fine to coarse grained sand.
0.5 - 1.6	Gravelly Clay, high plasticity, mottled grey, orange and red brown, fine to medium gravel and fine to coarse grained sand.
1.7 – 3.3	Mixture of Soil (80%) and Rock (20%): Soil generally comprises Gravelly Clay, low plasticity, mottled pale brown and orange brown, fine to medium gravel with fine to coarse grained sand Rock is laterised Sandstone/Siltstone, fine to medium grained, granular, mottled grey, brown, orange brown, red, black, low strength, highly weathered.