PRELIMINARY GROUNDWATER RESOURCE ASSESSMENT FOR THE OLD PIRATE GOLD PROJECT, TANAMI DESERT, NORTHERN TERRITORY

prepared for

ABM Resources NL

by

EARTH SYSTEMS

Environment | Water | Sustainability

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EXECUTIVE SUMMARY

ABM Resources NL (ABM) is developing the Old Pirate Gold Project, located in the Tanami Desert Region of the Northern Territory, Australia. The operation will include the development of infrastructure such as a tailings storage facility, waste rock pile/s, a processing plant and power, accommodation, workshops and office infrastructure.

It is understood that the Project will require a water supply of at least 960 m^3/d, corresponding to an average extraction rate of 11.1 L/s. Whilst mining activities are currently exempt from requiring a groundwater extraction license and do not fall under the provisions of the Water Act 2011, an application for an authorisation to carry out mining activities must be accompanied by a Mining Management Plan (MMP), which in turn must include a consideration of water resources.

This report contains an assessment of the water resources in the Project area including availability and sustainability.

Surface water flows are intermittent and cannot supply the site's water needs but this study has identified two potential groundwater sources that may be suitable. An assessment of the viability of borehole extraction rates and the potential long term sustainability has been completed for a number of target areas. The results of the assessment have been presented together with recommendations for further investigation of the target areas.

The two types of aquifer that have been identified as potential groundwater resources within the Project area are:

- hard-rock fractured bedrock aquifers; and
- unconsolidated sedimentary aquifers hosted within Tertiary to Recent palaeochannels cross-cutting the Project area.

Groundwater flow in bedrock aquifers is generally fracture-controlled, whilst flow in palaeochannels containing unconsolidated sediments incised into the bedrock, is intergranular. Both aquifers have potential yields in the order of 1-5 L/s, although data analysed as part of this assessment suggests that palaeochannels have a greater probability than the bedrock of yielding sustainable quantities of groundwater.

Initial indications are that the palaeochannel aquifers should be the primary targets for more detailed hydrogeological assessment. On that basis, six groundwater resource target areas within palaeochannel aquifers have been identified including locations close to the Mineral Lease as well as up to 35 km away.

Using data obtained from literature, the maximum potential yield of individual boreholes in these target areas has been estimated to be between 2.9 and 5.1 L/s. The actual yield achievable for each borehole and the sustainability of these yields will however vary according to a number of factors.

The long term sustainability of extraction from palaeochannels depends on recharge rates to the aquifer. Aquifer recharge is primarily observed during high intensity rainfall events (>50 mm/d) over a period of at least 24 hours. In general, the larger the palaeochannel catchment, the greater chance there is of achieving sustainable extraction in the long term.

Indicative groundwater balance calculations of potential recharge and extraction from palaeochannel aquifers suggest that locations within close proximity to the Mineral Lease are not as prospective as those further afield with larger catchments. Larger palaeochannel aquifers some distance from the

Mineral Lease are therefore more likely to yield sustainable volumes of groundwater to support site operations.

Of the six target areas considered in this study, calculations for target areas 3, 4 and 5 indicate that, assuming a 4.5 mm/year long term average rainfall across the catchments, there will be an insignificant groundwater level fall resulting from long term extraction at the proposed rate of 11.1 L/s. Preliminary estimates of maximum sustainable yields for target areas 3, 4 and 5 are 24 L/s, 11 L/s and 13 L/s, respectively. Lower sustainable yields were predicted for target area 1 (1 L/s), target area 1A (3 L/s) and target area 2 (6 L/s) although further work is required to verify these estimates.

There are limited data on groundwater quality, both locally and regionally, and no clear relationship between salinity and aquifer type has been established. Variable salinity may have implications for site water use, and palaeochannel groundwater resources may require desalination.

Evaluation of palaeochannel width, depth and structure will provide additional data to aid the location of extraction boreholes. Time domain electromagnetic geophysical surveys (TEM) should be used to facilitate identification of the preferred target area/s and the optimum locations for test borehole installation.

Once optimum locations are identified, drilling of test boreholes in the preferred target area/s should be completed and a program of aquifer and borehole testing undertaken to provide data for evaluation of the sustainability of such supplies.

As some of the target areas are located outside of the Mineral Lease area it will be necessary to identify and liaise with landowners and obtain permissions for development of such drilling targets.

In additional to detailed investigations of the identified potential target areas, groundwater level and quality data should continue to be collected at existing sites. Recommendations on this are provided as part of this report.

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1. Introduction

1.1. Project Background

ABM Resources (ABM) NL is developing the Old Pirate Gold Project, located in the Tanami Desert Region in the Northern Territory, Australia. The project is located approximately 820 km north-west of Alice Springs and approximately 16 km east of the Northern Territory and Western Australian border. The site is approximately 33 km south of the Tanami Road, which runs north-west from Alice Springs to the Northern Territory and Western Australian border. The project location is shown in Figure 1.

Mining will occur initially in an open pit to an approximate depth of 100 m. This may be followed by underground mining. The operation will require the development of infrastructure such as a tailings storage facility, waste rock pile/s, a processing plant and power, accommodation, workshops and office infrastructure.

The operation currently sources groundwater from the Corsair Bore and previously has extracted groundwater from Timmy's and Wilsons Bores, as no reliable surface water source is present within the Project area.

ABM has estimated that an extraction rate of approximately 11.1 L/s may be required to satisfy the future water demand of the project.

Two distinct aquifer categories have been identified as potential groundwater resources within the Project area:

- hard-rock fractured aquifers; and
- unconsolidated sedimentary aquifers hosted within Tertiary to Recent palaeochannels cross-cutting the Project area.

Timmy's Bore is located within a palaeochannel and the Corsair Bore is assumed to be within the fractured bedrock. These bores have been identified by ABM as potential production boreholes with a projected yield of 2 L/s and 2-3 L/s, respectively. Timmy's Bore is understood to have recently collapsed. Wilsons Bore was used for a period of approximately 2.5 years before drying up. It is unknown if this is within bedrock or surficial deposits.

Currently, there is limited understanding of the groundwater system within the Project area, restricting ABM from formulating informed decisions in terms of sustainable extraction rates and optimal groundwater management. A more thorough understanding of the potential for sustainable groundwater extraction and compliance issues is required for environmental permitting of the Project.

To address the information gap associated with the hydrogeological setting of the Project area and fulfil environmental permitting requirements, ABM commissioned Earth Systems to conduct a preliminary groundwater resource assessment for water supply for the proposed Old Pirate Project.

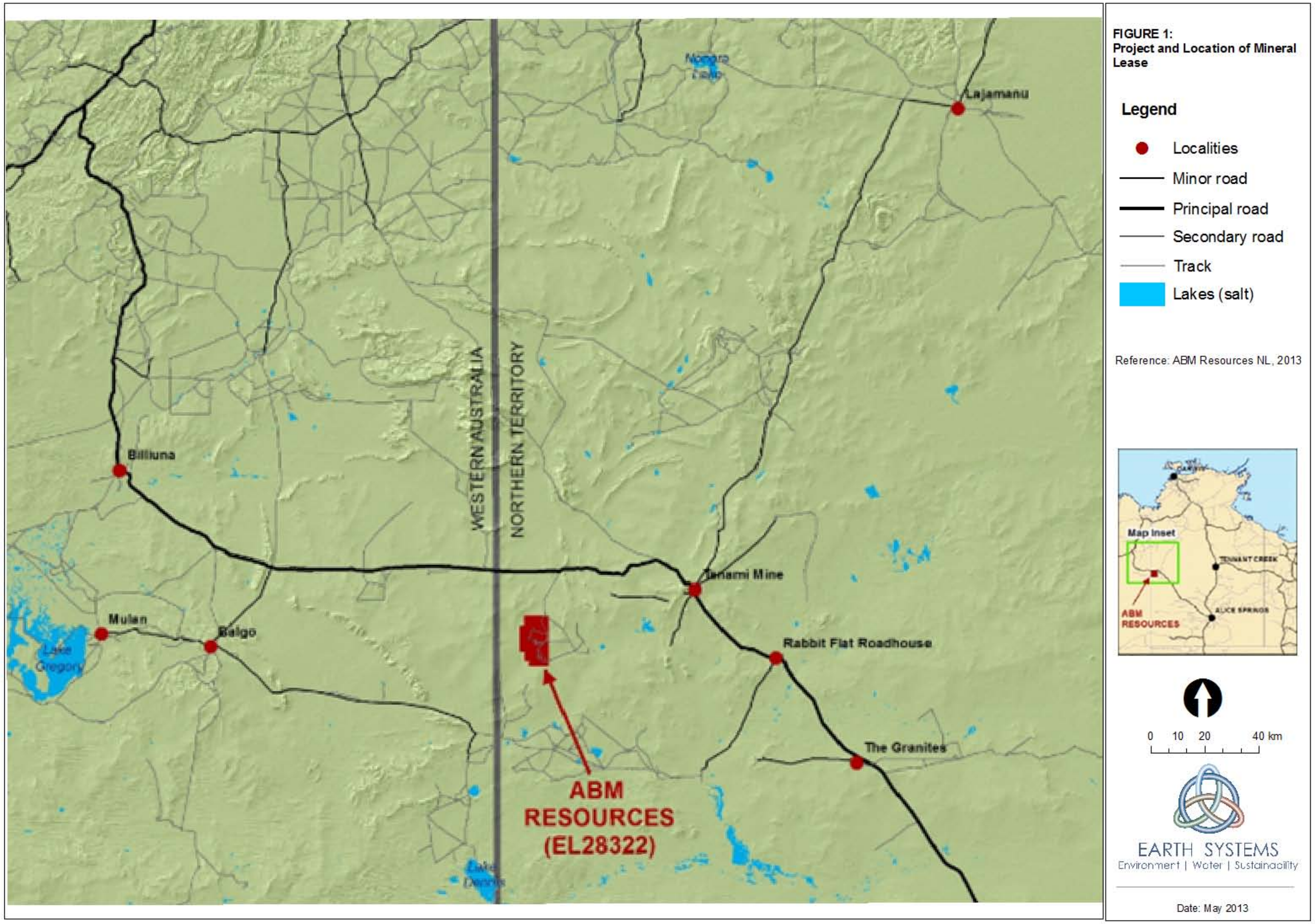

Figure 1: Project and Mineral Lease location map.

1.2. Environmental Setting

Traditional Owners and other users of groundwater

The EL28322 falls under Aboriginal Land and is held as inalienable freehold title under the Aboriginal Land Rights Act 1976 (ALRA 1976). Land within the vicinity of the Project area is understood to be managed by the Mt Frederick Aboriginal Land Trusts.

The Project area also lies within the Central Desert Shire which covers an area of approximately 282,089 km^2 and has a population of approximately 4,782 people. The Shire covers nine main communities or Shire Service Delivery Centres. None of these areas are located within the vicinity of the Mineral Lease and the closest centres are Lajamanu, Willowra, Yuendumu and Nyirripi which are located within a 250-400 km range from the Project. These centres are serviced by the Power and Water Corporation water supply system and also rely on groundwater resources. Outside of these centres, there are a few family outstations. Approximately 66 communities and 30 pastoral groups are located within the Central Desert Shire (Central Desert Shire online).

Other mining activity in the region includes Tanami Gold’s Coyote Gold Mine in Western Australia (10 km from the NT / WA border) and Newmont Mining Corporation’s Tanami Operations which consist of a largely fly in fly out work force. Tanami Gold also in the process of assessing the feasibility of re-opening the old Tanami and Groundrush mines.

There are several non-Aboriginal owned pastoral properties such as Supplejack, and Aboriginal owned cattle stations such as Tanami Downs. Closer to the Project area, there is a road house at Rabbit Flat providing basic supplies.

A list of registered bores within a 40 km radius of the Project area is provided in Appendix B.

Water dependent ecosystems

In terms of proximal sites of conservation significance, provisional classification of wetlands of regional significance in the Australian Natural Resources Atlas have been obtained for Lake Sarah, Lake Alec and Bullocks Head Lake. These lakes are slightly greater than 20 km south of the Old Pirate Project area. The assessment indicates that these lakes are classified as intermittent freshwater lakes (>8 ha) and are in “Good” condition but no data is available on threatening processes.

Drainage from the local area close to the Mineral Lease is ultimately understood to flow towards the south and Lake Mackay (200 km south of the Old Pirate Project area). Lake Mackay is a large saline lake straddling the border of Western Australia and the Northern Territory, has an area of 4737 km², being the fourth largest lake in Australia and is rated as having International Significance. The classification includes the main lake and associated outlying lakes and surrounding dune fields, lateritic plains and rises. Bare salt pans on the lake bed are fringed by samphire shrubland.

Inundation of the lake is episodic and results from substantial rainfall events. Although inundation is infrequent, the lake is relatively deep and can retain water for six months or more after flooding. There are no major marked drainage channels but surface and subsurface water flow from surrounding sand plains and sand dunes feed the lake.

There are two Indigenous Protected Areas (IPAs) within the region – the Northern Tanami IPA and the South West Tanami IPA, both of which are of international significance.

The South West Tanami IPA covers an area of 19,443 km^2 and is located approximately 50 km north east of the proposed operation. It is characterised by a mosaic of landforms and habitats that are distinct from the surrounding country and encompasses much of the extensive Central Tanami Desert palaeodrainage system. Other habitats include alluvial plains, dunefields, sandplains, rocky hills and rises, freshwater and saline lakes, and claypans. The IPA also encompasses ephemeral wetlands of regional significance such as Lake Ruth and Sanctuary Swamp, which are filled by runoff from surrounding rises, and the Tanami palaeodrainage system runs for some 50 km under the sandplain. The IPA is entirely Aboriginal freehold land and is held by five Aboriginal land trusts (Central Desert, Mangkururrpa, Yiningarra, Lake Mackay and Mt Frederick).

The Northern Tanami IPA covers an area of 40,000 km^2 and is located approximately 75 km east south east of the proposed operation. It encompasses a range of landscapes, from alluvial sandplains and broad palaeodrainage channels in the south to sandstone outcrops and laterite plateaus and black soil plains. Arid zone wetlands and ephemeral aquatic systems also form part of the area. It is managed by the Lajumanu community.

2. Objectives

The objective of this study is to conduct a desktop hydrogeological assessment to improve understanding of the groundwater systems in the Project area, for the purposes of identifying potential groundwater target areas, and to assist with the development of a sustainable groundwater utilisation strategy whilst fulfilling environmental permitting requirements.

3. Scope of Works

The scope of works is as follows:

- Review and collate existing geological, hydrogeological and water quality data.
- Use these data to develop a conceptual hydrogeological model for the Project area.
- Use the conceptual hydrogeological model to:
  - Provide an initial assessment of the aquifer recharge rates (palaeochannels and fractured bedrock).
  - Assess whether extraction from Timmy’s and Corsair Bores could be sustainable.
  - Identify target areas where there could potentially be sufficient groundwater to service the operation.
  - Provide strategic advice for future borehole locations and extraction rates if the current extraction strategy (use of existing bores) is unsustainable.
  - Devise a water quality and water level monitoring program for existing boreholes.
  - Confirm that Department of Mines and Energy (DME) requirements can be fulfilled.
- Prepare a report to be included in the Mining Management Plan (MMP).

4. Operational Water Requirements and Groundwater Extraction Regulation

4.1. Operational water requirements

Based on available data, the anticipated operational water requirements for the mine, mineral processing facilities, offices and village can be summarised as follows:

- Hourly extraction rate - 40m^3/h;
- Daily extraction rate - 960m^3/d;
- Annual extraction rate - 350,000 m^3/a.

These figures are equivalent to an average extraction rate of 11.1 L/s, which is considered the minimum requirement for Project water supply for the purposes of this assessment. No significant changes to extraction rates are anticipated during a 24 hour period and it is understood that extraction would be undertaken utilising a steady flow rate.

4.2. Groundwater extraction regulation

Mineral Titles Act 2012 and the Mining Management Act 2012

The Mineral Titles Act 2012 and the Mining Management Act 2012 are the principal pieces of legislation for the regulation of mining proposals in the Northern Territory. Both are administered by the Department of Mines and Energy (DME). The Mineral Titles Act 2012 operates in conjunction with the Mining Management Act 2012 to ensure the protection of the environment and the provision of economic and social benefits to communities affected by mining activities.

An application for an authorisation to carry out mining activities must be accompanied by a Mining Management Plan (MMP) and this must include consideration of water resources.

Water Act 2011

The Water Act 2011, as administered by the Water Resources Division of the Department of Land Resource Management, provides for the investigation, allocation, use, control, protection and management of surface water and groundwater resources, as well as the administrative process for licensing these activities.

Under the Water Act 2011, a groundwater extraction license is required anywhere in the Northern Territory if the bore is capable of pumping at a rate greater than 15 L/s, and the groundwater is used for one of the following purposes: agriculture, aquaculture, public water supply or industry. However, mining activities are exempt from requiring a groundwater extraction license.

Additionally, under the Water Act 2011, water bores constructed outside a Water Control District do not require a permit, however a mining proponent may be required to notify the Department of Health (pursuant to NT Public Health Act and NT Public Health Regulation), particularly if the water is to be used for potable supply.

Project specific considerations

Although extraction of water for mining purposes is exempt from obtaining a groundwater extraction license under the Water Act 2011, a number of comments regarding the Mine Management Plan (MMP) and water resource strategy were provided by DME on 23rd January 2013. This report addresses specific comments where applicable and where further work is required it sets out the way forward for addressing those comments.

Furthermore, consultation with the DME (*pers. comm*, April 2013) indicated a number of general recommendations for water bore construction and groundwater extraction in relation to mining projects:

- The MMP should include as much detail as possible regarding the proposed bore construction and groundwater extraction activities relating to the Project to enable the potential impacts to be assessed through the MMP;
- As a guide, it is recommended that the MMP include a similar level of information as the bore construction applications and groundwater extraction license applications under the Water Act 2011;
- DME will consult with the Water Resources Division when assessing the proposed groundwater resource use detailed in the MMP; and
- A National Water Initiative policy is currently being developed. This future policy should be considered when developing a water resource strategy, as regulatory requirements may change in the future.

The level of detail for an extraction license application to the Water Resources Division for non-mining operations includes (but is not limited to) the following information:

- Property and location details including a map showing location of existing or proposed bore(s), the location where the water is to be used, the method and route of conveying the water, and the lands in the immediate vicinity (ie. lot, portion, section, lease numbers, boundaries etc);
- Bore, pump and meter details (including location coordinates and copy of pump installation documentation and settings);
- Usage details including intended use, breakdown of expected usage and maximum amount;
- Waste water disposal management plan;
- Previous licenses;
- Property Development Plan noting separation distance between existing and proposed bores, contamination sources as well as hydraulic gradients);
- Meter type and pump numbers for license.

Much of this detail cannot be provided for the Old Pirate Project area at this stage, but as the Project progresses this information will be generated via ongoing assessment.

Section 84 of the Minerals Titles Act 2012 provides for right to enter and use land outside title area. The Act requires prior consent from the landowner and an application for an Access Authority. Such consent would be required for any bore installation works outside of the Mineral Lease and will be considered in relation to access to target areas.

For non-mining activities, a permit to construct a bore is granted subject to any other law that might affect the location or operation of a bore. In all cases there is a need to consider whether construction or operation of the proposed bore might result in other penalties or liabilities (eg. Northern Territory Aboriginal Sacred Sites Act). Finally, if the activity requires a license, water bore drilling needs to be undertaken by an NT licenced driller in accordance with the *Minimum Construction Requirements for Water Bores in Australia 2012* (3rd Edition) [1] (National Uniform Drillers Licensing Committee, 2011). It is recommended therefore that water supply bore drilling for the Old Pirate Project should also consider the adoption of such assessment and practices.

5. Geology

5.1. Surficial geology

In the absence of site specific data, the following description of the surficial geology within the Tanami region has been summarised predominantly from Magee (2009).

Ferricrete-capped deep weathering profiles are incised into deeply weathered Proterozoic to Mesozoic bedrock, indicating incision of an extensive perennial river network during previous wetter climates. Cenozoic surficial deposits of aeolian sand, alluvial sand/silt/clay, gravel, calcrete, silcrete and minor evaporite are widespread and form relatively thick sequences in the Cenozoic-filled palaeodrainage network.

The Cenozoic palaeodrainage system in the Tanami Region forms a network of topographic depressions with broad trunk palaeochannels and narrow higher-order palaeochannels, with evidence for significant tectonic disruption and diversion. Domahidy (1990) identified two large Cenozoic palaeochannels (hereafter referred to as palaeochannels) in the region, one west-trending and the other south-trending, which converge between Rabbit Flat and Tanami Downs and then head southwards towards Lake Mackay, incorporating additional tributaries on the way. Detailed mapping by Wilford (2000) identified and delineated an extensive and higher-order palaeodrainage network using surface flow modelling. These palaeochannels have been interpreted by Bell *et al* (2012) and the published regional map is presented in Appendix A.

The location of the main palaeochannels is shown in Figure 2. Local to the Old Pirate Project area, two main channels are present, Tanami and Nora.

Figure 3 shows the location of the present day alluvial sediments plotted within the surficial geology and Figure 4 shows the DEM data plotted with the palaeochannels. In the vicinity of the Project area, the surficial geology associated with the palaeochannel tributaries can be broadly correlated to the Digital Elevation Model (DEM) across the catchment (refer to Figures 3 and 4). The DEM in Figure 4 shows areas of bedrock (in red) at a relatively high elevation above the surficial alluvial deposits and present day alluvial channels at lower elevations (shown in blue). There is only several metres height difference across the Project area.

Locally, the Recent alluvium is seen to be generally coincident with the palaeochannels (Figure 3) and as such there is a broad, although not exact, correlation with present day surface water (flood) channels. Indeed, some areas of low elevation to the south of the Mineral Lease (shown in blue in Figure 4) are not interpreted as palaeochannels.

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[1] http://www.nrm.qld.gov.au/water/management/pdf/minimum-const-req.pdf

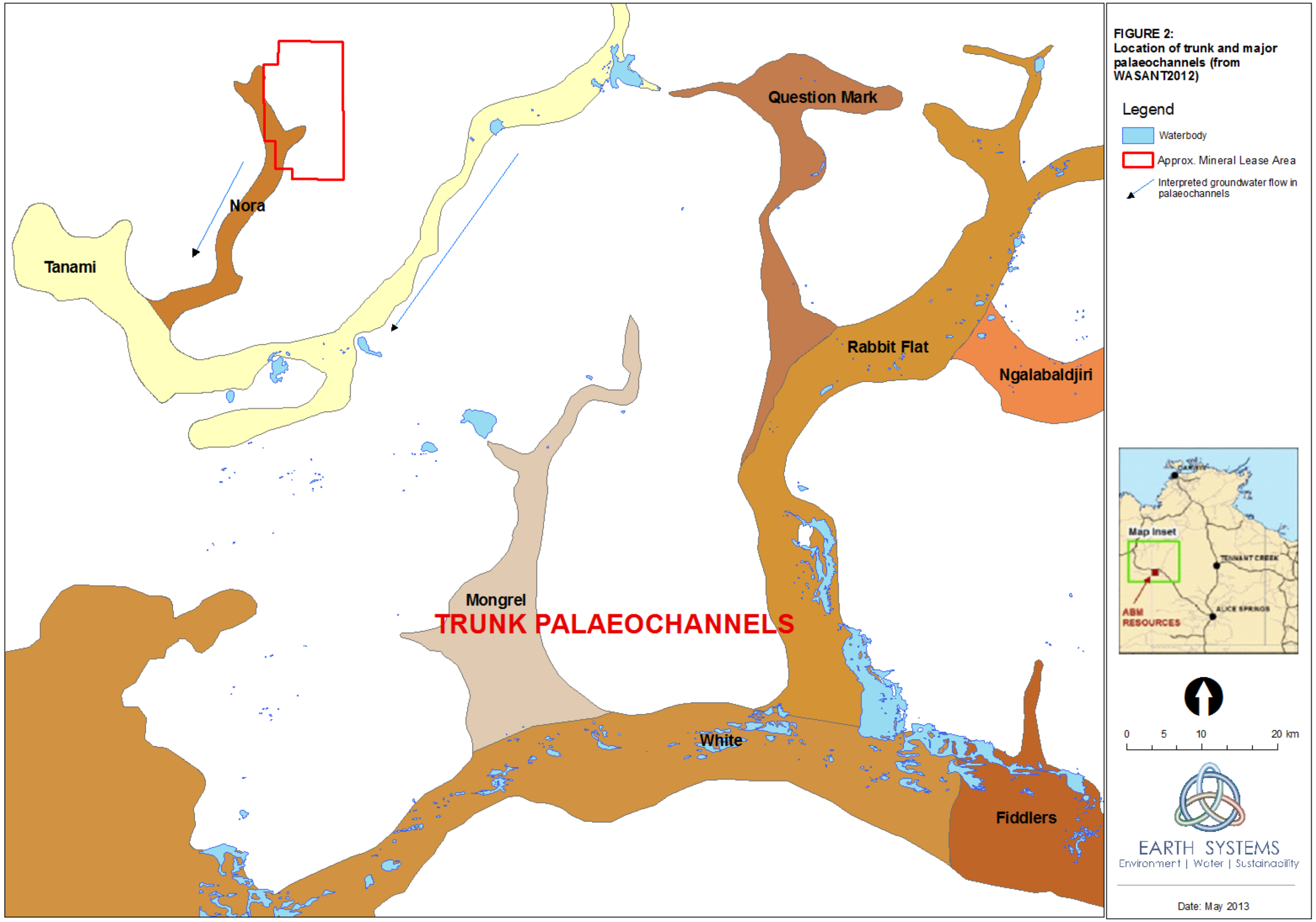

Figure 2: Location of trunk and major palaeochannels in bedrock. In accordance with DME requirements (23rd January 2013), the palaeochannel data used in this assessment was published by Geoscience Australia in GIS format from the Distribution of Palaeovalleys in Arid and Semi-arid WA-SA-NT mapping as WASANT Palaeovalleys 2012 (Bell *et al*, 2012) and represents a compilation of relevant published and unpublished work.

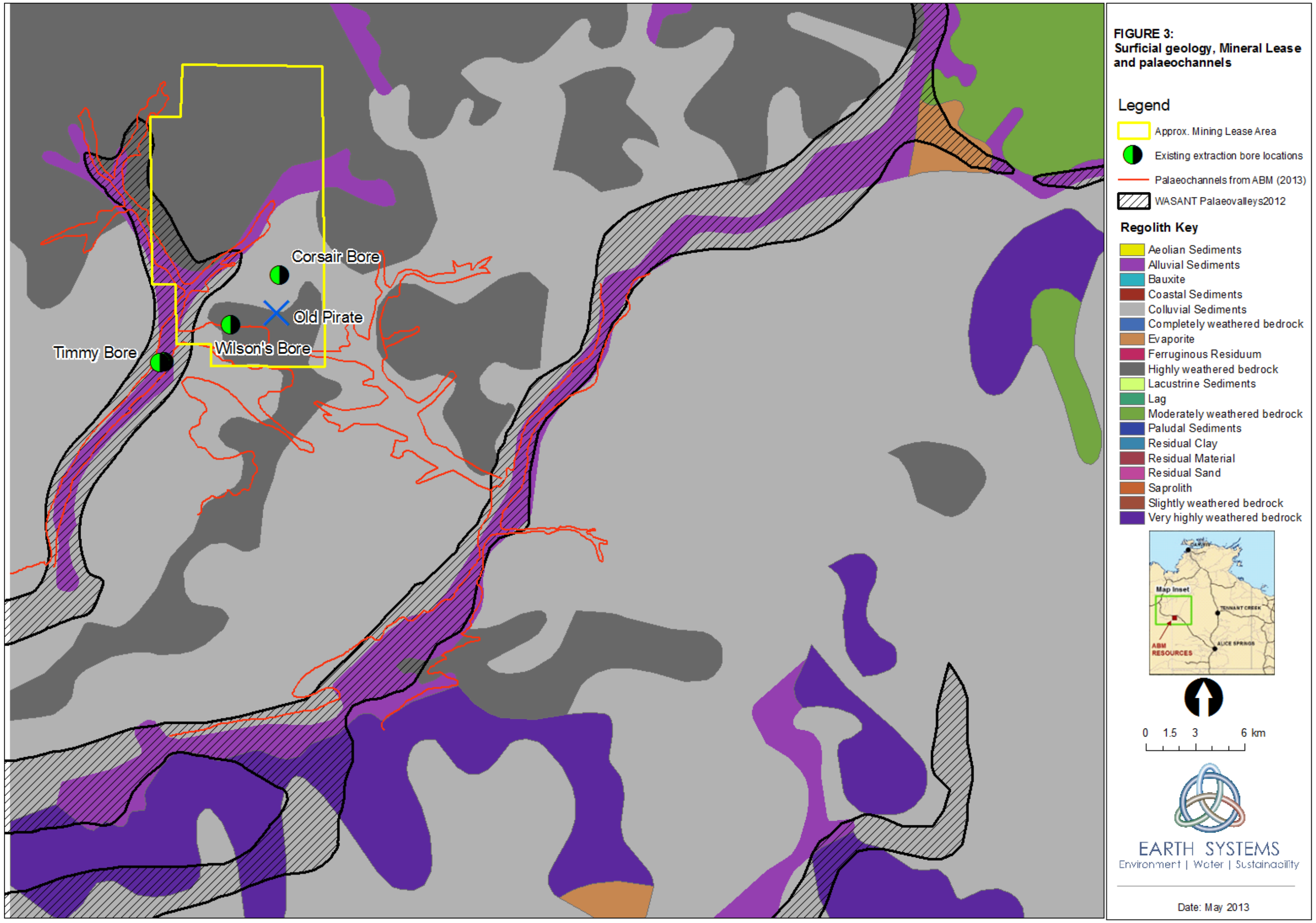

Figure 3: Surficial geology, Mineral Lease and major palaeochannels.

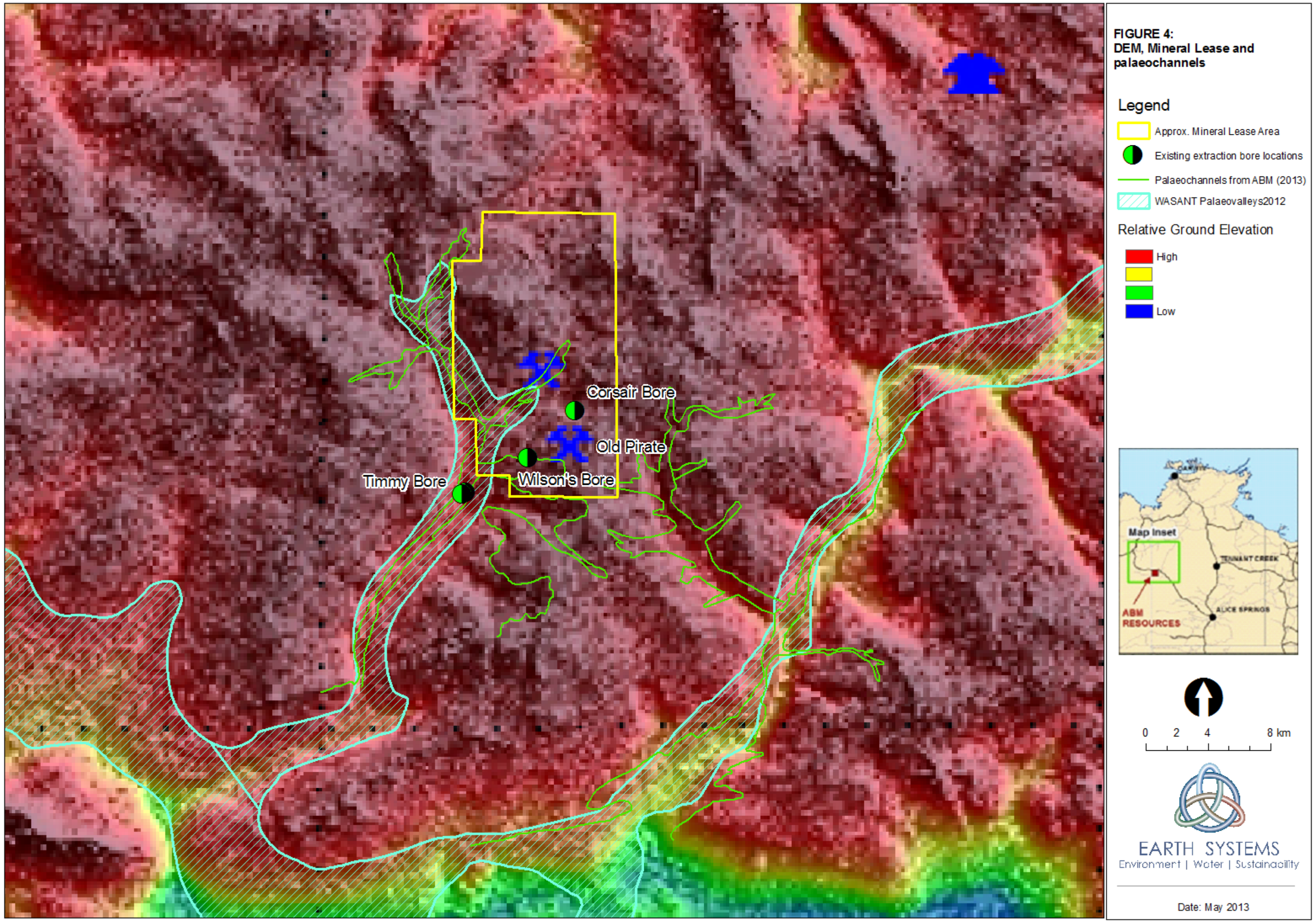

Figure 4: DEM, Mineral Lease and palaeochannels.

Airborne Radiometric Survey data (showing the distribution of naturally occurring uranium, thorium and potassium) has been used in conjunction with the DEM to assist in the detailed mapping of surficial geology. Variations in these radioactive elements assist with mapping the distribution of specific minerals across the catchment and as such can clarify the location of palaeochannels. The thorium (Th) and potassium (K) channels have proven most useful. For example, elevated thorium responses in the Proterozoic bedrock, possibly associated with monazite, provide a stark contrast with the thorium depleted palaeochannels (refer to Figure 5). Elevated potassium responses from phases such as illite (refer to Figure 6) also help to define the palaeochannels, although this is less obvious.

A composite radiometric and DEM plot with the interpreted palaeochannels is shown in Figure 7. This figure shows that the interpreted channels are generally coincident with the areas of darker colours (reds and purple) within the plots, although there is variable geological fill within the surficial parts of the channels as demonstrated by contrasts in the radiometric data.

Trunk palaeochannels contain unconsolidated alluvial clay and silt with common intercalated fine- to coarse-grained sand and gravel and various chemical precipitate deposits such as calcrete and silcrete. The course of these channels is often marked by sporadic, mostly round, salt and clay pans, which contain thin crusts of gypsum and other salts. Drilling has shown that up to 90 metres of infill sediment has been deposited in trunk palaeochannels near Tanami Downs Homestead and in the Tanami Mine borefield, although both the full and hydrogeologically effective depth will be variable (Bell *et al,* 2012).

The narrower higher-order palaeochannels within the upper catchment consist mostly of alluvial and colluvial material and are covered by sheet flood fan colluvium with little surface expression of the underlying palaeochannels (Wilford, 2000).

Secondary chemical precipitate and playa lacustrine deposits formed after palaeochannel infill and occlusion of surface flow. Massive and tabular calcrete is common throughout the region and is preferentially developed towards the centre of the main palaeochannel systems.

Calcrete deposits have formed by cementation and accumulation of carbonate, principally within the phreatic zone, and by surface sheet flow and subsurface groundwater flow. Precipitation of secondary calcite, as calcrete, displaces primary sediments and results in upward growth of low hummocky outcrops formed of white to pale grey inorganic calcrete, with sand grains and rock fragments common in the secondary cement. Mounded calcrete bodies are typically elevated several metres above the surface of the surrounding palaeochannels. Partial or complete replacement of basal calcrete by silcrete is also common (Domahidy, 1990; Wilford, 2000).

The thickness of calcrete deposits averages 12–15 metres (maximum of 18 metres of calcrete at Tanami Downs) and most are underlain and flanked by alluvial clay, sand and gravel. Calcrete also occurs widely in the subsurface.

A combination of DEM and Radiometric data therefore provides a reasonable basis for establishing the general location of palaeochannels beneath more recent surficial cover.

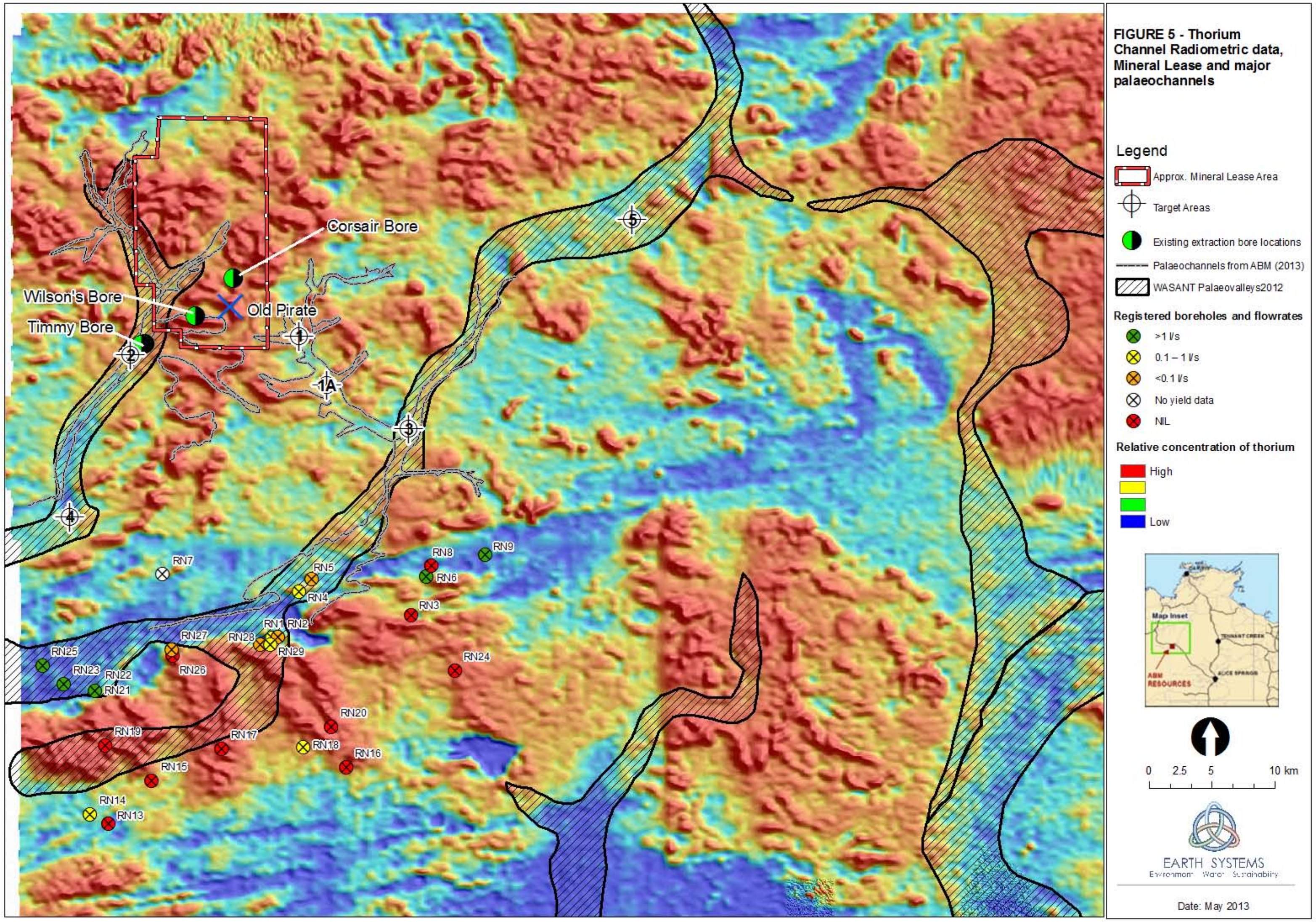

Figure 5: Thorium Channel Radiometric data, Mineral Lease and major palaeochannels.

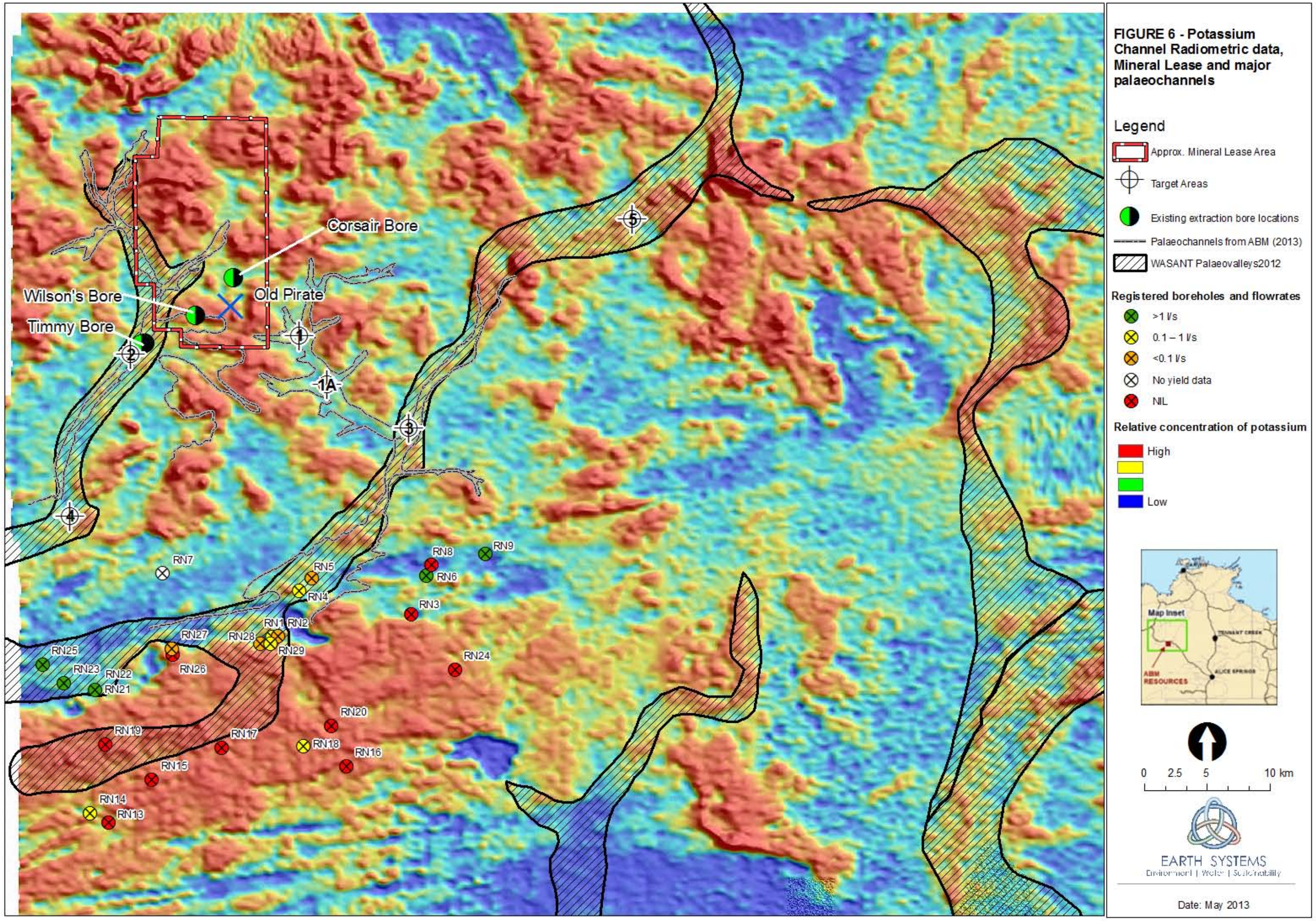

Figure 6: Potassium Channel Radiometric data, Mineral Lease and major palaeochannels.

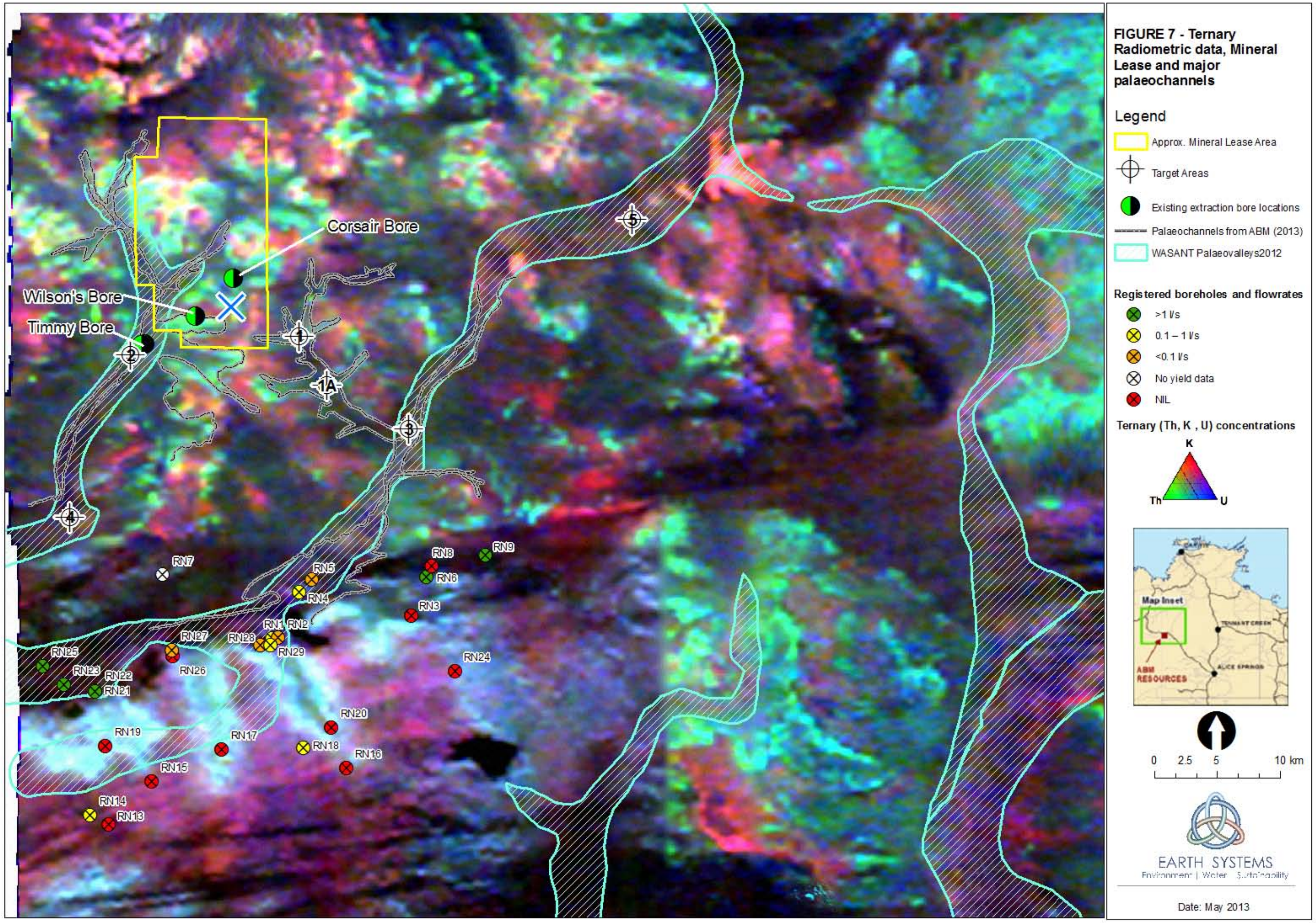

Figure 7: Ternary Radiometric data, Mineral Lease and major palaeochannels.

5.2. Bedrock geology

The Granite-Tanami Orogen (GTO) includes the Tanami Supergroup, Ware Group and associated intrusive rocks. Younger Meso- to Neoproterozoic cover sediments overlie the GTO. Archean basement to the GTO does not occur in the Project area. The bedrock geology is outlined in Figure 8.

The Tanami Supergroup is divided into the Dead Bullock Group and the Killi Killi Formation which are regionally overlain unconformably by the Ware Group and Mount Charles Formation. The Dead Bullock Group is a shale-dominated turbidite succession, occasionally iron-rich with minor chert beds (Bagas *et al*, in prep; Crispe *et al*., 2007). The Dead Bullock Group exceeds 1 km in thickness. The upper Dead Bullock Group becomes sandier as it transitions into the Killi Killi Formation. The Killi Killi Formation (approximately 4 km thick) is a sand-dominated turbidite succession with thinly- to thickly-interbedded, sandstones, siltstones and claystones. Some thicker siltstones/claystones (mega-shales) and amalgamated coarse channel sands, average 15 m. Dolerite sills and dykes commonly intrude the Upper Dead Bullock Group and Killi Killi Formations.

The Mineral Lease is almost exclusively on deep marine turbiditic sediments of the Killi Killi Formation which are locally intruded by the Buccaneer Monzogranite. Locally, the Killi Killi Formation consists of interbedded sandstones and shales with rare chert. In the Old Pirate area, the turbidites comprise interbedded coarse and fine grained sands with shales plus occasional thick amalgamated very coarse grained channel sands (averaging 15m in thickness) and thick shale rich successions (mega-shales). Dolerite sills and dykes commonly intrude the Upper Dead Bullock Group and Killi Killi Formations and a diorite sill is understood to be present at depth beneath the Old Pirate Project area.

The Old Pirate Project area the sediments have been folded into a broad southerly plunging anticline, which locally bifurcates.

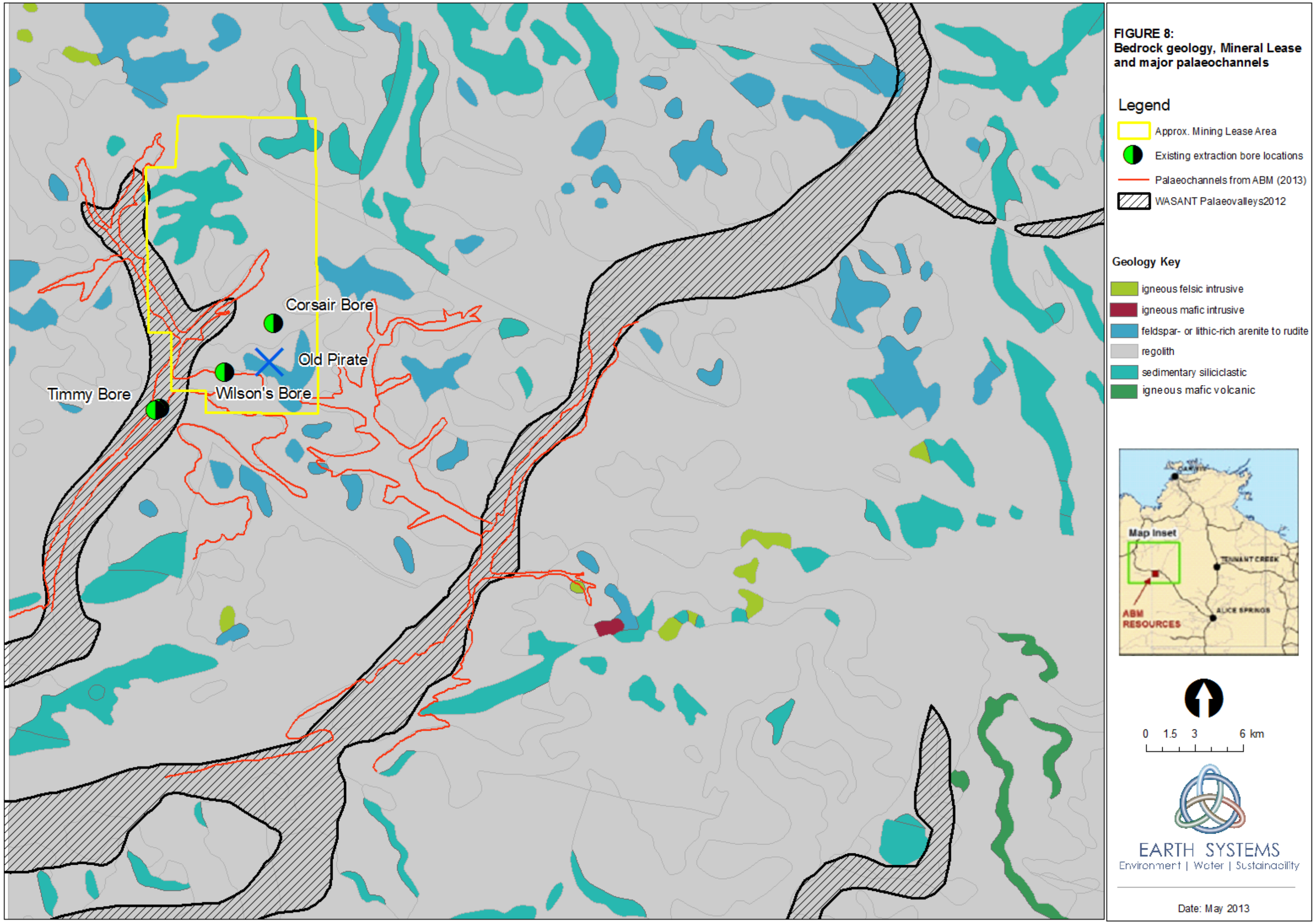

Figure 8: Bedrock geology, Mineral Lease and major palaeochannels.

6. Climate

The Tanami region has a typical Northern Australian hot semi-arid climate with hot summers where temperatures can reach in excess of 40°C. Winters are generally relatively mild although nights are cold with very occasional overnight minimum temperatures below 0°C.

Local data has been determined from the closest weather station located at Rabbit Flat (Australian Bureau of Meteorology station number 015548), approximately 90km to the east, where the following statistics have been determined based on averages between 1969 and 1998 (when the weather station was closed):

- Average annual rainfall is 430 mm.
- Average annual pan evaporation is approximately 2,775 mm (based on 7.6mm/d).
- Average annual maximum temperature is 33.6°C
- Average annual minimum temperature is 16.4°C.

Most of the average annual rainfall falls during a ‘wet season’ between November and April. Average pan evaporation for the region is between 2400 and 2800mm per annum (ABM, 2013), far exceeding the average annual rainfall of 430 mm.

Domahidy (1990) noted that between 1970 and 1990 Rabbit Flat recorded 50 mm of rainfall in 48 hours between one and five times per year, and 50 mm of rainfall in 24 hours between one and three times per year.

Table 6.1 summarises monthly averages for rainfall, evaporation and maximum and minimum temperatures.

Table 6.1: Climatic statistics – Rabbit Flat (mean figures for the period 1969-1998).

Month	Mean rainfall (mm)	Mean daily evaporation (mm)	Mean max daily temperature (°C)	Mean mini daily temperature (°C)
Jan	100	9.7	38.5	23.6
Feb	110.4	8.6	37.3	23.1
Mar	43	8.1	36.1	20.7
Apr	21.3	6.9	33	16.4
May	14	5.2	28.9	12.2
Jun	11.2	4.4	26	8.3
Jul	9.2	4.6	25.9	6.6
Aug	3.4	6.1	29.2	9.3
Sep	9.9	7.9	33.2	13.5
Oct	17.1	9.7	36.9	18.1
Nov	32.4	10.3	38.6	21.5
Dec	58	10.2	39.2	23.3
Average	**35.8**	**7.6**	**33.6**	**16.4**
Total	**430**	**92**	**403**	**197**

7. Surface water

No permanent surface water courses are present in the vicinity of the Old Pirate Project area but some ephemeral creeks and lakes occur over parts of the Project area. Surface water in these can persist for up to several months following heavy rainfall events. In general, the ephemeral channels are located above or in close proximity to the palaeochannels.

No data on surface water flow rates or locations has been obtained as part of this study.

Where there is topographic relief, these seasonal creeks typically drain into lowland lacustrine systems. In low relief sand plain country surface flooding often occurs following heavy rain. This sometimes forms floodways along low lying drainage channels which drain towards ephemeral lacustrine systems. Elsewhere, surface water either evaporates or recharges groundwater.

Lake Sarah, Lake Alec and Bullocks Head Lake are located just over 20 km to the south of the Old Pirate Project. The Lake Mackay system is the largest in the region, but is some 200 km south of the Old Pirate Project area. Other small unnamed lakes are also present to the east of the Project area.

8. Hydrogeology

8.1. Aquifer properties and yields

The general aquifer properties of the main surficial and bedrock lithologies identified in Section 5 are defined in Table 8.1.

Table 8.1: General aquifer properties.

Aquifer	Geology (See also Section 6)	Flow mechanism	Depth of sequence (m)	Relative Water Level
Calcrete and silcrete	Secondary chemical precipitates	Fracture flow –solution enhanced	At top of palaeochannel sequence up to 18m thick	Shallow - close to ground level
Palaeochannels	Tertiary to Recent Alluvial sediments	Intergranular	Up to 90m in main channels including sand and gravel, as well as clay and silt	Shallow - close to ground level
Bedrock – Tanami Group	Cemented metamorphosed sedimentary parent bedrock	Fracture flow – fractured and weathered bedrock	>150m	Deep within the bedrock but may be shallow in some locations

The alluvial aquifers (palaeochannel and associated deposits) are considered to be unconfined, whilst the bedrock is unconfined to semi-confined. This is based on a consideration of the hydrogeological setting and the data presented in Table 8.2.

Table 8.2: Aquifer yields and hydrogeological data – summary from Domadihy (1990).

Aquifer	Average borehole yield (L/s)	Maximum borehole yield (L/s)	Average borehole Depth (m)	Transmissivity (m^2/d)	Storage	Notes
Calcrete	2-10	20	25	406-5800	0.01-0.1 (estimated)	No figures for silcrete available. Assumed to be hydraulically connected to alluvium where present.
Palaeochannel alluvium	2	5	84	47-70	0.1-0.3 (estimated)	Yields from sand and gravel – channels are clay and silt rich. Assumed to be hydraulically connected to alluvium. A saturated thickness of 20m is assumed.
Bedrock - Mount Charles Formation	1.75	2	74	5-20	1.3×10^{-3}	Assumed as an estimation for the Dead Bullock Group and the Killi Killi Formation in absence of specific data for these formations.

No site specific aquifer properties have been obtained for the Dead Bullock Group or Killi Killi Formation of the Tanami Group, but data is available for the Mount Charles Formation which outcrops to the east of the Project area (as shown in Table 8.2). There are some similarities between the geology of the principal geological Groups and as such the properties of the Mount Charles Formation are considered to be broadly representative of the properties of the Tanami Group. Domadihy (1990) reports transmissivities of between 5 and $20m^2/d$ in the Mount Charles Formation. Groundwater flow in the bedrock is generally fracture-flow dominated. Transmissivities in the alluvial coarse sand and gravel are reported as being between 47 and $70m^2/d$ with dominant intergranular flow.

Storage coefficients for bedrock are low, reported as being less than 1.3×10^{-3} (Domadihy, 1990). Storage coefficients for the alluvials have not been obtained as there is insufficient data available. However, values of between 0.1 and 0.3 are considered to be reasonable based on experience.

Within the calcrete deposits the development of extensive fissures and cavities creates high permeability zones which are conducive to relatively high transmissivity values and low storage coefficients for aquifers. Calcrete outcrops in the region are up to 6 km wide and may extend up to 35 km down-valley, but these are likely to be even more extensive beneath near surface surficial alluvium and aeolian sand. Transmissivity values for calcrete and silcrete range from 406 to $5800m^2/d$. Storage coefficients have not been calculated, but a bulk value of between 0.01 and 0.1 could be expected.

Yields for boreholes installed in bedrock taken from literature sources (Domadihy, 1990) are generally low (between 1 and 2 L/s for the Mount Charles Formation).

Details of registered boreholes within 40 km of the Mineral Lease including water strike, level and yield are provided in Appendix B. Locations of these boreholes are shown in Figure 9.

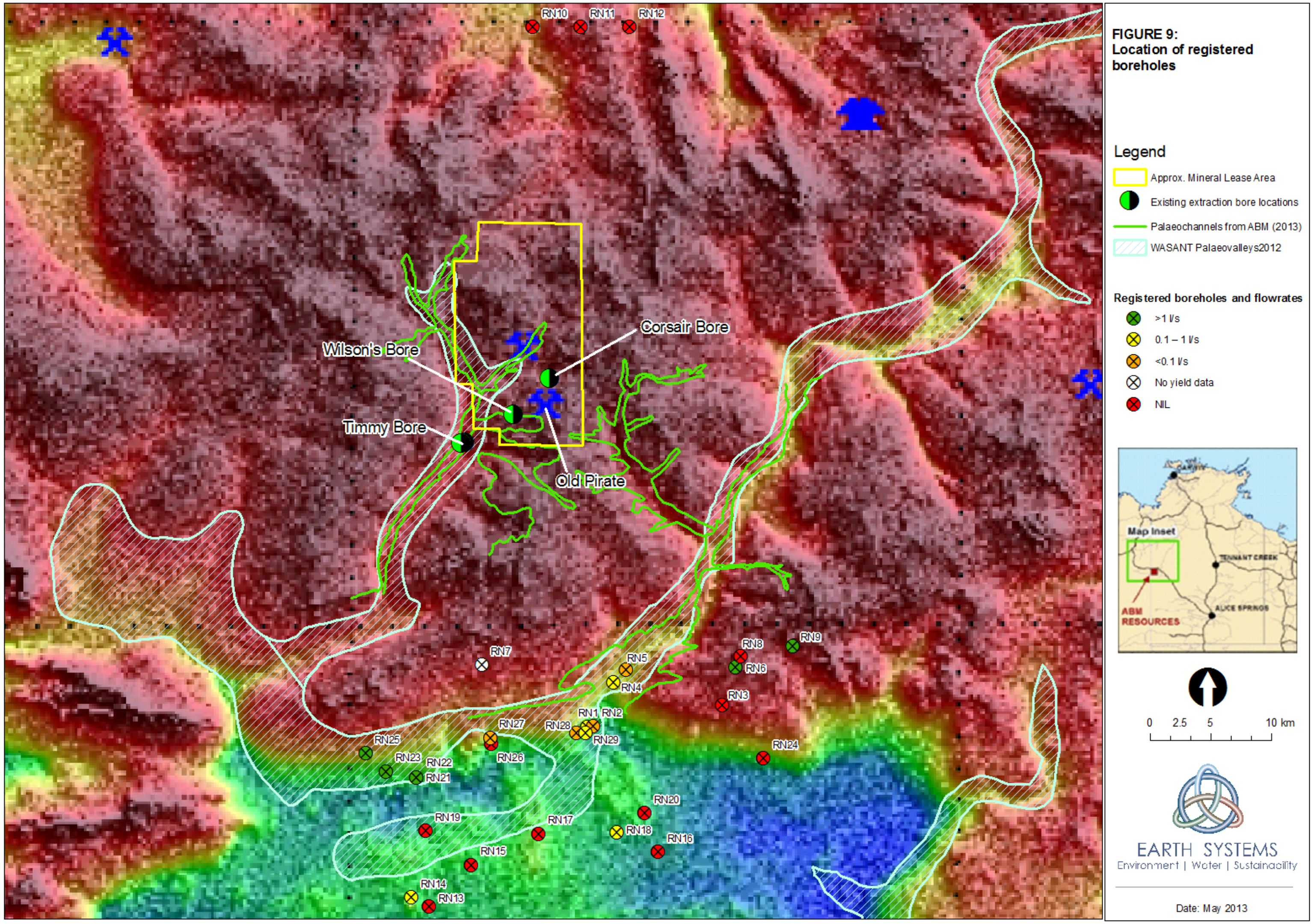

Figure 9: Location of registered boreholes.

The available hydrogeological data for these sites suggest that yields are generally very low (<1 L/s) in the bedrock and that these boreholes can often be dry. It should be noted, however, that the screened zone of the boreholes only just intersects the water table, and this will retard yield by limiting drawdown.

Higher yields have been identified in bedrock within the Project area (Corsair Bore) but the long term trend in water levels and hence estimation of the sustainability of extraction from this aquifer has yet to determined. Furthermore, Wilsons Bore, which is potentially installed in a bedrock aquifer, is understood to have dried up after 2.5 years of abstraction. Low storage capacity, when combined with low potential recharge (see Section 8.4) could limit the sustainable yield of water extracted from the bedrock.

Domadihy (1990) concluded that the palaeodrainage or palaeochannel deposits are major aquifers capable of providing good yields. Alluvial channels forming aquifers containing unconsolidated sand and gravel within the Tanami mine borefield are considered to be capable of delivering borehole yields of up to 5 L/s. Where calcrete and silcrete are present, yields could potentially be increased.

Locally, Timmy's Bore is understood to be capable of producing up to 2 L/s but this borehole recently collapsed and this yield cannot be confirmed.

Data for Registered boreholes shows that there are significant differences between yields in bedrock and palaeochannels. Whilst there are two boreholes installed in bedrock which have produced yields in excess of 1 L/s, the majority are either dry holes or have lower yields. Conversely, none of the boreholes located in palaeochannels are recorded as dry and in general these register yields.

It should be noted that a number of the boreholes have been installed only just below the strike water level in each borehole. This will restrict the performance of these boreholes and the available pumping rate due to the small operating head in the borehole. As such, the achievable yield from palaeochannels may be greater than that recorded from existing boreholes.

English *et al* (2012) commented that developing accurate estimates of groundwater yields in individual palaeochannel aquifers is challenging due to the complexity and variability of palaeochannel dimensions and sediment infill.

8.2. Groundwater levels

Groundwater levels locally within the bedrock aquifer have been recorded from exploration boreholes in the Project area, and are estimated to be generally between 90–150 m below ground level (mbgl), averaging approximately 100 mbgl (ABM, 2013). Other published borehole data from the Northern Territory Government suggests that groundwater levels in bedrock are significantly shallower than this. Data from registered boreholes in Appendix B suggests groundwater strikes between 21 and 67 mbgl in bedrock.

Magee (2009) suggests that in palaeochannel calcrete aquifers, the saturated thickness is slightly less than the total calcrete thickness, with water level being generally 3–6 m below the surface (in comparison, water levels in alluvium were estimated at 5-10 mbgl). The saturated thickness in calcrete / silcrete aquifers averages 7 m in the Tanami mine borefield and 15 m in the Billabong borefield. Where calcrete / silcrete is present, a hydraulic connection between this and alluvium in the palaeochannels can be inferred from the groundwater levels.

Limited details are available for boreholes currently servicing exploration operations across the Mineral Lease (Timmy's, Corsair and Wilsons). Some groundwater level data are available, but only limited details of borehole construction or drawdown are known and the reliability of these groundwater levels is therefore uncertain. Table 8.3 summarises the available groundwater level data for these boreholes.

The groundwater level data in Table 8.3 suggests that groundwater in bedrock is below the palaeochannel groundwater levels indicating that locally, there is no significant connection between groundwater in the palaeochannels and the bedrock aquifers. Shallower groundwater levels in bedrock within a 40 km radius of the Mineral Lease suggest that there may however be variability in the hydraulic connectivity between palaeochannels and bedrock.

Table 8.3: Water levels and depths for current and former extraction boreholes.

Bore	Easting*	Northing*	Elevation (mAHD)	Geology	Depth - Current & (Drilled)	Water Level (mbgl) – April 2013	Notes
Timmy's Bore	509507	7764901	424	Palaeochannel –Tertiary silcrete and alluvium. Clays below 25m to depth of hole.	10m – borehole collapsed. (42m).	5.8	Borehole is registered (RN016568). Data has been taken from borehole sheet. Yield understood to be 2 L/s. Reasonable water quality. Borehole was 34.7m deep in earlier assessment. Also known as Strezza's Bore.
Corsair Bore	516550	7770180	438	Fractured bedrock – interbedded sand and siltstone	150m (150m)	95	Drilled in 2010 near high yielding exploration borehole. Yield understood to be 2-3 L/s (possibly up to 4 L/s) but sustainability of this is unknown. Previous water level recorded as 110 mbgl.
Wilsons Bore	513529	7767170	430	Unknown but potentially bedrock	92m (unknown)	40.4	Used for 2.5 years until 2012 when it is understood to have run dry. Yielded up to 4L/s. Groundwater currently in borehole.

8.3. Groundwater flows

Groundwater flows in the palaeochannels are anticipated to be generally parallel to the channel alignment. Although there is no water level data available to confirm flow directions or groundwater gradients in the palaeochannels, historical drainage has been interpreted to be towards the south and west and Lake Mackay. Based on knowledge of the current topography, groundwater flow is considered to be primarily in the same direction as these historic flows.

For the purpose of this preliminary assessment, groundwater flow in the palaeochannels is therefore considered to primarily to the south and south west. Local variations in groundwater flow directions may exist, but confirmation of this would require additional monitoring boreholes and additional time series data. Groundwater gradients in palaeochannels are anticipated to be relatively shallow but again no specific data is available to corroborate this.

Groundwater flow directions within the bedrock aquifer are also unknown but are anticipated to be generally towards the south and west, corresponding with the flow direction in the palaeochannels.

8.4. Groundwater recharge

Groundwater recharge to an aquifer occurs primarily through rainfall infiltration, surface water leakage and groundwater throughflow from adjacent aquifers. The sustainability of extraction for any given target area or target palaeochannel catchment would be proportional to the size of the catchment and the extraction volume versus recharge rate. Hence, the volume of recharge and the catchment area are both important considerations in the identification of groundwater resources for the Project, and evaluation of their sustainability.

Since rainfall across the region is low and evaporation and evapotranspiration are high, recharge of bedrock and unconsolidated aquifers only occurs significantly during high rainfall events. In addition, surface flow also only occurs during such events. In general, recharge only occurs following rainfall events of greater than 50 mm in 24-48 hours (English *et al,* 2012), such as those associated with cyclonic events. Based on estimates from similar terrain at Wiluna in Western Australia (Chapman 1962), rainfall intensity of >50 millimetres in 48 hours is required to induce general runoff and recharge.

Good recharge conditions in the Tanami region can be assumed to occur during these events (the frequency of high rainfall events was discussed in Section 6).

Only minor recharge of surficial palaeochannel or bedrock aquifers is likely to occur from surface water bodies, largely due to their transient nature.

Magee (2009) summarises potential rates of recharge from a number of studies, as follows:

- Domahidy (1990) calculated a recharge rate of 4.5 mm/year. This figure was supported by other recharge studies undertaken by Sanders (1972) at Wiluna, where 5% of high-intensity rainfall events (equal to 1% of average annual rainfall) recharge calcrete aquifers.
- In contrast to the optimistic recharge calculations of Domahidy (1990), Cresswell *et al*. (1999) derived more conservative recharge estimates for groundwater in a palaeodrainage tributary to Lake Mackay. This palaeochannel tributary is in a more arid climate than Rabbit Flat, with an average annual rainfall <250 mm, and an average annual evaporation of >3,000 mm. The recharge rate was estimated to be <1 mm/year suggesting that there has been no effective recharge to the aquifer in recent times. However, groundwater quality data from Timmy's Bore would suggest that some modern recharge may be occurring.

No new data were found during this assessment and no data has been obtained for the area immediately adjacent to the Mineral Lease. A figure of 4.5 mm/year or 1% of the total annual average rainfall was therefore considered to be a reasonable estimate of recharge to the palaeochannels for the purposes of this assessment, based on the results summarised above. Estimates of groundwater recharge to the bedrock aquifer have not been determined but may be slightly lower.

Discharge from palaeochannel aquifers is generally very low and residence times are up to 20,000 years within the Thalweg (in this instance defined as the deepest part of the channel) as reported by English *et al* (2012). Outflow must therefore be slow and hence evapotranspiration may play a part in maintaining groundwater levels in the aquifer. Surface discharge from bedrock aquifers is considered to be similarly low.

8.5. Conceptual Hydrogeological Model

A conceptual hydrogeological model has been developed based on the geological and hydrogeological setting. This is summarised below.

- The Mineral Lease is almost exclusively located on a bedrock sequence of Proterozoic metasediments punctuated by the Buccaneer Monzogranite.
- Deep Mesozoic palaeochannels are incised into the bedrock and are filled with alluvial sedimentary deposits including sands and gravels, clays and silts. Secondary calcrete and silcrete deposits are present in places within the channels.
- Palaeochannels could be up to 5 or 6 km wide and up to 90 m thick, but local boreholes (Timmy's Bore) are shallower and only confirm depths up to 40 m.
- Surface water flow only occurs after periods of intense rainfall (>50 mm in 24-48 hours) but can persist for several weeks or months. There is no permanent surface water flow.
- Groundwater recharge to palaeochannel aquifers occurs primarily as a result of infiltration following periods of heavy rainfall. Rainfall levels across the region are low and evaporation and evapotranspiration rates are high. Rainfall intensity of >50 mm in 24-48 hours is required to induce recharge. A total annual average of 4.5 mm/year or 1% of rainfall is considered to be a reasonable estimate of recharge to palaeochannels (and potentially bedrock).
- Groundwater flow in palaeochannels is intergranular whilst in calcrete and silcrete this is predominantly fracture flow. Fracture flow dominates in bedrock.
- Groundwater resources are currently understood to be present locally at shallow depths in palaeochannel aquifers (approx. 5mbgl) and at depth in the bedrock aquifer (>90 mbgl).
- There is likely to be a hydraulic connection between calcrete, silcrete and alluvium in the palaeochannels.
- Higher groundwater levels in the palaeochannel aquifers relative to the bedrock aquifers indicate that, within the Project area, there is likely to be poor hydraulic connection between these aquifers[2]. However, shallower bedrock water levels have been recorded within 40 km of the Project area and this suggests that at some locations there is potential for a good hydraulic connection to exist. Groundwater recharge to bedrock aquifers is possible via percolation from palaeochannel aquifers.
- Where a hydraulic connection exists between the palaeochannel and bedrock aquifers, the potential groundwater resource will be greater than that considered here, since there could be some flow from the bedrock aquifer to palaeochannels during extraction for Project water supply.
- Proximal to the Old Pirate Project area, groundwater yields from bedrock boreholes are estimated to be potentially up to 4 L/s and of the order of 2 L/s from palaeochannels, but these values may not be indicative of regional yields. Water level drawdowns and the long term sustainability at these stated flows are currently unknown.

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[2] The groundwater level data also supports the assumption above that recharge to the palaeochannels occurs primarily through rainfall infiltration.

9. Water Quality

9.1. Surface water

No surface water quality data has been obtained for surface water courses within the vicinity of the Old Pirate Project area.

9.2. Groundwater

Groundwater quality data can assist in understanding the nature of recharge to bedrock and surficial aquifers. For example, low salinity groundwater (as indicated by low total dissolved solids, TDS) may correspond to areas of active recharge (particularly within the shallow surficial deposits) whereas high salinity (high TDS) groundwater may be indicative of low recharge and throughflow (long residence times). An understanding of groundwater quality is also relevant to assessing the feasibility of any groundwater resource for Project water supply and the potential requirement for treatment prior to on site use.

Limited groundwater quality data are available for both bedrock and palaeochannel aquifers in the vicinity of the Project area. Available groundwater quality data has been compiled from:

- Published water quality data for palaeochannels in the Tanami area (Magee, 2009).
- Data from Northern Territory registered boreholes within a 40 km radius of the Project area (refer to borehole construction details in Appendix B and water quality data in Appendices C and D). The borehole locations for which water quality data are available are shown in Figure 9. This includes 5 boreholes intersecting palaeochannels (RN21, RN22, RN23, RN25 and RN29) and 4 boreholes into bedrock (RN6, RN7, RN9 and RN18).
- Data provided by ABM for 3 boreholes located within the Project area (Timmy's, Wilsons and Corsair Bores) as provided in Appendix E. Refer to borehole locations in Figure 9. Additional samples from these sites have been collected recently and submitted for analysis, but the data were not available at the time of reporting.

Published water quality data indicates that palaeochannels in the Tanami region have groundwater salinity ranging from fresh (<1,000 mg/l) to very saline (approximately 33,000 mg/l) (Magee, 2009). A number of sources, including Magee (2009), suggest that there may be decreases in groundwater quality over time as mixing of fresh and saline waters occur throughout the depth of the aquifer.

Of the Northern Territory registered boreholes within 40 km of the Project area, groundwater salinities were in the order of 1,000-10,000 mg/L (TDS), within the range reported by Magee (2009). The 5 palaeochannel sites were characterised by salinity values of 5,000-10,000 mg/L (TDS), whereas the lower salinity values observed (1,000-2,000 mg/L) were associated with 2 boreholes within the bedrock aquifers.

Within the Project area, similar salinities were measured at 2 boreholes within bedrock aquifers (around 2,000 mg/L at Corsair Bore and 7,000 mg/L at Wilsons Bore; 14 October 2012). Relatively low salinity (420 mg/L TDS) was measured from Timmy's Bore (palaeochannel aquifer). It should be noted, however, that this analysis was collected in April 1994 and no data is available after that time.

Magee (2009) has suggested that elevated salinity levels predominate because of the high rate of evapotranspiration, especially in low-lying downstream reaches where clay pans and salt lakes are common and the water table is shallow. Groundwater salinity in Tanami region palaeochannels and calcrete (which are generally hydraulically connected and have similar water quality) is understood to display a number of trends including:

- An increase in salinity from tributaries to trunk palaeochannels;
- An increase in salinity from the periphery to the centre of trunk palaeochannels;
- An increase in salinity with distance downstream in trunk palaeochannels; and
- An increase in salinity with depth in palaeochannel aquifers.

In general, salinity appears to be dominated by sodium and chloride, with additional contributions from sulfate, bicarbonate and other major ions (Ca, Mg and K). Other groundwater quality parameters that appear to be elevated include nitrate (up to 250 mg/L NO_3 in palaeochannels and 40-50 mg/L NO_3 in bedrock aquifers) and total hardness (up to 2,000 mg/L $CaCO_3$ in palaeochannels and 6,000 mg/L $CaCO_3$ in bedrock aquifers). Metal concentration data are limited to Corsair and Wilsons Bores, where some metals - arsenic (0.2 mg/L), barium (0.03 mg/L), manganese (0.28 mg/L), strontium (2.9 mg/L) and zinc (0.04 mg/L) - appear to be slightly elevated. However, the relative proportion of metals in dissolved versus particulate forms is currently unknown.

In summary:

- There is very limited data on groundwater quality in the region.
- Groundwater salinity is variable and may have implications for site water use (depending on chemical specifications for process water).
- There is possibly more evaporative concentration of salinity in the palaeochannel aquifers relative to the bedrock aquifers, although there are insufficient data to confirm this.
- The use of palaeochannel groundwater resources may require treatment (eg. desalination), depending on the location of the borehole and water use (process water, dust suppression, potable water, etc).
- It is possible that palaeochannel salinity levels tend to increase down-valley. This may be an important consideration in the identification of viable and sustainable groundwater resources for the Project.
- In addition to salinity, there is a possibility that there could be precipitation of carbonates particularly if extraction takes place from calcrete.

10. Discussion

10.1. Identification of groundwater resource target areas

Based on the findings presented in Sections 5 to 9, a number of 'target areas' of interest have been identified where there could potentially be sufficient groundwater to service the Old Pirate Project.

The following aspects were considered during the selection of target areas:

- Distance from Project area.
    - The target areas are located within a 35 km radius of the Project area.
- Aquifer type.
    - Based on a consideration of the potential yield, estimated rainfall recharge and aquifer storage capacity, target areas are located within the palaeochannels rather than bedrock[3].
- Palaeochannel size.
    - The target areas are generally located within the larger mapped palaeochannels rather than the smaller palaeochannels, which are considered to be significantly more likely to provide a sustainable resource than the network of small tributary systems within the Mineral Lease[4].
- Catchment area.
    - In general, the larger the catchment of the target area, the higher chance there is of achieving a sustainable groundwater yield.
- Potential ecosystem impacts[5].
    - No major water dependant ecosystems have been identified in close proximity to the proposed targets areas and as such these environments are not considered to be at risk through the proposed extraction of groundwater.
- Potential impacts on Indigenous Protected Areas.
    - Neither of the Indigenous Protected Areas (IPAs) are within the target catchment areas and consequently there is no predicted impact from extraction within the proposed target areas.

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[3] Yields in palaeochannels (in the alluvium, calcrete and silcrete) have the potential to be consistently greater than those in the bedrock. Furthermore, storage in the bedrock is likely to be significantly lower than that within the palaeochannels. The capacity for rainfall recharge should also be greater across the more permeable unconsolidated deposits than across the bedrock.

[4] The main trunk channels mapped shown in Figure 2 are a significantly greater distance from the Project area.

[5] The near-surface setting of palaeochannels and the potential connection with vegetation and other ecosystems makes these aquifers potentially more sensitive than other aquifers present in large sedimentary basins or within extensive dolomite terrains (English *et a*l, 2012).

In total, six target areas were selected on the basis of DEM, radiometric and interpreted palaeochannel data. The target areas and selection rationale are outlined in Table 10.1, and their locations area shown in Figure 10. Indicative catchment areas associated with these targets area are outlined in Figure 11.

The areas are general targets where further investigation is considered warranted, and are not intended to represent optimum borehole locations (which will ultimately depend on local ground conditions).

Thalweg analysis would assist in identifying the areas of greatest potential for abstraction, however no local geological model of palaeochannels is available.

Detailed definition of three dimensional subsurface conditions within each target area could be achieved via time domain electromagnetic (TEM) surveys. This would facilitate identification of the preferred target area/s and optimum locations for test borehole installation.

Table 10.1: Location of groundwater resource target areas and the rationale for selection.

Target area	**Approximate location * #**		**Approx. Distance from Old Pirate Project (km)**	**Total catch-ment for target area (km^2)**	**Selection rationale**	**Potential limitations**
	Easting	**Northing**				
1 and 1A	521,800	7,765,470	6	11.5 and 23.6	Closest potential catchment to the Project area	Two sub catchments in small palaeochannels to the south east of the Mineral Lease. Relatively small catchment area may limit sustainability of groundwater supply.
2	508,360	7,763,970	8.5	47.3	Close to existing borehole known to yield approx. 2 L/s. Water quality is likely to be reasonable.	Limited catchment and width of palaeochannel may restrict development of a good size well field achieving full yield.
3	530,520	7,758,060	17	170	As close as possible to the Project area within main palaeochannel.	
4	503,520	7,751,000	20	82.9	Within main palaeochannel and relatively close to the Project area.	
5	548,370	7,774,790	33	95	Within main palaeochannel and has a reasonable size catchment relatively close to the Project area.	

* Datum = GDA 94 MGA zone 52.

[#] Target areas for groundwater supply for the Project are mostly located outside of the Mineral Lease. It is understood that until such time as ELA 29790 is granted, an Access Authority will be required for use (and therefore development) of boreholes outside of the lease under the Mineral Titles Act Sec 84.

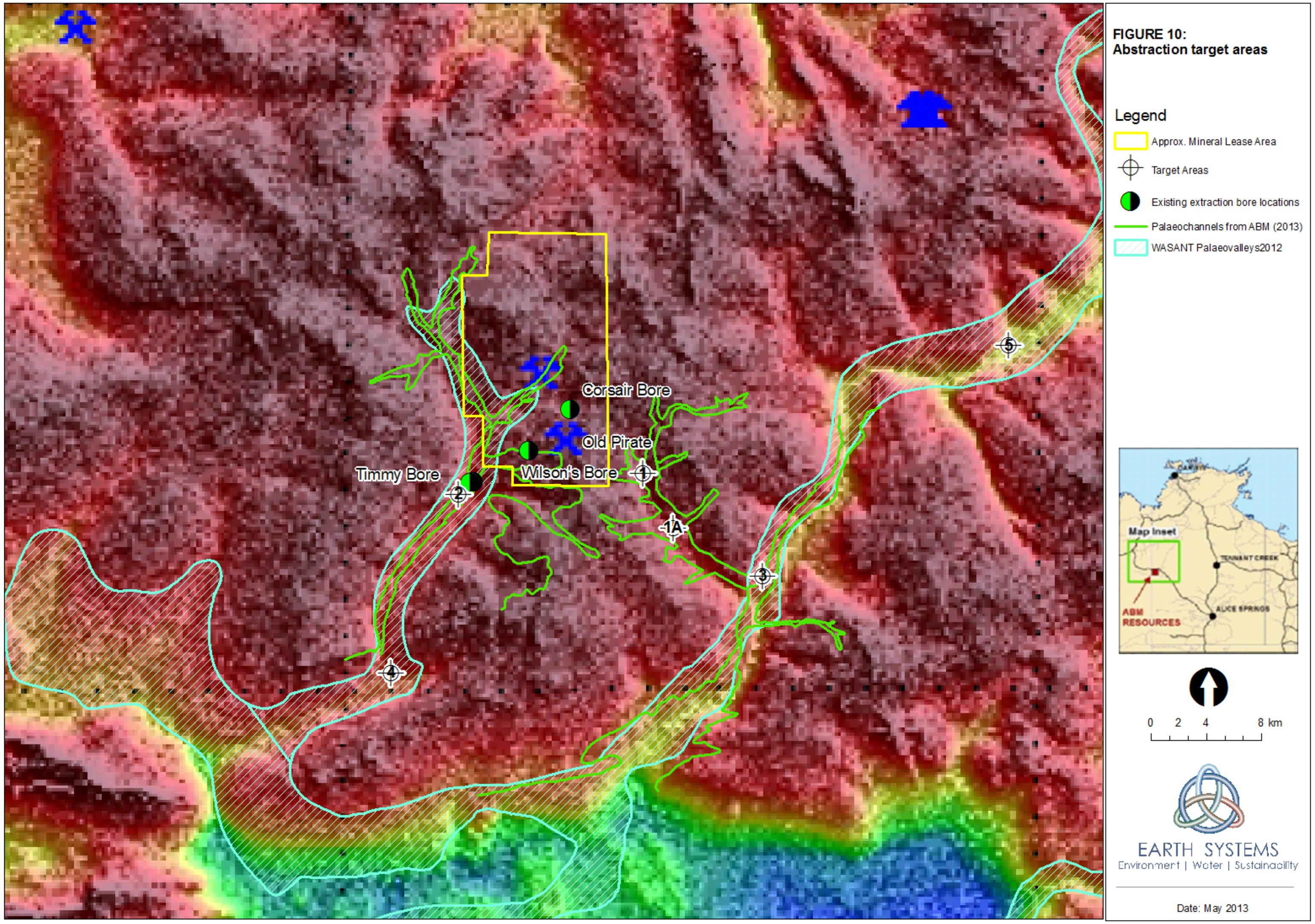

Figure 10: Abstraction target areas.

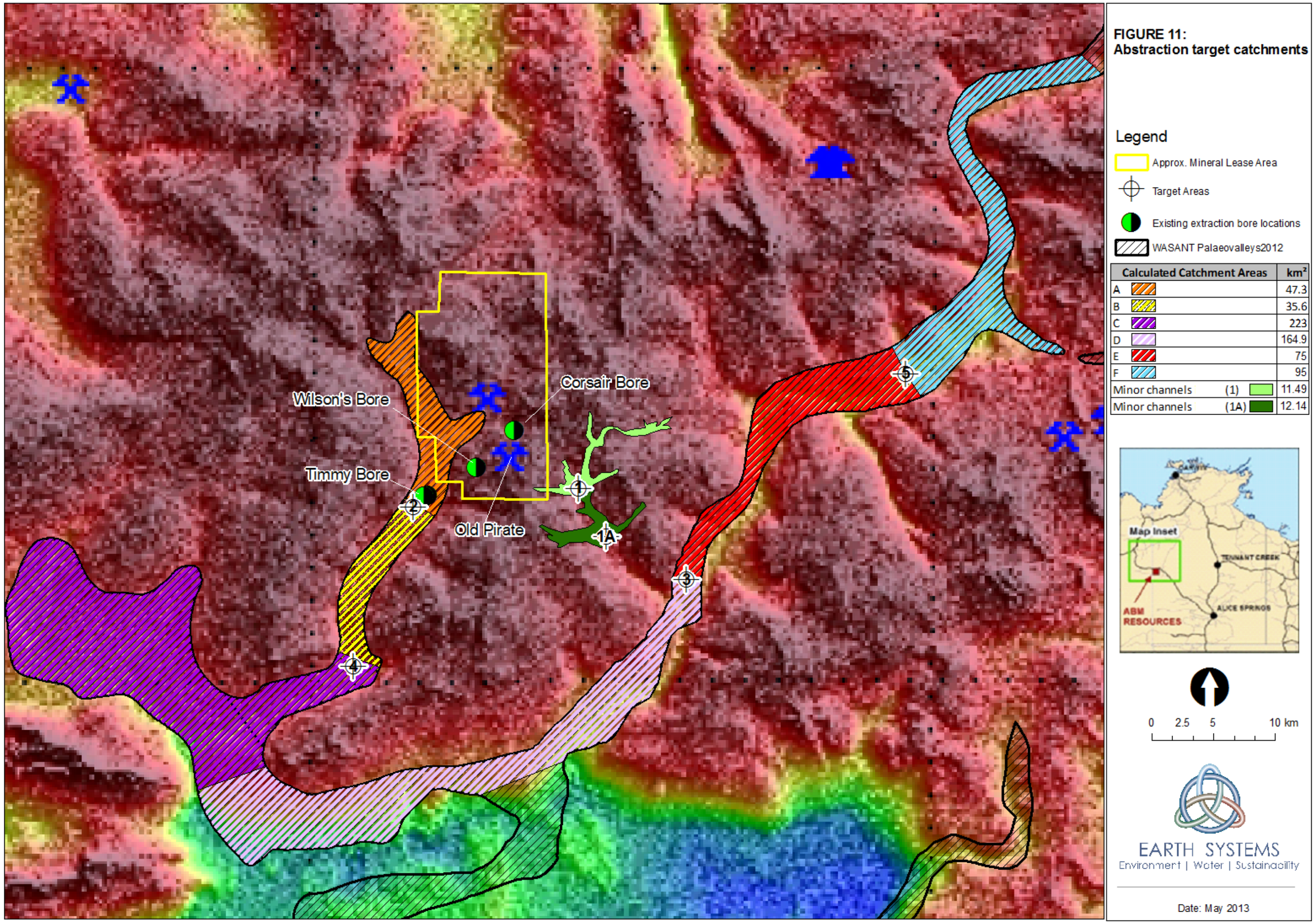

Figure 11: Abstraction target catchments.

10.2. Indicative groundwater yields from target areas

A preliminary assessment of potential groundwater yields has been conducted for each of the target areas listed in Table 10.1. Furthermore, in accordance with DME requirements (23rd January 2013), this assessment considers the likely water balance for target area catchments and as such provides an initial assessment of the sustainability of potential groundwater resources for the Project.

This assessment is based on preliminary estimates of (Appendices D and E):

- The theoretical potential yield achievable from an individual borehole within each target area, based on aquifer properties presented in Section 9, using the method of Farvolden (1959).
- The sustainability, or potential for long term drawdown, associated with groundwater abstraction at each target area[6].

At this stage, there is limited information on the geometry of the palaeochannels at each target area and as such calculations were undertaken for individual boreholes rather than a consideration of any type of full borefield design assuming that there would be sufficient spacing to ensure minimal interference between individual bores.

Estimates of sustainable yield were calculated using the individual catchment areas associated with each target area as outlined in Figures 10 and 11. The calculations were used to estimate recharge rates across the catchment, for comparison with the extraction rate proposed by ABM (11.1 L/s).

In general, estimates were based on the established conceptual model. Although calcrete or silcrete are expected to be the highest yielding formations, these are not present in all areas, and hence the calculations only used estimated aquifer properties of the alluvium in the palaeochannels. The potential yield and sustainability calculations are considered to be reasonably conservative as a result.

Whilst there will be a relatively large drawdown in the aquifer close to individual boreholes and there will be an initial period of local aquifer depletion, the purpose of the calculations is to examine the potential long term sustainability of extraction. As such, the assessment considers if there will be a general reduction in groundwater levels across the catchment.

The potential for long term drawdown of groundwater was estimated along with the magnitude of change. Three scenarios were considered for recharge to the aquifer – a yearly average recharge rate (4.5 mm/a), low recharge rate (1 mm/a) and zero recharge.

The preliminary calculations were based on the following assumptions:

- Borehole extraction reaches a point of steady state, such that a relatively stable water level develops in the vicinity of the borehole.
- Aquifer properties are uniform across the catchment area.
- Groundwater flow is parallel to the channel sides and all of this flow upgradient of the target area can be intercepted.

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[6] No national groundwater sustainable yield definition has yet been adopted by all states and territories. The definition agreed upon by the National Groundwater Committee is: *The groundwater extraction regime, measured over a specified planning timeframe that allows acceptable levels of stress and protects dependent economic, social and environmental values.*

- Flow is generally to the south and the full channel length hydraulically upgradient of the target area is available for recharge and extraction.
- Targets areas located to the south of the Mineral Lease have larger catchment areas, intercept a greater volume of throughflow and therefore have a greater capacity for recharge, than those to the north.
- Based on available data there is a saturated thickness of 20 m of productive strata within the channel which has a transmissivity of between 40 and 70 m^2/d. Two storage coefficients at the potential upper and lower end of the scale (0.05 and 0.3) were considered to calculate the possible derogation of groundwater over time.

  There is no groundwater recharge occurring from the bedrock aquifer. The calculations of sustainability are therefore conservative as only rainfall recharge directly to the channels is accounted for.

10.3. Results

Long term borehole yield

Using the method of Farvolden (1959) the theoretical long term yield for individual boreholes has been calculated using literature values outlined in Section 8.

A maximum theoretical yield of between 2.9 and 5.1 L/s was estimated for individual boreholes (Appendix F). This is in line with literature values but confirmation of this for individual target areas requires further assessment as such yields will be subject to geological variability.

The calculations are best case figures and the estimated borehole yields may reduce over time if there is a reduction in water levels across a catchment (refer to catchment sustainable yield estimates below). There could also be a general reduction of borehole yield over time since boreholes and the immediate area of the aquifer may be subject to deterioration via chemical and physical processes.

Catchment sustainable yield

Estimated sustainable yields for each target area are provided in Appendix G and summarised in Tables 10.2 and 10.3. The table outlines the estimated maximum potential reduction in groundwater levels averaged across the catchment.

Based on the preliminary results in Table 10.2, it is anticipated that across the majority of target areas, although local drawdown will occur, groundwater extraction is likely to result in only limited reduction of groundwater levels across the catchment, in most cases only as a result of below average groundwater recharge.

In general target areas close to the Project area have small catchments and may not be large enough to establish a long term sustainable extraction. Target areas located further away from the Project area have relatively large catchment areas and may therefore be more sustainable in the long term.

It is important to note that there is currently considered to be minimal outflow from the target area aquifers and that extraction will result in a change to the local conceptual model meaning that the introduction of drawdown has the potential to facilitate additional recharge.

Further investigation of all target areas is warranted to confirm the sustainability of groundwater resources in these areas.

Table 10.2: Preliminary estimates of maximum groundwater level change and the likelihood of achieving sustainable yield for the palaeochannel aquifers in each target area (assuming a Project water demand of 11.1 L/s).

Target area	Est. max annual GW level change – 4.5mm/a recharge	Est. max annual GW level change - 1mm/a recharge	Est. max annual GW level change - zero recharge	Comments on sustainability of yield
1	-0.51 m	-0.59 m	-0.61 m	Catchment area contains a series of relatively minor channels. Borehole yields may reduce over time as catchment groundwater levels may be lowered by extraction.
1A	-0.21 m	-0.28 m	-0.3 m	Catchment area contains a series of relatively minor channels. Borehole yields may reduce over time as catchment groundwater levels may be lowered by extraction.
2	-0.06 m	-0.13 m	-0.15 m	Borehole yields may reduce over time as catchment groundwater levels may be reduced by extraction.
3	Insignificant	-0.02 m	-0.04 m	A reasonable catchment with a good area of recharge. If the yields can be achieved it is predicted to be a potential area capable of providing a sustainable resource. Short term reductions in aquifer water levels are anticipated where annual recharge is low.
4	Insignificant	-0.06 m	-0.08 m	Capable of potentially providing a sustainable resource in the long term but short term reductions in aquifer water levels are anticipated where annual recharge is low.
5	Insignificant	-0.05 m	-0.07 m	Capable of potentially providing a sustainable resource in the long term but short term reductions in aquifer water levels are anticipated where annual recharge is low.

Table 10.3: Preliminary estimates of maximum sustainable yield for the palaeochannel aquifers in each target area.

Target area	Preliminary estimate of maximum sustainable yield
1	1 L/s
1A	3 L/s
2	6 L/s
3	24 L/s
4	11 L/s
5	13 L/s

11. Conclusions

The key conclusions of this study are outlined below:

- Surface water flows are intermittent and cannot supply the site's water needs. This study has identified two potential groundwater sources (alluvial palaeochannel and bedrock aquifers) that may be suitable.
- The bedrock aquifers are generally fracture-controlled, with typical water depths of 20-150 mbgl, yields in the order of 1-5 L/s and salinity values of around 1,000-10,000 mg/L (TDS).
- Palaeochannels containing unconsolidated sediments are incised into the bedrock, and generally comprise porous rock aquifers, with typical groundwater depths of 5-10 mbgl, yields in the order of 1-5 L/s and salinity values of around 5,000-10,000 mg/L (TDS).
- Based on average groundwater levels in each aquifer type, it is considered likely that there is often little hydraulic connectivity between the two. However, some recharge of the bedrock aquifer from the palaeochannels is possible at some locations.
- Initial indications are that the palaeochannel aquifers should be the primary targets for future more detailed hydrogeological assessments.
- The long term sustainability of extraction from palaeochannel aquifers will depend on recharge rates to the aquifer. Aquifer recharge is primarily observed during high intensity rainfall events (>50 mm/d) over a period of at least 24 hours. In general, the larger the palaeochannel catchment, the greater chance there is of achieving sustainable extraction in the long term.
- Indicative groundwater balance calculations of potential recharge and extraction from palaeochannel aquifers suggest that locations within close proximity to the Mineral Lease are not as prospective as those further afield with larger catchments.
- Larger palaeochannel aquifers some distance from the Mineral Lease are more likely to yield sustainable volumes of groundwater to support site operations.
- Target area 3 appears to have the largest catchment, is closest to the Project area and is likely to sustainably provide the project water requirements (11.1 L/s). It is therefore the current preferred groundwater target area.
- There are limited data on groundwater quality, both locally and regionally, and no clear relationship between salinity and aquifer type has been established. Variable salinity may have implications for site water use, and palaeochannel groundwater resources may require desalination.
- Six groundwater resource target areas within palaeochannel aquifers have been identified. These include locations close to the Mineral Lease. Time domain electromagnetic surveys (TEM) would facilitate identification of the preferred target area/s and optimum locations for test borehole installation.
- A program of drilling and testing should then be undertaken. This should include:
  - Drilling of test boreholes in the preferred target area/s and to depths established from geophysical (TEM) surveys.
  - Use of both step and constant rate pumping tests to establish the likely long term yield.
  - Groundwater level, groundwater quality and climate monitoring.

- As the target areas are located outside of the Mineral Lease area it will be necessary to identify and liaise with the landowners and obtain permissions from the DEM for development of drilling targets as required. An initial dialogue at an early stage is advised to ensure that the necessary permissions can be obtained in a timely manner.
- The location of other water users who may be impacted will need to be considered. Establishing the location of other users and liaising with them throughout subsequent feasibility work should commence as early as possible.
- In additional to detailed investigations of potential target areas, groundwater level and quality data should continue to be collected at existing sites, as follows:
  - Ideally water level data loggers should be installed in the existing Corsair and Wilsons Bores, together with a barometric data logger. It is understood that Timmy's Bore has collapsed and that it would be impossible to install a data logger.
  - Data loggers should be used to collect groundwater level data at regular intervals, providing much greater data resolution and a long-term continuous water level database for cross reference to meteorological data.
  - Groundwater flow data from extraction bores should also be recorded. A flow meter should be installed on the rising main and totaliser readings collected preferably daily or with a data logger.
  - If data loggers are not installed in boreholes, water level data should be collected manually at least weekly where possible. If using data loggers, data could be downloaded at the time of water sampling (monthly).
  - Dips should be measured to a fixed datum on the borehole (such as the top of the casing or other fixed point) and the details of this point recorded.
  - The borehole datum should be surveyed to a common site or national datum.
  - Water quality sampling should be undertaken monthly following the procedures outlined in Appendix H "Protocol for Groundwater Quality Analysis".

12. Recommendations

Based on the results and conclusions of this preliminary groundwater resource assessment, the following recommendations are made:

- Conduct a TEM survey across each of target areas in order to identify the optimum aquifer drilling targets.
- Consider potential impacts on groundwater use by local communities and pastoral groups during the identification optimum mine water supply boreholes.
- Install a single, large diameter pump test borehole in each target area based on results of the TEM surveys.
- Conduct detailed testwork on each bore to identify yields and water quality from different parts of the geological sequence encountered.
- Locate existing registered boreholes across the Mineral Lease and incorporate relevant boreholes into routine water level monitoring program to improve understanding of local hydrogeology.
- Seek permission to use the boreholes from relevant landowners before groundwater extraction from pump test boreholes, in accordance with DME requirements.
- Routinely monitor groundwater levels and quality from Timmy’s, Corsair and Wilsons Bores, where possible, in accordance with DME requirements.
- Ensure that new boreholes would need to be installed and rehabilitated using current best engineering and environmental practices, in accordance with DME requirements.

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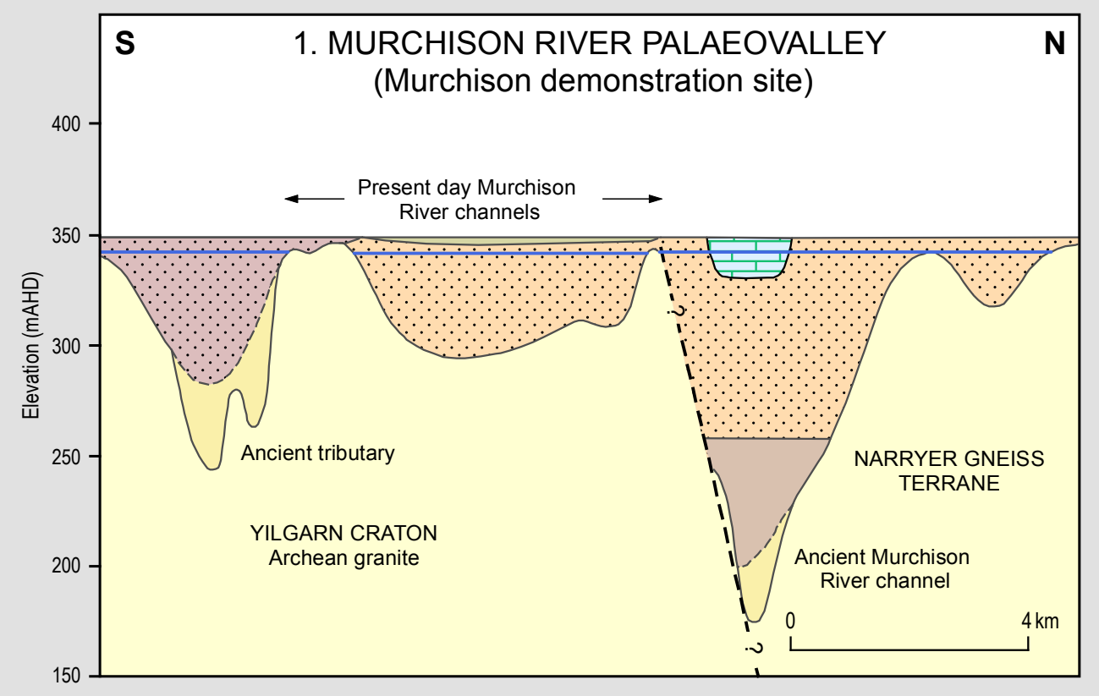
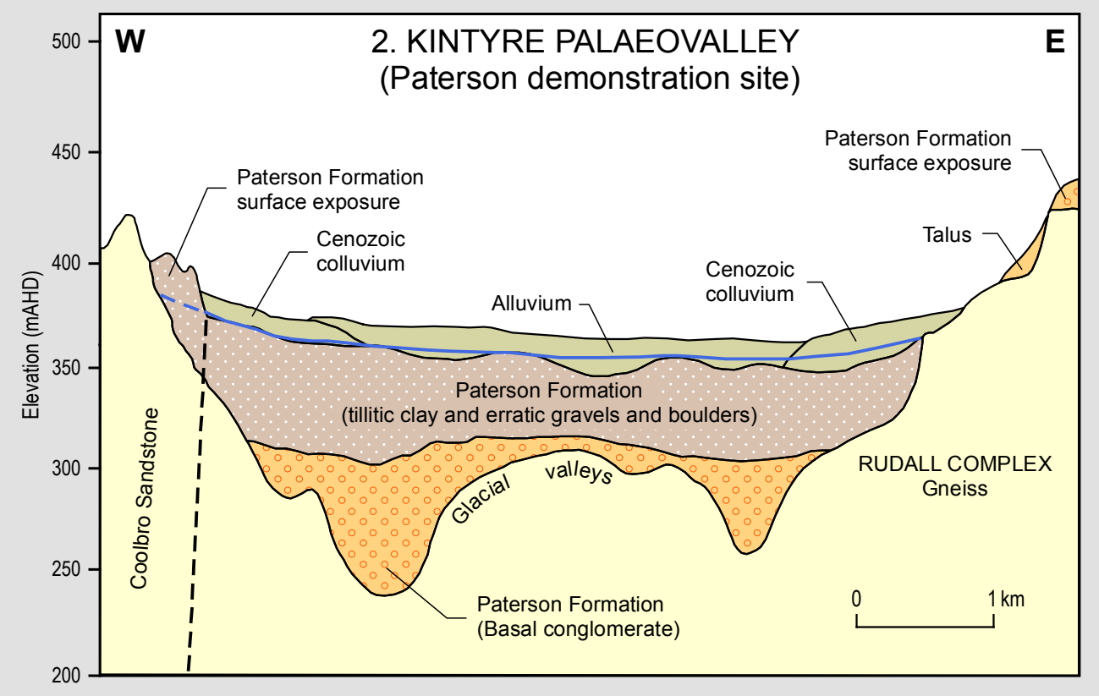
APPENDIX A

WASANT Palaeovalley Map



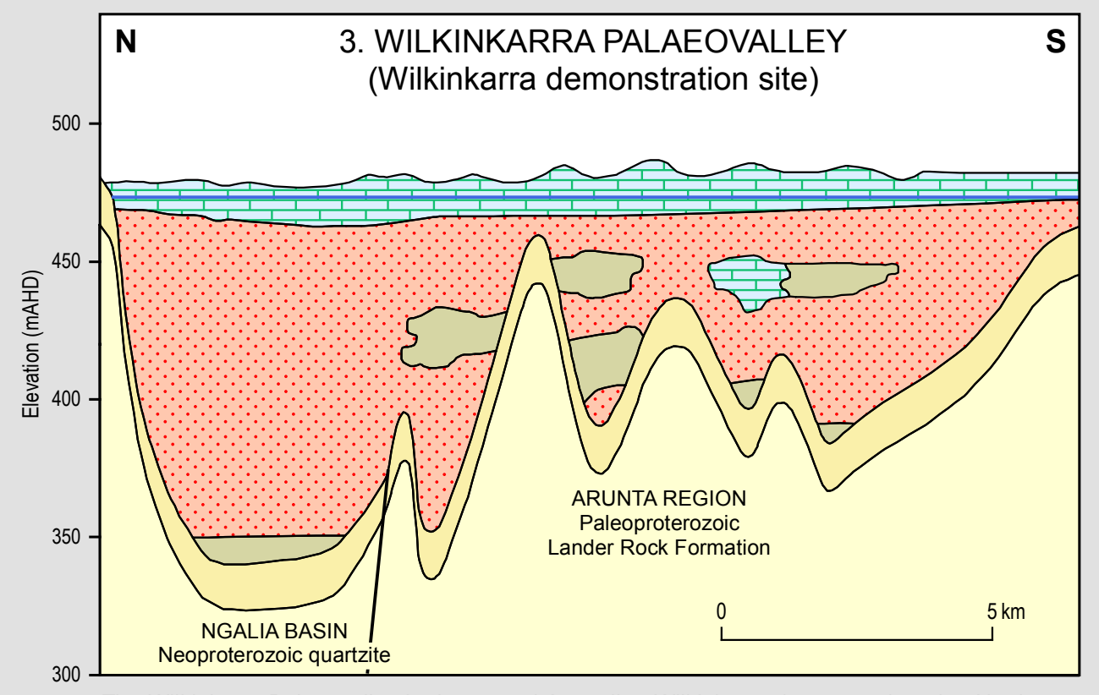
1. MURCHISON RIVER PALAEOVALLEY
(Murchison demonstration site)

Murchison River cross section at Beringarra near the western edge of the Yilgarn Craton in the Murchison demonstration site, Western Australia. Palaeo-river incision here was along the contact between Archean granite and the Narryer Gneiss Terrane. Multiple buried river channels were spread over 16 kilometres, south to north. A gravity survey detected the eroded surface of fresh bedrock (buried basement topography). Weathered bedrock zones (saprolite) were disclosed through drilling. Palaeovalleys in the Murchison region are up to 200 metres deep, infilled with Late Cenozoic alluvium that is sandier than in most other parts of the Yilgarn Craton. Relatively large volumes of variable quality groundwater occur in these aquifers.



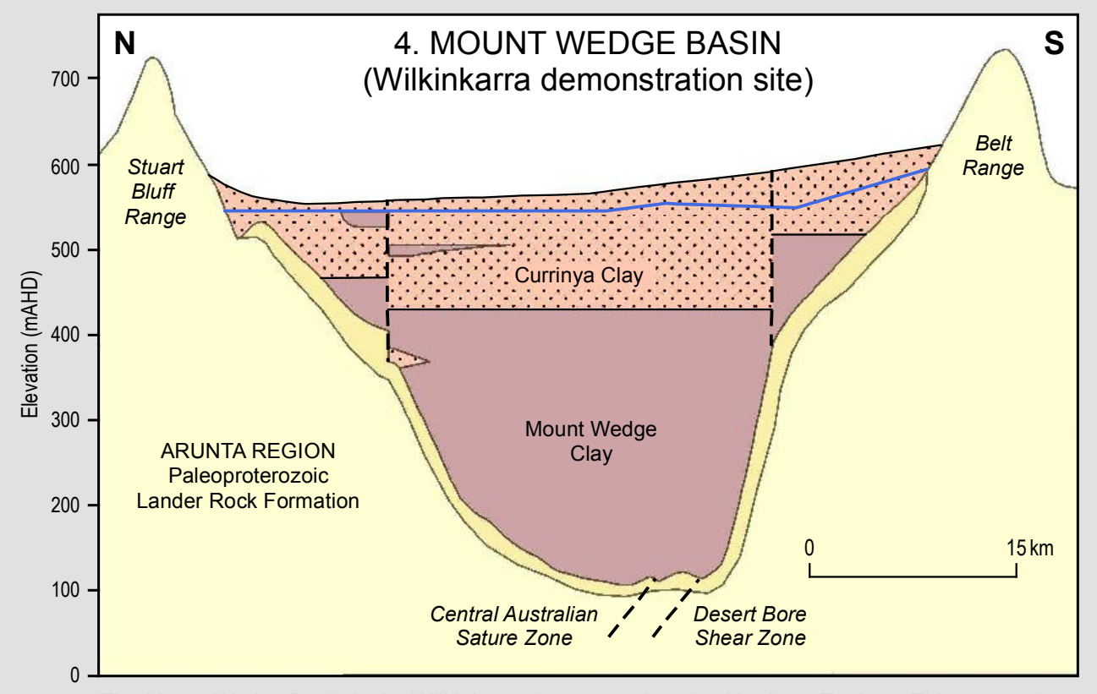
2. KINTYRE PALAEOVALLEY
(Paterson demonstration site)

Kintyre Palaeovalley in the Rudall Uplands defined by airborne electromagnetic (AEM) data, in the Paterson demonstration site, Western Australia. This section, in the Yandagooge Creek catchment, shows crystalline Proterozoic bedrock deeply scoured, to 200 metres or more. The valley is infilled with Permian glaciogenic Paterson Formation sediments. This formation comprises basal gravels/conglomerate (target aquifer) and overlying thick tillitic clay, which in turn is overlain by Cenozoic alluvium. The basal Permian conglomerates and Cenozoic alluvium provide important water supplies.



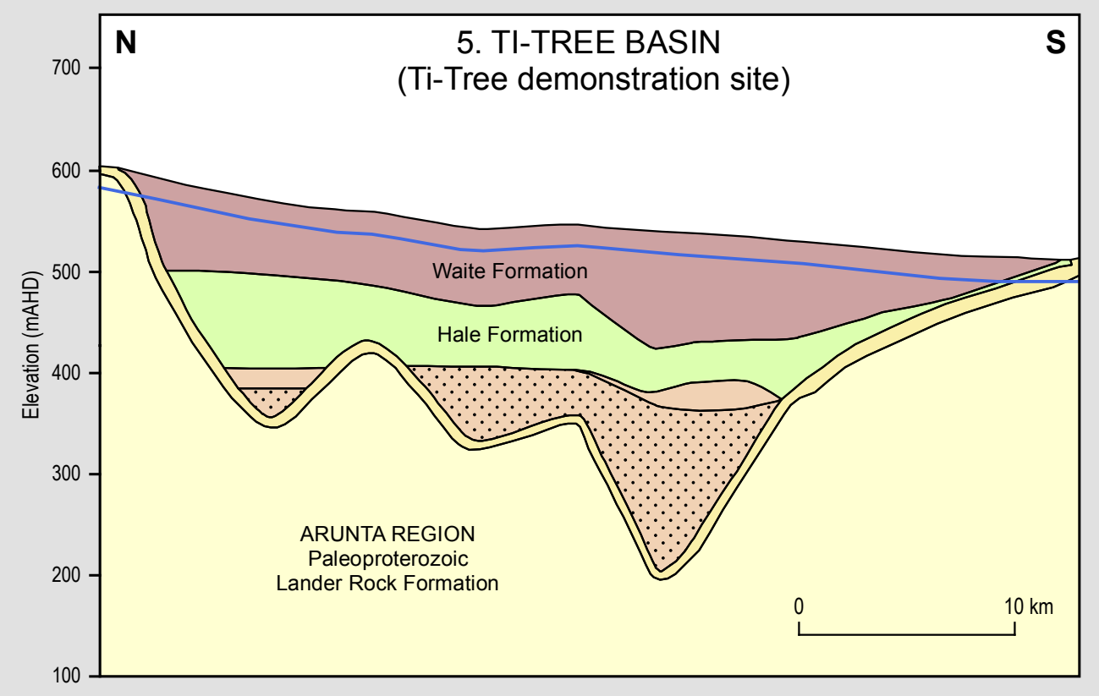
3. WILKINKARRA PALAEOVALLEY
(Wilkinkarra demonstration site)

The Wilkinkarra Palaeovalley in the central Australian Wilkinkarra demonstration site, Northern Territory. Multiple irregular channels are incised into the underlying bedrock units. The sediment infill sequence is sand-dominated, typical of moderately to highly energetic fluvial deposition. A thin calcrete horizon is extensively developed at the surface. Lithology and structure based on detailed drilling and ground geophysics. Previously unknown fresh groundwater supplies were encountered in palaeovalleys beneath dunefields in the area.



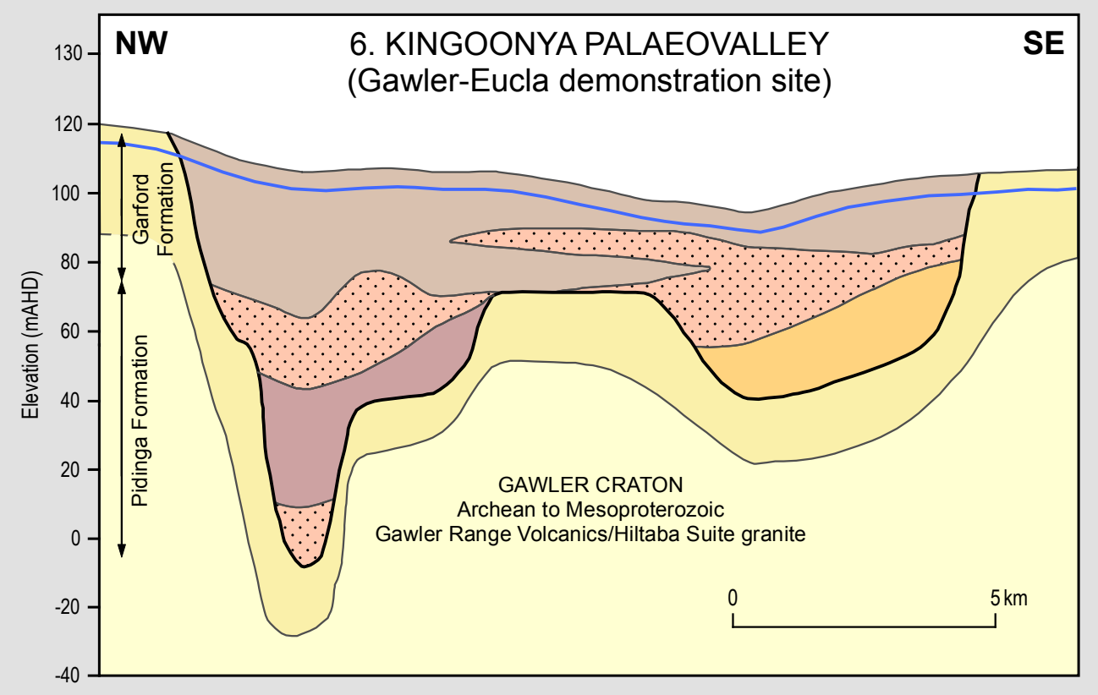
4. MOUNT WEDGE BASIN
(Wilkinkarra demonstration site)

The Mount Wedge Basin in the Wilkinkarra demonstration site, Northern Territory. This mountain-front basin contains nearly 500 metres of Cenozoic sediment infill, interpreted to have formed in lacustrine to alluvial fan depositional environments. Significant fresh to brackish quality groundwater resources occur in this palaeovalley system. Lithology and structure based on ground geophysics and drilling.



5. TI-TREE BASIN
(Ti-Tree demonstration site)

The Ti-Tree Basin in the Ti-Tree demonstration site, Northern Territory. Cenozoic sediment infill is over 300 metres deep in some places, although the basement surface is irregular and sediment facies vary across the basin. Typical of most central Australian palaeovalleys the sedimentary sequence is overprinted by intense chemical weathering. The lithology and structure are based on extensive drilling and airborne electromagnetic (AEM) data. Large volumes of good quality groundwater are stored in the basin.



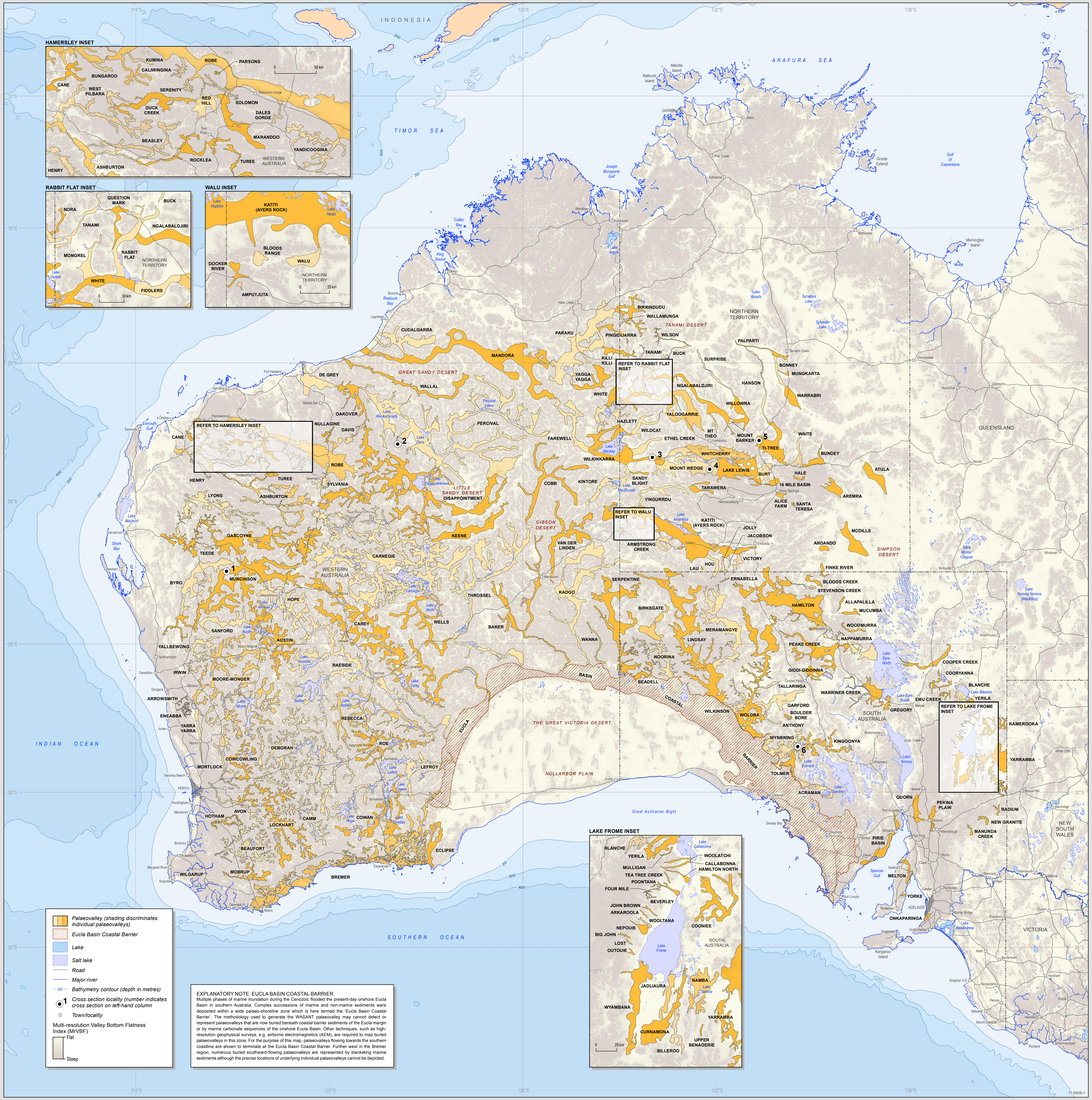
6. KINGOONYA PALAEOVALLEY
(Gawler-Eucla demonstration site)

The Kingoonya Palaeovalley in the Gawler-Eucla demonstration site, South Australia. This section shows two distinct palaeochannels infilled with a variable Cenozoic sedimentary sequence, and seperated by a buried basement high. The coarse sand and gravel sequence in the south-east is the highest yielding aquifer interval (lithologic compositions based on detailed rotary drilling transect; *after Hou, 2004*).

- ▦ *Calcrete*
- ▨ *Clay*
- ▨ *Carbonaceous clay and lignite*
- ▨ *Clayey silt and sand lenses*
- ▨ *Silty clay and sand lenses*
- ▨ *Sandy clay*
- ▨ *Sandy silt and sand lenses*
- ▨ *Clayey sand*
- ▨ *Silty sand*
- ▨ *Sand*
- ▨ *Gravelly clay*
- ▨ *Coarse sand and gravel*
- ▨ *Conglomerate*
- ▨ *Weathered basement*
- ▨ *Basement*
- — *Water table*
- — *Fault zones*
- - - *Inferred fault*
- — *Facies*
- - - *Inferred facies*

CROSS SECTION NOTE:

Detailed technical reports for each demonstration site listed in these cross sections are available as Geoscience Australia Records *(GA Record 2012/05 to 2012/09)* and can be downloaded from the GA internet site at: http://www.ga.gov.au/cedda/publications/96



- ▥ *Palaeovalley (shading discriminates individual palaeovalleys)*
- ▨ *Eucla Basin Coastal Barrier*
- 🟦 *Lake*
- ▭ *Salt lake*
- — *Road*
- — *Major river*
- — 200 — *Bathymetry contour (depth in metres)*
- ⦿1 *Cross section locality (number indicates cross section on left-hand column*
- ▫ *Town/locality*

Multi-resolution Valley Bottom Flatness Index (MrVBF)
Flat
Steep

EXPLANATORY NOTE: EUCLA BASIN COASTAL BARRIER

Multiple phases of marine inundation during the Cenozoic flooded the present-day onshore Eucla Basin in southern Australia. Complex successions of marine and non-marine sediments were deposited within a wide palaeo-shoreline zone which is here termed the 'Eucla Basin Coastal Barrier'. The methodology used to generate the WASANT palaeovalley map cannot detect or represent palaeovalleys that are now buried beneath coastal barrier sediments of the Eucla margin or by marine carbonate sequences of the onshore Eucla Basin. Other techniques, such as high-resolution geophysical surveys, e.g. airborne electromagnetics (AEM), are required to map buried palaeovalleys in this zone. For the purpose of this map, palaeovalleys flowing towards the southern coastline are shown to terminate at the Eucla Basin Coastal Barrier. Further west in the Bremer region, numerous buried southward-flowing palaeovalleys are represented by blanketing marine sediments although the precise locations of underlying individual palaeovalleys cannot be depicted.

11-5836-1

Australian Government
Geoscience Australia
National Water Commission

WASANT PALAEOVALLEY MAP

SCALE 1:4 500 000
0 100 200 300 400 500 Kilometres
MERCATOR PROJECTION
Central Meridian: 126°E Standard Parallels: 26°S
Geocentric Datum of Australia

PREFACE:

This map of palaeovalleys in arid and semi-arid parts of Western Australia (WA), South Australia (SA) and the Northern Territory (NT), shows the interpreted distribution of palaeovalleys including those obscured beneath desert dunefields. The map extent is defined by the Köppen-Geiger classification of arid and semi-arid zones of WA, SA and NT (Figure 1). This map was produced as part of the 'Water for Australia's arid zone – identifying and assessing Australia's palaeovalley groundwater resources project' (termed the 'Palaeovalley Groundwater Project') that was funded by the National Water Commission (NWC) and led by Geoscience Australia, with support from respective state and territory government agencies. The four-year project (2008-2012) aimed to provide information about the role of palaeovalleys as aquifers in widespread regions where groundwater resources are scarce or need to be investigated for the future.

EXPLANATORY NOTES:

The map was compiled using national-scale datasets (including Digital Elevation Models and geological maps), existing geoscientific data and reports in combination with expert knowledge. New information was obtained through demonstration studies in selected sites (Figure 2); examples of palaeovalley cross sections from these sites are shown on the left-hand column of the map. The methodology used to produce the map is described in the companion project summary report by English et al. (2012), cited below. This broad-scale map is intended to enhance our knowledge of Australian arid zone palaeovalleys as widespread but little understood geologic elements and potentially contribute to an improved understanding of palaeovalley aquifers. The palaeovalleys shown on the map do not necessarily correspond with underlying groundwater resources or indicate prospective borehole sites. Rather, the map serves as a guide for more detailed future hydrogeological investigation in areas of interest.

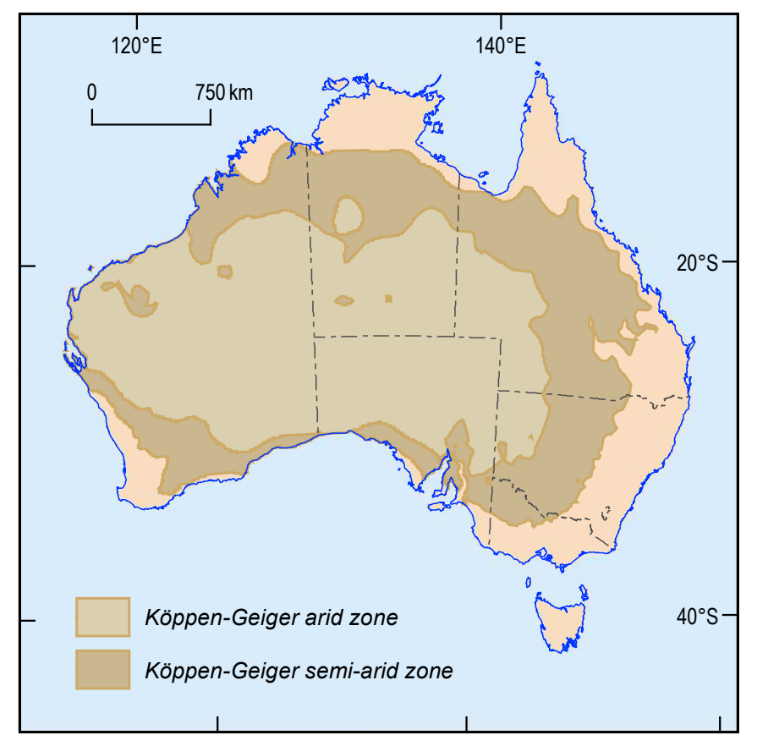


Figure 1: Köppen-Geiger classification of arid and semi-arid zones (reference 4 below).

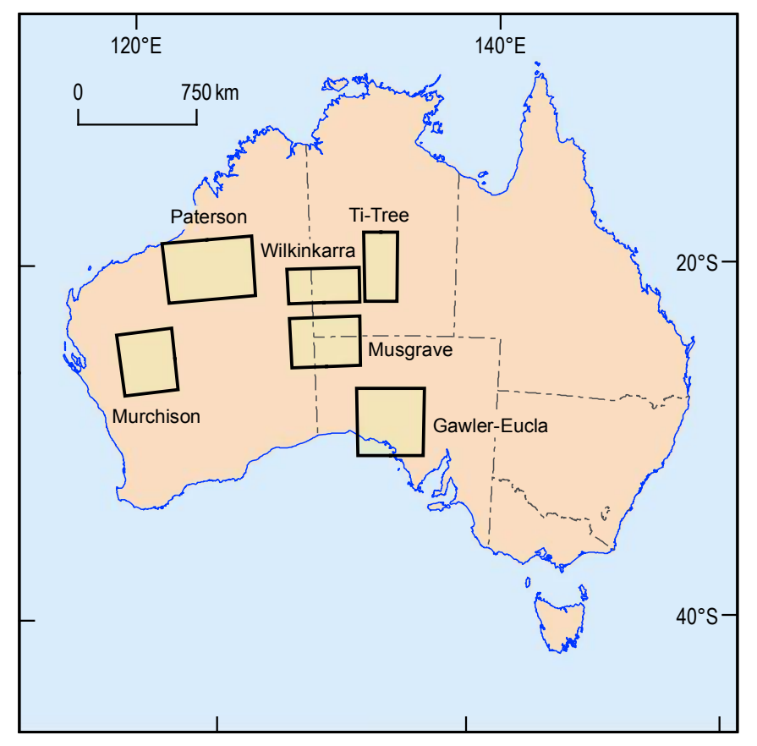


Figure 2: Palaeovalley demonstration sites.

CROSS SECTION NOTES:

1. Examples of cross sections shown in the left-hand column illustrate the heterogeneity and complexity (in terms of size, shape, structure and sediment infill) of palaeovalleys within the arid and semi-arid zone.
2. Most palaeovalleys shown on the map are now infilled with variably thick sequences of Cenozoic sediments, although some contain older (Mesozoic and Paleozoic) sequences, such as the Permian glacial-derived sediments in the Paterson Province (WA).
3. The infill sequences depicted in these sections range from unconsolidated sediments to fully lithified sedimentary rocks. For consistency, the lithologic descriptions used here refer to the primary sediment type regardless of the degree of lithification.
4. The sediment infill sequences are variably affected by chemical weathering. In places this has overprinted the original sediment compositions and also destroyed much of the primary sedimentary fabric.
5. In most cases relatively thin (less than two metres) deposits of regolith and aeolian sands blanket the uppermost palaeovalley sediment layers, although dunes up to 20 metres high may occur in desert regions. These cover sequences were not deposited by fluvial or lacustrine processes associated with the palaeovalleys so have not been shown.
6. To maximise the display of information the cross sections have inconsistent scales, conveying the significant variations in palaeovalley depths and widths.

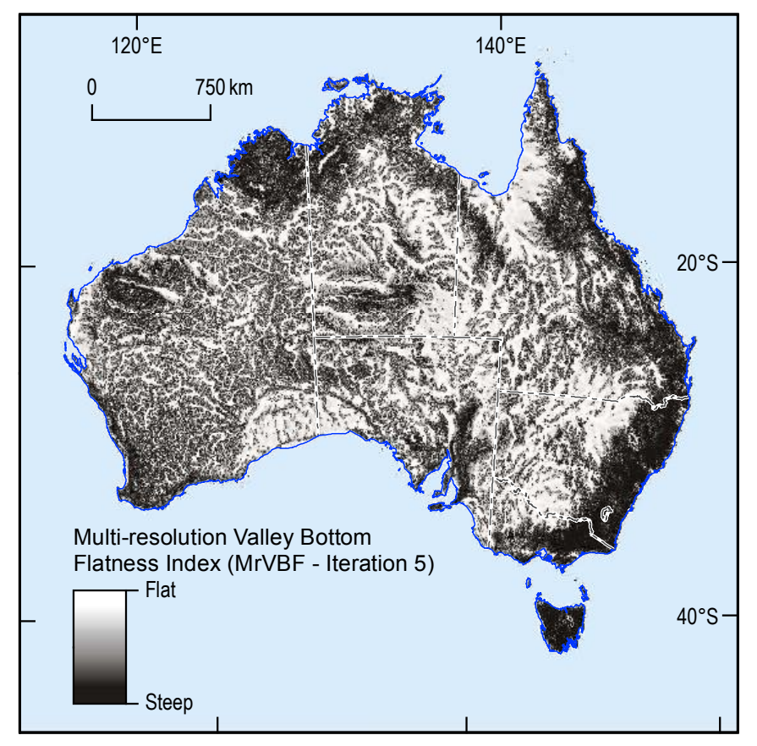


Figure 3: Multi-resolution Valley Bottom Flatness Index (MrVBF) Digital Elevation Model (Gallant and Dowling, 2003).

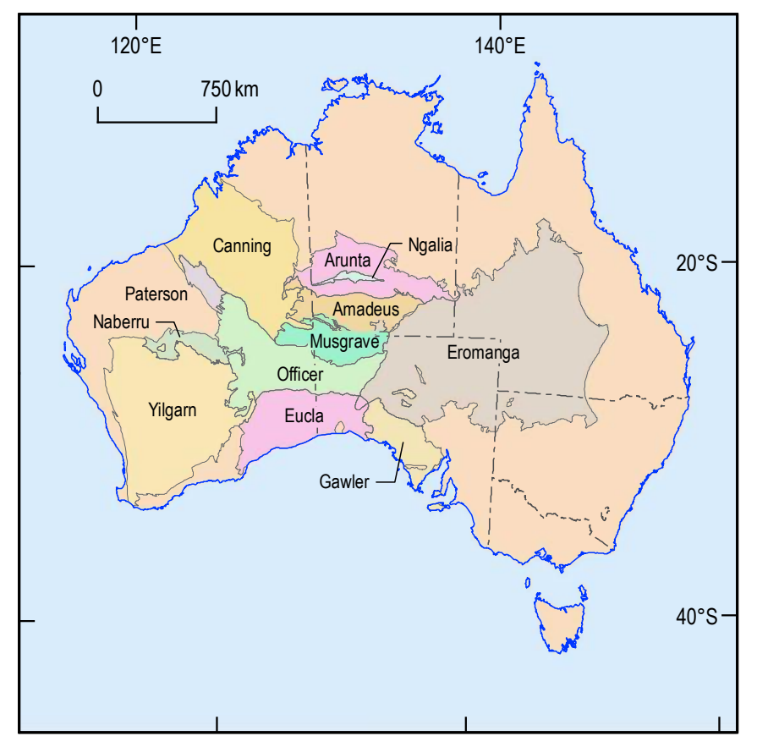


Figure 4: Geological provinces within the WASANT study area.

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4. Köppen-Geiger classification of arid and semi-arid zones: http://www.bom.gov.au/climate/environ/other/koppen_explain.shtml

ACKNOWLEDGEMENTS:

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Cartography by Silvio Mezzomo and Theo Chiotis, Products and Promotion, Geoscience Australia.

BIBLIOGRAPHIC REFERENCE:

Bell, J.G., Kilgour, P.L., English, P.M., Woodgate, M.F., Lewis, S.J. and Wischusen, J.D.H. (compilers), 2012.
WASANT Palaeovalley Map – Distribution of Palaeovalleys in Arid and Semi-arid WA-SA-NT (First Edition), scale: 1:4 500 000.
Geoscience Australia Thematic Map (Geocat № 73980) – hard-copy and digital data publication: http://www.ga.gov.au/cedda/maps/96

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APPENDIX B

Location and details of registered boreholes within a 40 km radius

Figure 9 ref number	Registration number	Name	Drilled date	Easterly	Southerly	Drill depth	Logged Strata	Bedrock or Palaeochannel	WL Strike (mbgl)	SWL (mbgl)	Flow rate (L/s)	WQ	WQ test date	Notes
RN1	RN004439	A83/1 1ATT 0.2LPS B.H.L. DUD 23K NE OF PEDESTAL HILL.MA	10/08/1964	519632.7	7741363.4	45.7	Clay and Limestone	Palaeochannel	13.7	10.7	0.2	Stated as "good".	?	
RN2	RN004727	B.H.L.RIVATE 0.02LPS DUD N/TRC BULLOCK HEAD	6/01/1965	520132.7	7741413.4	18.2	Clay, sandstone and Limestone	Palaeochannel	12.2	12.2	0.03	?	N/A	
RN3	RN013965	A83/15 DRY DUD 2.8K STH OF CENTURY RN 14177	6/03/1984	530775.6	7743189.4	50	Siltstone or shale	Bedrock	NIL	NIL	NIL	N/A	N/A	
RN4	RN004501	B.H.L.NO3 0.5LPS DUD 61K W HOMESTEAD NO TRACE	14/08/1964	521832.6	7745063.4	25.9	Limestone and Sandstone	Palaeochannel	18.2	?	0.5	Extremely high TDS = 58300ppm	28/09/1964	
RN5	RN004708	B.H.L.0.02LPS DUD APX 4K N OF B.H.L. NO TRAC	23/12/1964	522832.6	7746063.4	32	Sandstone, siltstone and shale	Palaeochannel	27.5	?	0.03	?	N/A	
RN6	RN014177	A83/22 CENTURY BORE 4K NTH OF CENTURY TANK	3/12/1984	531932.6	7746263.4	67.5	Sandstone and siltstone	Bedrock	44, 53 and 65	27.0	1.3	Stated as "good". Basic analysis included - TDS = 955 mg/l	14/05/1989	Yield increases with depth
RN7	RN004664	A83/4 DRY DUD ???? NO TRACE 6.4 k/m (N) OF LAKE SARAH.	1/12/1964	510932.7	7746463.4	25.9	Sand, clay, siltstone and shale	Bedrock	?	?	?	Basic analysis included - TDS = 2235 mg/l	Jan-66	Has a yield but this is unknown
RN8	RN014176	RN14176. 2KM (NE) OF RN14177	2/12/1984	532332.6	7747163.4	48	Sandstone, siltstone and shale	Bedrock	NIL	NIL	NIL	N/A	N/A	

Figure 9 ref number	Registration number	Name	Drilled date	Easterly	Southerly	Drill depth	Logged Strata	Bedrock or Palaeochannel	WL Strike (mbgl)	SWL (mbgl)	Flow rate (L/s)	WQ	WQ test date	Notes
RN9	RN003800	MCFARLANE PEAK BORE NOT USED 2K S/E OF RN	?	536677.6	7748029.4	54.9	Sandstone, siltstone and shale	Bedrock	33.5 and 36.5	30.5	1.8	Stated as "unsuitable for livestock". Basic analysis included - TDS = 7610 mg/l	2/09/1970	
RN10	RN011319	TANAMI STRAT HOLE No85.BMR 53km (W-NW) OF Mt TANAMI.	1/01/1971	515132.6	7799163.2	36.9	Tuff and greywacke	Bedrock	NIL	NIL	NIL	N/A	N/A	
RN11	RN011318	TANAMI STRATA HOLE No84.BMR 50km (WNW) OF MT TANAMI.	1/01/1971	519132.6	7799163.2	9.3	Sandstone - Killi Killi Fm	Bedrock	NIL	NIL	NIL	N/A	N/A	
RN12	RN011317	ANAMI STRATA HOLE No83.BMR 46km (WNW) OF MT TANAMI.	1/01/1971	523132.5	7799163.2	39.6	Sandstone and mudstone - Killi Killi	Bedrock	NIL	NIL	NIL	N/A	N/A	
RN13	RN014172	MT TRACY A83/20 DRY DUD 550M SOUTH OF MT TRACY	29/11/1984	506564.7	7726511.4	55	Sandstone and siltstone	Bedrock	NIL	NIL	NIL	N/A	N/A	
RN14	RN004000	MT TRACEY 0.2LPS SALTY DUD 400 M SE MT TRACEY. NO TRACE	6/09/1963	505132.7	7727263.4	25.9	Sandstone and siltstone	Bedrock	21.3	21.3	0.2	N/A	N/A	
RN15	RN013963	ADV NOA83/17. DRY DUD 10km (SE) OF	6/03/1984	510045.7	7729938.4	50	Siltstone and claystone	Bedrock	NIL	NIL	NIL	N/A	N/A	

Figure 9 ref number	Registration number	Name	Drilled date	Easterly	Southerly	Drill depth	Logged Strata	Bedrock or Palaeochannel	WL Strike (mbgl)	SWL (mbgl)	Flow rate (L/s)	WQ	WQ test date	Notes
		WILSONS CAVE												
RN16	RN014173	A 83/21 DUD 3.9K STH EAST OF POMMIES KNOB	30/11/1984	525535.7	7731047.4	50	Siltstone and claystone	Bedrock	NIL	NIL	NIL	N/A	N/A	
RN17	RN014597	83/26 SEEPAGE DUD 5 K W OF POMMIES BORE	26/12/1985	515628.7	7732527.4	60	Siltstone and shale	Bedrock	45.0	?	NIL	N/A	N/A	Seepage only
RN18	RN004033	POMMIES KNOB 0.6LPOS SALTY DUD 800M S POMMIES KNOB	21/08/1963	522132.7	7732663.4	121.9	Siltstone	Bedrock	53.4 and 67	52	0.6	Residue on evaporation approx. 20 - 23,000 ppm.	N/A	
RN19	RN005173	PRIVATE DUD NO TRACE 3K SSE OF WILSONS CAVE RN5172	20/06/1965	506332.7	7732763.4	45.7	Sandstone and shale	Palaeochannel	NIL	NIL	NIL	N/A	N/A	Possibly not within a palaeochannel - geology isn't as expected
RN20	RN013964	A83/16 DRY DUD 3K N/E OF POMMIES BORES.	6/03/1984	524383.7	7734229.4	50	Siltstone or shale	Bedrock	NIL	NIL	NIL	N/A	N/A	
RN21	RN005172	WILSONS CAVE 11.2K NNE BLOODWOOD BORE WA	1/10/1965	505532.7	7737163.4	11.6	Limestone and quartzite	Palaeochannel	7.6	7.6	1.3	Basic analysis included - TDS = 8320 in 1970 and 14320 mg/l in 1989	12/05/1989	1989 Sample unanalysed for more than one month but general derogation of quality with time

Figure 9 ref number	Registration number	Name	Drilled date	Easterly	Southerly	Drill depth	Logged Strata	Bedrock or Palaeochannel	WL Strike (mbgl)	SWL (mbgl)	Flow rate (L/s)	WQ	WQ test date	Notes
RN22	RN014914	A83/28 WILSONS CAVE DUPLICATE 200M ENE OF WILSONS CAV	2/12/1986	505632.7	7737263.4	34	Limestone	Palaeochannel	27	6		Stated as "fair". Basic analysis included - TDS = 4700 mg/l	2/12/1986	
RN23	RN004844	83/5 1ST ATT.1.2LPS SALTY DUD 3K WNW OF WILSONS CAVE N/	7/05/1965	503032.7	7737663.4	60.9	Tertiary clays and other sediments over siltstone	Palaeochannel	12.1 and 57.9	48.7	1.2	Residue on evaporation approx. 56,000 ppm.		
RN24	RN012901	A 83/13. 13km (NNW) OF FERDYS BORE	7/05/1965	534232.6	7738763.4	150	Limestone, shale and siltstone	Bedrock	NIL	NIL	NIL	N/A	N/A	
RN25	RN004960	A83/5 NO2 SALTY DUD N/TRACE 4KM (WNW) OF WILSONS CAVE?	1/12/1990	501332.7	7739163.4	45.7	Sandstone and clay	Palaeochannel	18.2, 45.7	18.2	1.3	Residue on evaporation approx. 40,000 ppm.		Location considered to dubious in borehole record
RN26	RN004129	LAKE SARA NO 2 DUD NO TRACE 9.6K E LAKE SARA STOCK ROU	30/10/1963	511732.7	7739963.4	33.5	Tertiary clays and other sediments over siltstone	Bedrock	NIL	NIL	NIL	N/A	N/A	
RN27	RN004002	LAKE SARA NO1 0.06LPS DUD 15.5 N/W OF POMMYS KNOB NO/TR	10/09/1969	511632.7	7740463.4	30.4	Tertiary clays and other sediments over siltstone	Palaeochannel / Bedrock?	12.1	12.1	0.06	N/A	N/A	Uncertainty over bedrock or palaeochannel aquifer
RN28	RN004728	B.H.L.PRIVATE NO6 0.01LPS DUD BULLOCK HEAD YARD AREA N/	9/01/1965	518732.7	7740863.4	36.6	Limestone and siltstone	Palaeochannel	12.1	12.1	0.01	N/A	N/A	

Figure 9 ref number	Registration number	Name	Drilled date	Easterly	Southerly	Drill depth	Logged Strata	Bedrock or Palaeochannel	WL Strike (mbgl)	SWL (mbgl)	Flow rate (L/s)	WQ	WQ test date	Notes
RN29	RN004476	A83/1 2ATT B.H.L.0.12LPS DUD 57.6K W HOMESTEAD	RN004476	519532.7	7740863.4	47.2	Limestone and clay over siltstone	Palaeochannel	12.1	12.1	0.12	Residue on evaporation approx. 2800 ppm.	10/09/1964	

APPENDIX C

Palaeochannel Water Quality

ES Figure 4 Ref number	Units	RN21	RN21	RN21	RN21	RN22	RN23	RN23	RN25	RN29
Registration number		RN005172	RN005172	RN005172	RN005172	RN014914	RN004844	RN004844	RN004960	RN004476
Drill depth	m	11.6	11.6	11.6	11.6	34	60.9	60.9	45.7	47.2
Logged Strata		Limestone and quartzite	Limestone and quartzite	Limestone and quartzite	Limestone and quartzite	Limestone	Tertiary clays and other sediments over siltstone	Tertiary clays and other sediments over siltstone	Sandstone and clay	Limestone and clay over siltstone
WL Strike (mbgl)	mbgl	7.6	7.6	7.6	7.6	27	12.1 and 57.9	12.1 and 57.9	18.2, 45.7	12.1
SWL (mbgl)	mbgl	7.6	7.6	7.6	7.6	6	48.7	48.7	18.2	12.1
Sampling Date		12/11/1965	2/09/1970	23/11/1979	12/05/1989	2/12/1986	10/05/1965	10/05/1965	16/07/1965	10/09/1964
pH			8	7.9	7.6	7.9				8.1
EC	µS/cm @ 25 °C		11800	14070	14320	9100				
TDS	mg/l @ 180 °C		8320	9710		4700				
Residue on Evaporation	mg/l	9000					56050	48900	39750	2770
Total Hardness	mg/l as $CaCO_3$	1822	1655	2100	2050	939				1004
Total Alkalinity	mg/l as $CaCO_3$		290	382	424	221				
Na	mg/l		2135			1204				
K	mg/l		330			163				
Ca	mg/l	195	173			100				166
Mg	mg/l	339	298			168				143
Fe	mg/l		<0.1			5.3				
SiO_2	mg/l		76			80				
Cl	mg/l	3490	3456	3724	400	1780				1020
SO_4	mg/l	1690	1470			838				428
NO_3	mg/l		252			158				
HCO_3	mg/l	314	354	466	517	269				342
CO3	mg/l									
F	mg/l		2.3			1.5				
PO_4	mg/l		<1							
NaCl (calculated from Cl)	mg/l			6137	659	2937				

APPENDIX D

Bedrock Water Quality

ES Figure 4 reference number	Units	RN6	RN6	RN7	RN9	RN9	RN9	RN9	RN18	RN18	
Registration number		RN014177	RN014177	RN004664	RN003800	RN003800	RN003800	RN003800	RN004033	RN004033	
Drill depth	m	67.5	67.5	25.9	57.9	56.9	55.9	54.9	121.9	121.9	
Logged Strata		Sandstone and siltstone	Sandstone and siltstone	Sand, clay, siltstone and shale	Sandstone, siltstone and shale	Sandstone, siltstone and shale	Sandstone, siltstone and shale	Sandstone, siltstone and shale	Siltstone	Siltstone	
WL Strike (mbgl)	mbgl	44, 53 and 65	44, 53 and 65	?	33.5 and 36.8	33.5 and 36.7	33.5 and 36.6	33.5 and 36.5	53.4 and 67	53.4 and 67	
SWL (mbgl)	mbgl	27.0	27.0	?	33.5	32.5	31.5	30.5	52	52	
Sampling Date		14/05/1989	3/12/1984	1/01/1966	13/12/1962	10/09/1963	17/01/1965	8/09/1970	10/09/1963	10/09/1963	
pH		7.5	7.4	7.7	7.3		7.5	7.4	7.8	7.6	
EC	μS/cm @ 25 °C	1570	1670					9860			
TDS	mg/l @ 180 °C	955	1030	2235	7019			7610			
Residue on Evaporation	mg/l					8396	8200		20130	22792	
Total Hardness	mg/l as $CaCO_3$	421	451	740	2680		2910	2795	6186	6360	
Total Alkalinity	mg/l as $CaCO_3$	259	247	462				210			
Na	mg/l	148	151	460	1275			1435			
K	mg/l	26	28	83	128			121			
Ca	mg/l	88	85	76	389		444	429	874	948	
Mg	mg/l	49	58	132			436	420	973	1019	
Fe	mg/l	0.8	0.5	0.2				1.3			
SiO_2	mg/l	34	38					13			
Cl	mg/l	260	280	650	2210		2375	2381	7820	8260	
SO_4	mg/l	123	103	282	2154		2379	2500	4103	4464	
NO_3	mg/l	53	42		0			12			
HCO_3	mg/l	316	301	250	431		368	256		256	243
CO3	mg/l			31	nil		nil			nil	nil
F	mg/l	0.7	0.9	1.5				1.8			
PO_4	mg/l							<1			

APPENDIX E

Operational Bore Water Quality

Operational Borehole	**Units**	**Timmy's Bore**	**Wilsons Bore**	**Corsair Bore**
Bedrock or Palaeochannel		Palaeochannel	Bedrock??	Bedrock
Current and (drilled) depth	m	10m – borehole collapsed. (42m).	92m (unknown)	150m (150m)
Logged Strata		Silcrete and alluvium inc. clay	Unknown	Sand and Sandstone
WL Strike (mbgl)	mbgl	Unknown	Unknown	Unknown
SWL in 2013 (mbgl)	mbgl	5.8	40.4	95
Sampling Date		3/04/1994	14/10/2012	14/10/2012
pH		7.8	7.79	7.87
EC	μS/cm @ 25 °C	574	13000	3670
TDS	mg/l @ 180 °C	421	7330	2140
Residue on Evaporation	mg/l			
Total Hardness	mg/l as $CaCO_3$	201	1830	1030
Total Alkalinity	mg/l as $CaCO_3$	230	590	237
Na	mg/l	27	1680	305
Na	mg/l	33	192	44
K	mg/l	41	233	172
Ca	mg/l	24	303	145
Mg	mg/l	<0.1	<0.05	<0.05
Fe	mg/l	106		
SiO_2	mg/l	24	2480	807
Cl	mg/l	21	1760	360
SO_4	mg/l	23		
NO_3	mg/l	281		
HCO_3	mg/l	nil		
CO3	mg/l	1.3		
F	mg/l			
NaCl (calc from Cl)	mg/l	40		
Al	mg/l		0.04	<0.01
As	mg/l		0.002	0.197
Be	mg/l		<0.001	<0.001
Ba	mg/l		0.017	0.03
Cd	mg/l		<0.0001	0.0013
Cr	mg/l		0.012	<0.001
Co	mg/l		<0.001	0.001
Cu	mg/l		0.006	0.001
Pb	mg/l		<0.001	<0.001
Mn	mg/l		0.001	0.28
Mo	mg/l		<0.001	<0.001
Ni	mg/l		0.004	<0.001
Se	mg/l		0.02	<0.01
Sr	mg/l		4.5	2.88
Ti	mg/l		<0.01	<0.01
V	mg/l		<0.01	<0.01
Zn	mg/l		0.041	0.016
B	mg/l		1.32	<0.05

APPENDIX F

Potential yield achievable in individual boreholes

Calculated max theoretical long term yield for individual boreholes (Farvolden Method Only)

		m3/d	l/s
Long term yield (Q20)	**Min Transmissivity**	254	2.9
	Max Transmissivity	444	5.1

Parameter	**Value**	**Units**
Min Transmissivity	40	m2/d
Max Transmissivity	70	m2/d
Confined/unconfined?	unconfined	n/a
Available Head = 2/3rds Sat Thickness		
Saturated thickness	20	m
Available Head	13.3	m

Notes

The calculations do not take account of borehole interference in a wellfield

Bores in a wellfield may demand lower pumping rates due to intrference effects

The aquifer is unconfined and therefore 2/3rds of the saturated thickness is applied

Where groundwater levels will drop due to insufficient recharge yields will be reduced in the long term

Theoretical long-term yield of a proposed production well determined by using either the

Farvolden Method

$Q_{20} = (0.68)(T)\ (H_A) \times (0.7)$

or the

Moell Method

$$Q_{20} = \frac{Q(H_A)}{s_{100} + 5\triangle s} \times 0.7$$

where

H_A = available head (in metres)
s_{100} = the drawdown at 100 minutes (in metres)
Q = well pumping rate during the pumping test (in cubic metres per day [m^3/d])
Q_{20} = sustainable yield for a 20-year period (in m^3/d)
$\triangle s$ = drawdown per log cycle of time
T = transmissivity (in square metres per day [m^2/d])
0.7 = 70% safety factor

The Moell formula is commonly used where large drawdowns occur at the beginning of the pumping period.

For confined aquifers, the available head (H_A) is equal to the distance between the non-pumping water level in the well prior to the pumping test and the top of the aquifer or the top of the completion interval, which ever is less.

For unconfined aquifers, the available head (H_A) is chosen to be equal to 2/3 of the difference between the base of the aquifer and the non-pumping water level in the well (or 2/3 of the saturated thickness of the aquifer).

APPENDIX G

Estimated sustainability of abstraction for individual target areas

Calculated Catchment Areas from Figure 11

	km^2	**m^2**
A	47.3	4.73E+07
B	35.6	3.56E+07
C	223	2.23E+08
D	164.9	1.65E+08
E	75	7.50E+07
F	95	9.50E+07
Minor channels - 1	11.49	1.15E+07
Minor channels - 1A	12.14	1.21E+07

Calculated available catchment resources and net changes in storage for borehole targets

SCENARIO: 4.5mm annual recharge - long term average

Borehole target		**1**	**1A**	**2**	**3**	**4**	**5**
Total catchment area (m2)		1.15E+07	2.36E+07	4.73E+07	1.70E+08	8.29E+07	9.50E+07
Catchment Areas		Minor Channels 1	Minor Channels 1 and 1A	A	E + F	A + B	F
Available groundwater in catchment (m3)	Min Storage coefficient	1.15E+07	2.36E+07	4.73E+07	1.70E+08	8.29E+07	9.50E+07
	Max Storage coefficient	6.89E+07	1.42E+08	2.84E+08	1.02E+09	4.97E+08	5.70E+08
Annual recharge (m3)		51705	106335	212850	765000	373050	427500
Annual catchment deficit/excess (m3)		-298935	-244305	-137790	414360	22410	76860
Estimated average annual catchment water level change (m)	Min Storage coefficient	-0.52	-0.21	-0.06	0.05	0.01	0.02
		Water level falls	**Water level falls**	**Water level falls**	**No net change**	**No net change**	**No net change**
	Max Storage coefficient	-0.09	-0.03	-0.010	0.01	0.00	0.00
		Water level falls	**Water level falls**	**Water level falls**	**No net change**	**No net change**	**No net change**

Parameter	**Value**	**Units**
Conversion factor km2 to m2	1000000	n/a
Min storage coefficient	0.05	n/a
Max storage coefficient	0.3	n/a
Hourly abstraction	40	m3
Annual abstraction	3.51E+05	m3
Annual average recharge	0.0045	m/a
Assumed saturated thickness	20	m

Notes

Catchment areas for boreholes are taken from Figure 11 and assumes that there is no abstraction upgradient in other target boreholes

It is assumed if a positive change to the water level is calculated then there is no net result as this would be evaporated or lost elsewehere since the system was previously in equilibrium

The exception to the above statement is if there is a year with low rainfall where depetion occurs in which case excess recharge will provide additional recharge at that time

Available groundwater in catchment assumes that there is no abstraction elsewhere

Assumes that the full channel width is within the catchment

Calculated available catchment resources and net changes in storage for borehole targets

SCENARIO: 1mm annual recharge

Borehole target		**1**	**1A**	**2**	**3**	**4**	**5**
Catchment Areas		Minor Channels 1	Minor Channels 1 and 1A	A	E + F	A + B	F
Total catchment area (m2)		1.15E+07	2.36E+07	4.73E+07	1.70E+08	8.29E+07	9.50E+07
Available groundwater in catchment (m3)	Min Storage coefficient	1.15E+07	2.36E+07	4.73E+07	1.70E+08	8.29E+07	9.50E+07
	Max Storage coefficient	6.89E+07	1.42E+08	2.84E+08	1.02E+09	4.97E+08	5.70E+08
Annual recharge (m3)		11490	23630	47300	170000	82900	95000
Annual catchment deficit/excess (m3)		-339150	-327010	-303340	-180640	-267740	-255640
Estimated average annual catchment water level change (m)	Min Storage coefficient	-0.59	-0.28	-0.13	-0.021	-0.06	-0.05
		Water level falls	**Water level falls**	**Water level falls**	**Water level falls**	**Water level falls**	**Water level falls**
	Max Storage coefficient	-0.10	-0.05	-0.021	0.00	-0.01	-0.01
		Water level falls	**Water level falls**	**Water level falls**	**Water level falls**	**Water level falls**	**Water level falls**

Parameter	**Value**	**Units**
Conversion factor km2 to m2	1000000	n/a
Min storage coefficient	0.05	n/a
Max storage coefficient	0.3	n/a
Daily abstraction	40	m3
Annual abstraction	3.51E+05	m3
Annual average recharge	0.0010	m/a
Assumed saturated thickness	20	m

Notes

Catchment areas for boreholes are taken from Figure 11 and assumes that there is no abstraction upgradient in other target boreholes

It is assumed if a positive change to the water level is calculated then there is no net result as this would be evaporated or lost elsewehere since the system was previously in equilibrium

The exception to the above statement is if there is a year with low rainfall where depetion occurs in which case excess recharge will provide additional recharge at that time

Available groundwater in catchment assumes that there is no abstraction elsewhere

Calculated available catchment resources and net changes in storage for borehole targets

SCENARIO: No annual recharge

Borehole target		**1**	**1A**	**2**	**3**	**4**	**5**
Catchment Areas		Minor Channels 1	Minor Channels 1 and 1A	A	E + F	A + B	F
Total catchment area (m2)		1.15E+07	2.36E+07	4.73E+07	1.70E+08	8.29E+07	9.50E+07
Available groundwater in catchment (m3)	Min Storage coefficient	1.15E+07	2.36E+07	4.73E+07	1.70E+08	8.29E+07	9.50E+07
	Max Storage coefficient	6.89E+07	1.42E+08	2.84E+08	1.02E+09	4.97E+08	5.70E+08
Annual recharge (m3)		0	0	0	0	0	0
Annual catchment deficit/excess (m3)		-350640	-350640	-350640	-350640	-350640	-350640
Estimated average annual catchment water level change (m)	Min Storage coefficient	-0.61	-0.30	-0.15	-0.04	-0.08	-0.07
		Water level falls	**Water level falls**	**Water level falls**	**Water level falls**	**Water level falls**	**Water level falls**
	Max Storage coefficient	-0.10	-0.05	-0.025	-0.01	-0.01	-0.01
		Water level falls	**Water level falls**	**Water level falls**	**Water level falls**	**Water level falls**	**Water level falls**

Parameter	**Value**	**Units**
Conversion factor km2 to m2	1000000	n/a
Min storage coefficient	0.05	n/a
Max storage coefficient	0.3	n/a
Daily abstraction	40	m3
Annual abstraction	3.51E+05	m3
Annual average recharge	0.0000	m/a
Assumed saturated thickness	20	m

Notes

Catchment areas for boreholes are taken from Figure 11 and assumes that there is no abstraction upgradient in other target boreholes

It is assumed if a positive change to the water level is calculated then there is no net result as this would be evaporated or lost elsewehere since the system was previously in equilibrium

The exception to the above statement is if there is a year with low rainfall where depetion occurs in which case excess recharge will provide additional recharge at that time

Available groundwater in catchment assumes that there is no abstraction elsewhere

APPENDIX H

Protocol for Groundwater Quality Analysis

WATER QUALITY

Parameter		Units	Limit of Detection	Method Reference	Method	Maximum Holding Time	Sample Bottle and Preservation
Field Parameters							
pH		–	0.01	APHA 4500-H^+ B	Electrometry		N/A
Electrical conductivity (EC)		µS/cm	1	APHA 2510 B	Electrode		
Oxidation-reduction potential (ORP)		mV	1				
Turbidity		NTU	0.1	APHA 2130 B	Photometry		
General Parameters							Plastic bottle: 500 mL Preservative: None
pH		–	0.01	APHA 4500-H^+ B	Electrometry	6 hours	
Electrical conductivity (EC)		µS/cm	1	APHA 2510 B	Electrode	28 days	
Total dissolved solids (TDS)		mg/L	10	APHA 2540 C	Gravimetry	7 days	
Total suspended solids (TSS)		mg/L	1	APHA 2540 D	Gravimetry	7 days	
Acidity (CaCO_3)		mg/L	1	APHA 2310 B	Titration	28 days	
Alkalinity - Total (as CaCO_3)		mg/L	1	APHA 2320 B	Titration	14 days	
Hardness (Total as CaCO_3)		mg/L	1	APHA 2340 B	Calculated		
Major Ions & Ligands							
Calcium (Ca^{2+})		mg/L	1	APHA 3120	ICP-AES	28 days	
Potassium (K^+)		mg/L	1	APHA 3120	ICP-AES	28 days	
Magnesium (Mg^{2+})		mg/L	1	APHA 3120	ICP-AES	28 days	
Sodium (Na^+)		mg/L	1	APHA 3120	ICP-AES	28 days	
Chloride (Cl^-)		mg/L	1	APHA 4500-Cl^- B	Titration	28 days	
Fluoride (F^-)		mg/L	0.1	APHA 4500-F^- C	Ion-selective electrode	28 days	
Sulfur Species							
Sulfate (SO_4^-)		mg/L	1	APHA 4500-SO4^- E	Turbidimetry	28 days	
Nutrients							
Nitrate (NO_3^- as N)		mg/L	0.01	APHA 4500-NO_3^- I	FIA-Photometry	2 days	
Ammonia (as N)		mg/L	0.01	APHA 4500 NH_3^- - H	FIA-Photometry	24 hours	
Reactive Phosphorus as P		mg/L	0.01	APHA 4500 P - G	FIA-Photometry	28 days	
Phosphorus - Total		mg/L	0.01	APHA 4500 P - H	FIA-Photometry	28 days	Plastic bottle: 250 mL Preservative: Sulfuric acid Chill to 4°C
Total Kjeldahl nitrogen (TKN as N)		mg/L	0.1	APHA 4500-N_{org} D	FIA-Photometry	28 days	
Chemical Oxygen Demand (COD)		mg/L	5	APHA 5220 B	Titration	28 days	
Carbon							
Total Organic Carbon (TOC)		mg/L	1	APHA 5310 B	IR Spectrometry or titration	28 days	Amber Glass Vial: 40 mL Preservative: Sulfuric acid Chill to 4°C
Dissolved Organic Carbon (DOC)		mg/L	1	APHA 5310 B	IR Spectrometry or titration	28 days	Amber Glass Vial: 40 mL Preservative: Sulfuric acid Chill to 4°C Field filtered to 0.45 µm
Total Carbon (TC)		mg/L	1	APHA 5310 B	IR Spectrometry or titration		Plastic Bottle: 500 mL Preservative: None Chill to 4°C
Cyanide							
Free cyanide (CN^-)		mg/L	0.004	APHA 4500-CN^- C&N	FIA-Photometry	14 days	Opaque plastic bottle: 125 mL Preservative: Sodium hydroxide
Weak acid dissociable (WAD) cyanide (CN^-)		mg/L	0.004	APHA 4500-CN^- I&N	FIA-Photometry	14 days	
Total cyanide (CN^-)		mg/L	0.004	APHA 4500-CN^- C&N	FIA-Photometry	14 days	
Metals – Dissolved							Plastic bottle: 60 mL Preservative: Nitric acid Field filtered to 0.45 µm
Aluminium	Al	mg/L	0.01	USEPA 6020	ICP-MS	6 months	
Antimony	Sb	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Arsenic	As	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Bismuth	Bi	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Boron	B	mg/L	0.05	USEPA 6020	ICP-MS	6 months	
Cadmium	Cd	mg/L	0.0001	USEPA 6020	ICP-MS	6 months	
Chromium	Cr	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Cobalt	Co	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Copper	Cu	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Iron	Fe	mg/L	0.05	USEPA 6020	ICP-MS	6 months	
Lead	Pb	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Lithium	Li	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Manganese	Mn	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Molybdenum	Mo	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Nickel	Ni	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Selenium	Se	mg/L	0.01	USEPA 6020	ICP-MS	6 months	
Silver	Ag	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Tellurium	Te	mg/L	0.005	USEPA 6020	ICP-MS	6 months	
Thallium	Tl	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Thorium	Th	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Uranium	U	mg/L	0.001	USEPA 6020	ICP-MS	6 months	
Vanadium	V	mg/L	0.01	USEPA 6020	ICP-MS	6 months	
Zinc	Zn	mg/L	0.005	USEPA 6020	ICP-MS	6 months	
Mercury (Hg)	Hg	mg/L	0.0001	APHA 3112-Hg B	CV/FIMS	28 days	
Microbiology							Sterile Plastic Bottle: 250 mL Preservative: Sodium Thiosulfate Chill to 4°C and deliver sample to laboratory within 12 hours of sampling
E. coli		MPN/g	20	AS 4276.6		24 hours	
Faecal Coliforms		MPN/g	20	AS 4276.6		24 hours	
Total Coliforms		MPN/g	20	AS 4276.4		24 hours	
Hydrocarbons							Glass bottle: 1,000 mL Preservative: Sulfuric acid
Oil and grease		mg/L	5	APHA 5520 B	Gravimetric	28 days	
Total petroleum hydrocarbons (TPH)		µg/L	20	USEPA 5030	P&T/GC/MS	28 days	
Total recoverable hydrocarbons (TRH)		µg/L	20	USEPA 8260	P&T/GC/MS	28 days	

GROUNDWATER LEVELS

Parameter	Units	Limit of Detection	Method	Frequency	Monitoring locations	Notes
Groundwater Level	m	0.01	Water levels to be measured to a fixed datum either manually using a dip meter or electronically using data loggers	Weekly if manually dipped or hourly if the data is collected using a data logger.	Corsair and Wilsons Bores. Other bores will be added to the program as required.	A barometric logger should be used to record barometric pressure close to the monitoring bores (unless loggers are fitted with vented cables). Data logger downloads should be completed monthly.