Government of South Australia
Department for Energy and Mining

South Australia Strategic Hydrogeological Framework

STUART SHELF REGION

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Department for Energy and Mining

Department for Environment and Water

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Foreword

Sustainable water sources are fundamental to our State's economic growth, environment, and quality of life. Access to water has been a longstanding constraint on the development of some of South Australia's most prospective mineral laden regions. Changing rainfall patterns leading to a drier climate, will exacerbate this situation unless South Australia can identify alternative secure sources of water.

To overcome this limitation South Australia has invested in a strategic hydrogeological framework that deepens our existing knowledge of the water beneath us. By improving our knowledge of groundwater resources, we aim to minimise risks and create greater certainty to investors seeking to progress resource projects within the arid regions of South Australia.

This strategic hydrogeological framework covers the Stuart Shelf, part of the larger Gawler Graton and a world-renowned copper province. Olympic Dam, Carrapateena and Prominent Hill are three operating copper-gold projects in the shelf, however discoveries of several copper deposits including the Oak Dam deposit suggest a substantial potential for future developments.

As international demand for copper grows, to satisfy the global energy transformation, and the further urbanisation of major economies (such as China and India), there is significant opportunity to further develop this world-class copper province. However, sustainable development requires a better understanding of the region's groundwater sources.

This strategic hydrogeological framework pulls together the most contemporary and comprehensive data and information available on groundwater within the Stuart Shelf. It includes analyses of projected water demand and the capacity of known groundwater resources to support it. It also includes a roadmap to help inform Government decision-making and guide further investment to address knowledge gaps and constraints.

The development of this strategic hydrogeological framework was a joint initiative between the Department for Energy and Mining and the Department for Environment and Water. Both departments have a long-standing history of collaboration to create and collate data to better inform the decisions the government and investors make to sustainably advance our State.

To find out more about the framework and the broader exploratory and analytic work carried out by South Australia's internationally recognised team of geoscientists, I encourage you to contact the Department for Energy and Mining. My thanks are extended to everyone involved in producing these important contributions to the state's hydrogeological knowledge.

Dr Paul Heithersay PSM FTSE FSEG FAusIMM
Chief Executive
Department for Energy and Mining

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Executive Summary

SCOPE AND OBJECTIVES

This report covers the development of the Strategic Hydrogeological Framework for the Stuart Shelf region (the study area).

The Stuart Shelf region has a high concentration of known mineral resources, dominated by some of the richest iron oxide-copper-gold (IOCG) deposits in the world. As the primary area of the state where copper and other mineral resources are concentrated, the Stuart Shelf is an area of focus for the government to guide and support mining development. Such development requires a significant amount of water, given the ore processing requirements, and water is very limited in the study area. The framework examines the potential for local groundwater resources to alleviate this constraint and presents an action plan for the State to advance the investigation and development of groundwater resources to support mining.

WATER DEMAND FOR MINING

Known mineral resources in the study area total 12.6 Gt of ore. There are two active mines (Olympic Dam and Carrapateena) producing a combined 15 Mt of ore per year, with long mine lives predicted (more than 50 years in the case of Olympic Dam). There are also several developing projects, some of which are the subject of advanced feasibility studies, indicating a high likelihood of mining expansion in the area.

Current mine water use totals 18 GL/y, with local saline groundwater resources supplying ~6 GL/y and the remainder being sourced externally from the Great Artesian Basin, which is of lower salinity. Mine water demand is projected to increase to ~30–60 GL/y by 2050 based on estimated production rates and typical mine water requirements. The framework examines the extent to which groundwater resources in the study area can support this demand.

GROUNDWATER RESOURCES AND THEIR CAPACITY

The geology of the study area has given rise to a compartmentalised and heterogeneous groundwater system. Groundwater is saline to hypersaline, recharge is very low and yields are variable but can be high in places. Current use of groundwater (outside of the existing mining operations) is very limited and restricted to a small number of stock wells that access local, shallow groundwater resources along drainage lines where small pockets of lower salinity groundwater can occur. Groundwater Dependent Ecosystems (GDEs) are linked to some groundwater fed pools along drainage lines and springs, which include several on or around Lake Torrens—one of Australia's largest saline playa lakes and a sacred site for Traditional Owners.

A qualitative assessment using current information indicates that the groundwater resources in the study area are unlikely to have sufficient capacity to meet the cumulative mine water demands projected; particularly so when water quality requirements are factored in, which dictate that a reasonable portion of the total water demand needs to be of low salinity.

Given there is a low likelihood of groundwater resources in the study area being able to meet the projected water demands, this indicates that an external source of water (e.g. Northern Water Supply) would be required to achieve this level of mining development. However, even if an additional external water supply is developed, groundwater will likely play a significant ongoing role as a primary water resource. Furthermore, some future projects may not have ready access to an external water supply (e.g. due to capital costs) and may need to rely on local groundwater resources. Based on these considerations, there will be continued demand for groundwater resources, with the following groundwater supply options being the most prospective:

- Development of a saline water supply in the Andamooka Limestone and ongoing development of the Tent Hill aquifer in the Stuart Shelf-Arrowie Basin Zone.
- Ongoing development of a saline water supply in the Stuart Shelf-Cariewerloo Basin Zone from the Tent Hill and Pandurra aquifers to the north and the Pandurra and Whyalla Sandstone aquifers to the south.
- The Torrens Basin aquifers subject to further groundwater exploration.

Given the location of the resources relative to the mineral deposits is quite disparate, the development of the groundwater resources and associated infrastructure will likely continue to be developed on a project-by-project basis.

OPPORTUNITIES, CONSTRAINTS AND ISSUES ARISING

The key opportunities in developing groundwater resources to assist mining development include:

- Economic growth and development associated with mining development.
- Water to communities as an extension of mining and groundwater resource development.

The constraints include:

- Limited capacity of groundwater resources relative to projected cumulative long-term water demands.

- Management of salinity and other potential water quality considerations.
- Uncertainties related to:
  - Groundwater resource estimation and long-term sustainability of supply.
  - Mine planning: timing, demand quality and quantity, costs of developing resources, water supply security.

The issues arising include:

- Competition for water resources (e.g. well interference across tenement boundaries).
- Potential impacts (and cumulative impacts) of groundwater resource extraction to existing users and GDEs.

ACTION PLAN

An action plan has been formulated to address the knowledge gaps, constraints and the issues arising. The action plan is designed to prioritise government efforts in the short to medium-term (<5 years). The following actions have been identified:

1. Undertake fieldworks and desktop investigations (including groundwater flow modelling) to address knowledge gaps and better understand the capacity of the groundwater resources, with works to include:
   a. Reviewing and refining the groundwater monitoring network.
   b. Regional-scale pilot drilling and testing program to understand aquifer hydraulic properties and potential accessible storage.
   c. Liaison with existing groundwater users (stock and domestic) to better understand their water access requirements and potential opportunities for the provision of additional water.
   d. Identify and characterise potential GDEs to assess their sensitivity to changes in groundwater quantity (e.g. level and flux) and quality.
   e. Development of a regional-scale numerical groundwater flow model to quantify the cumulative impact of groundwater abstraction from multiple developments (the existing modelling platforms have been focussed on individual developments) and to assess the capacity of the resource to meet demand for a range of development scenarios.
2. Maintain dialogue with project proponents to better understand mine water demand projections.
3. Work with industry to develop a conceptual approach to co-ordinated groundwater resource management. This framework would recognise:
   a. Competing impacts (e.g. well interference) would need to be managed
   b. Joint responsibility of cumulative impacts of groundwater extraction (e.g. to springs on Lake Torrens)
4. Develop a water data protocol (as a state-wide activity) that describes how groundwater data can be collected and collated as part of future mineral exploration.

1 Introduction

1.1 BACKGROUND

South Australia is the driest state within the driest inhabited continent on Earth. Poor access to water is a critical constraint to resource and economic development, particularly for mining development in areas to the north of Goyder's Line.

In seeking to facilitate mining development and economic growth, the South Australian government is considering ways in which it could assist in improving access to water to unlock the mineral opportunities in this region. Some of the works being undertaken include:

1. The Northern Water Supply project being led by Infrastructure SA [Infrastructure SA 2022]), which is considering a significant infrastructure investment involving the construction of a coastal desalination plant and pipeline to transfer treated seawater from the Spencer Gulf to support a new and emerging industries in the Upper Spencer Gulf, b) growth of the mining sector in the State's northern region, and c) support growth in other sectors (e.g. horticulture, pastoral and agriculture).
2. A Water and Infrastructure Corridors Initiative comprising two components:
   - A transport and corridors study, informed by the development of an economic 'heat map', to:
     a. identify the need for possible infrastructure corridors to connect regional economic activity with access to transport, power and water, and;
     b. establish a process to provide for land access negotiations and agreements along such corridors.
   - The development of strategic hydrogeological frameworks to examine the potential for groundwater resources to mitigate water constraints to mining development. The framework is to cover the state's priority mineral provinces in the far north (or north of Goyder's Line), with the initial focus being on two study areas: the Stuart Shelf region of the Gawler Craton, and the Braemar Province (see Figure 1).

This report covers the development of the Strategic Hydrogeological Framework for one of the key study areas: the Stuart Shelf region of the Gawler Craton.

The framework is a joint initiative between the Department for Energy and Mining (DEM) and the Department for Environment and Water (DEW), with DEM acting as the lead agency. CDM Smith has been engaged in a secondment capacity to drive the delivery of the framework as part of the DEM-DEW team.

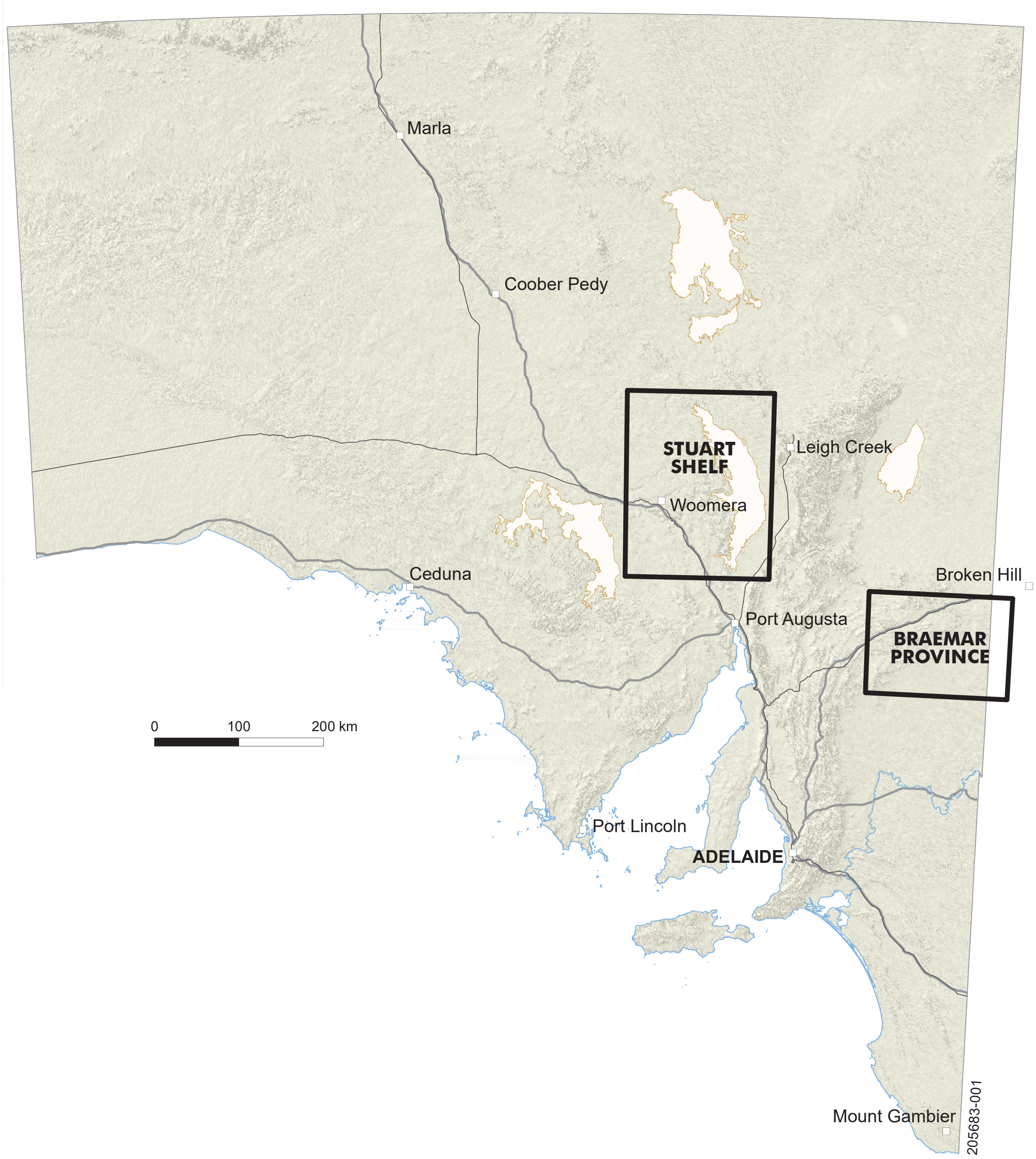

Figure 1 *Strategic Hydrogeological Framework Study Areas*

1.2 OBJECTIVES

The objective of the Strategic Hydrogeological Framework is to present an up-to-date understanding of the water requirements to develop the mineral resources in the defined region of interest (the Stuart Shelf) and an up-to-date understanding of the groundwater resources that could potentially support this mining activity. Based on an analysis of likely mine water demand and the capacity of the groundwater resources to support this demand, a 'road map' is to be developed which is to inform where government efforts can best be directed in the short-to-intermediate term (over the next 5 years or so) to prove up these groundwater resources and instigate corridor planning for water delivery infrastructure.

1.3 STUDY AREA AND SCOPE

The Stuart Shelf has been selected as an area of interest (study area) due to a high concentration of known mineral resources, dominated by iron oxide-copper-gold (IOCG) deposits, in what is a water-limited region. World demand continues to grow for copper, gold and other metallic commodities, and the study area hosts two world class IOCG assets (Olympic Dam and Carrapateena) with several other significant deposits defined. Seeking to capitalise on the increased demand for copper driven by the transition away from fossil fuels, South Australia is seeking to triple its copper production to 1 million tonnes per annum (Mtpa) by 2030 (South Australia's Copper Strategy 2017[1]). As the primary area of the state where copper and other mineral resources are concentrated, the Stuart Shelf is an area of focus for the government to guide and support mining development. Such development requires a significant amount of water, given the ore processing requirements, and water is very limited in the study area.

Figure 2 shows the location of the study area. It covers an area of the Gawler Craton that bounds Lake Torrens and is overlaid by the Stuart Shelf. The mineral resources contained within the study area are primarily IOCG deposits of the Gawler Craton but also include sedimentary hosted deposits of the Stuart Shelf.

The acknowledged water constraints to mining development in the Stuart Shelf area is a key driver for the Northern Water Supply (NWS) project. The Strategic Hydrogeological Framework presented here is separate yet complementary to the NWS project, in that the framework's focus is on groundwater resources contained within the study area but it considers the linkages to other water supply options from outside the of study area (e.g. the NWS or the Great Artesian Basin [GAB]). It is expected that the framework will provide useful context to studies being undertaken for the NWS, which is currently being assessed via a business case.

1 www.energymining.sa.gov.au/home/events-and-initiatives/initiatives/south_australias_copper_strategy

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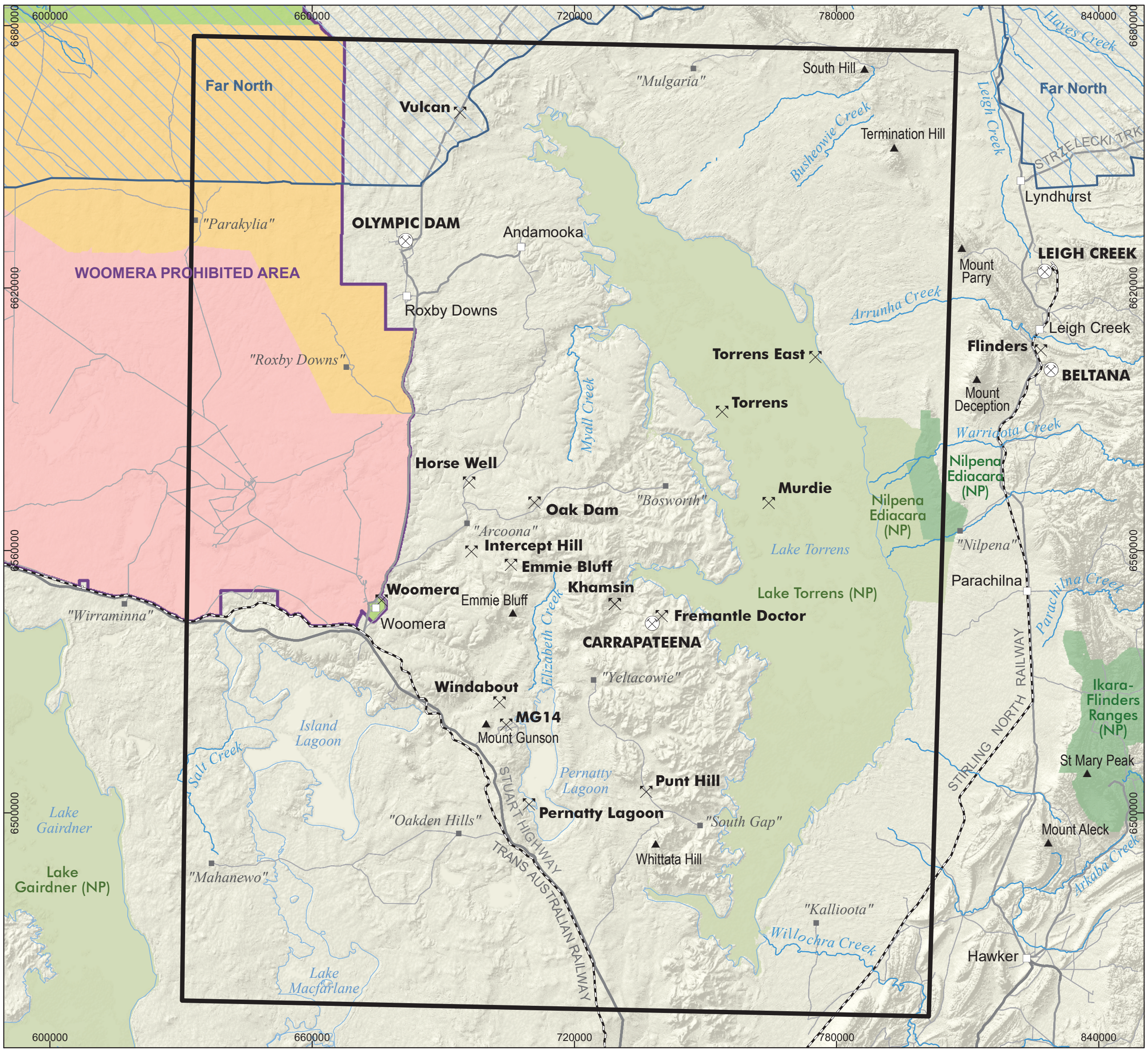
STUART SHELF TOPOGRAPHIC LOCATION



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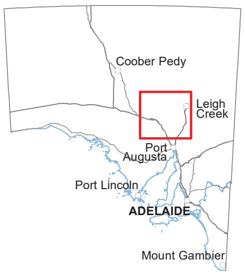

0 25 50 km
GDA2020 Projection Zone 53

Current as at May 2023

Study area

Mines and projects

- Major mine
- Mining project/deposit

Woomera Prohibited Area

- Outer boundary
- Defence continuous use zone
- Defence infrequent zone
- Defence periodic use zone 1

Prescribed Wells Areas

Parks and reserves

- No mineral exploration access
- Mineral exploration access

Topographic information

- Locality
- Homestead
- Hill or peak
- Watercourse
- Lake
- Highway
- Secondary road
- Minor road
- Railway

Figure 2 *Stuart Shelf study area*

1.4 THIS REPORT

This report is structured to present the Strategic Hydrogeological Framework as a logical review and analysis of the available information to arrive at a road map, as follows:

- Section 2 presents a summary of the known mineral resources contained within the study area and the status of mining activity (from exploration to feasibility studies to operations).
- Section 3 examines mine water requirements and presents an estimate of the projected water demand to develop the mineral resources. Water quality requirements are also described.
- Section 4 presents a summary of the regional hydrogeology and describes what is known about the potential groundwater resources within the study area and its immediate surrounds. The prospectivity of these groundwater resources is interrogated.
- Section 5 presents an analysis of whether the capacity of the potential groundwater resources in the region (described in Section 4) is sufficient to meet the projected mine water demands (described in Section 3). A SWOT Analysis (Strengths, Weaknesses, Opportunities and Threats) is undertaken to assess the groundwater resource potential.
- Section 6 presents a road map to guide government efforts in groundwater and corridor planning in helping to facilitate the mining investment and activity. It presents an action plan that is framed around addressing the key knowledge gaps, constraints and developing pathways to navigate the issues arising.

Mining industry stakeholders are being engaged and consulted in the development of this framework. A draft version of this report was circulated for review and feedback, and a project workshop was held to discuss the key findings and recommendations. The following parties have been consulted in the development of this framework:

- OZ Minerals
- BHP
- Coda Minerals
- Argonaut Resources
- Cohiba Minerals
- FMG
- Gold Road
- Department for Energy and Mining
- Department for Environment and Water
- Department for Infrastructure and Transport

2 Study area, mineral resources and development

2.1 STUDY AREA

The Stuart Shelf study area is shown in Figure 2. It is situated to the west of the Flinders Ranges and includes Lake Torrens and the area west to Lake Gairdner. The landscape is generally flat, with numerous playa lakes and occasional low hills in the south and extensive windblown dune fields in the north around Olympic Dam. The climate is arid, with hot dry summers and cool winters.

Mean annual rainfall is ~160 mm[2] and potential evaporation is around 3,000 mm, so water availability is a key limiting factor for land use and mining activities. Currently, the major land use is pastoral. Prior to European settlement the region was occupied by the Kujani, Kokatha and Pangkala people (Tindale, 1974).

2 Mean annual rainfall was 139 mm since 1998 at Roxby Downs Olympic Dam Aerodrome (BOM station 16096), and 181 mm since 1949 at Woomera Aerodrome (BOM station 16001).

2.2 MINERAL RESOURCES

The spatial boundaries of the Stuart Shelf study area have been defined to include some of the major mineral resources of the Olympic copper-gold province, which extends northwest towards Coober Pedy and southeast through the Adelaide Hills. Figure 3 shows the locations of the main deposits that are being developed and mined in the study area.

The Gawler Craton basement rocks beneath the Stuart Shelf host some of the richest IOCG mineralisation in the world. These deposits are thought to have formed ca. 1595–1575 Ma during major volcanic and intrusive activity in the area (Reid 2019). Mineralisation is typically copper-iron sulfide chalcopyrite and gangue pyrite, forming 10–15% of the rock mass.

The supergiant Olympic Dam deposit (Cu, Au, U, Ag) was discovered in 1975, leading to the designation of the IOCG class of deposits worldwide and the delineation of South Australia's Olympic copper-gold province. This deposit is at least an order of magnitude larger than any of the other known deposits in the province (Table 1). JORC-compliant resources in the study area include Olympic Dam, Carrapateena and its satellite deposits (Fremantle Doctor and Khamsin), and the deposits associated with the Elizabeth Creek project (MG14, Windabout, and Emmie Bluff).

The study area includes two active mines – Olympic Dam and Carrapateena – currently producing in the vicinity of 10 Mt and 5 Mt of ore per year respectively. Both mines are exclusively underground operations due to the economics of mining beneath the thick overburden. Olympic Dam has an expected mine life of more than 50 years, while Carrapateena has an expected mine life of around 20 years. The current mining rates compared to total resource estimates would suggest much longer mine lives are possible. In both cases continued resource development initiatives will likely extend the mine lives beyond the currently indicated timeframes.

Developing projects in the study area include those listed in Table 2, with an indication of their development status.

Table 1 *JORC-compliant total mineral resources in the study area.*

Deposit name	Owner	Total resource						
		Ore Gt	Cu Mt	U^3O^8 Mt	Au kt	Ag kt	Co kt	Zn kt
Olympic Dam[a]	BHP	11.32	80.5	2.61	3.53	14.78	-	-
Carrapateena[b]	OZ Minerals	0.96	5.4	-	0.24	2.58	-	-
Fremantle Doctor[c]	OZ Minerals	0.10	0.7	-	0.05	0.31	-	-
Khamsin[d]	OZ Minerals	0.20	1.2	-	0.02	0.34	-	-
MG14[e]	Coda Minerals	0.002	0.02	-	-	0.03	1	-
Windabout[e]	Coda Minerals	0.02	0.14	-	-	0.14	9	-
Emmie Bluff[f]	Coda Minerals	0.04	0.6	-	-	0.47	20	70
	Totals	**12.64**	**88.5**	**2.61**	**3.84**	**18.65**	**30**	**70**

a *30 June 2022, BHP annual report 2022 (measured, indicated, and inferred)*
b *30 June 2020, OZ Minerals ASX announcement (measured, indicated, and inferred)*
c *12 November 2018, OZ Mineral resource statement (inferred)*
d *23 March 2014, OZ Minerals resource statement, ASX Announcement (inferred)*
e *26 October 2020, Coda Minerals ASX Announcement (indicated)*
f *20 December 2021, Coda Minerals ASX Announcement (indicated, and inferred)*

Table 2 *Developing mining projects in the study area.*

Project	Commodities	Owner	Development Status
Oak Dam	Cu, Au, U, Ag	BHP	Advanced Exploration
Fremantle Doctor	Cu, Au, Ag	OZ Minerals	Exploration
Khamsin	Cu, Au, Ag	OZ Minerals	Pre-Feasibility Study
Elizabeth Creek[a]	Cu-Co-Ag	Coda Minerals	Feasibility Studies
Intercept Hill	Cu, Au, Ag	White Tiger Resources	Exploration
Lake Torrens	IOCG	Argonaut Resources	Exploration
Torrens East	IOCG	Auroch Minerals	Exploration
Pernatty Lagoon	IOCG	Red Metal	Exploration
Punt Hill	IOCG	Red Metal	Exploration
Woomera	IOCG	Petratherm	Exploration
Horse Well	IOCG	Cohiba Minerals	Desktop review
Vulcan	IOCGU	Tasman Resources / FMG	Exploration

a *Includes MG14, Windabout and Emmie Bluff sedimentary deposits, and Emmie Bluff Deep IOCG deposit*

While the rocks of the Gawler Craton host the bulk of the mineral resource, it is thought that up to 40% of South Australia's copper deposits are contained in the overlying sedimentary formations of the Stuart Shelf cover sequence (Krapf et al 2022). Sedimentary hosted copper deposits are typically thin (<50 m) but laterally extensive (several kilometres) with associated cobalt, lead, and zinc (Krapf et al 2022). Orebodies are commonly hosted in sandstone, siltstone, shale, and dolomite in intracratonic sedimentary basins. For example, the Elizabeth Creek project includes sediment hosted copper-cobalt-silver sulfide deposits in the Stuart Shelf (MG14, Windabout, and Emmie Bluff) and potentially also a deeper IOCG deposit (Emmie Bluffs Deep) in the underlying Gawler Craton. Sedimentary mineralisation at this location is thought to have formed through replacement of diagenetic pyrite within dolomitic shales of the Tapley Hill Formation.

Exploration activities have recently been occurring beneath Lake Torrens, with a range of highly prospective IOCG targets (e.g., Argonaut Resources), potentially rivalling Olympic Dam if confirmed. Current exploration leases are shown in Figure 4.

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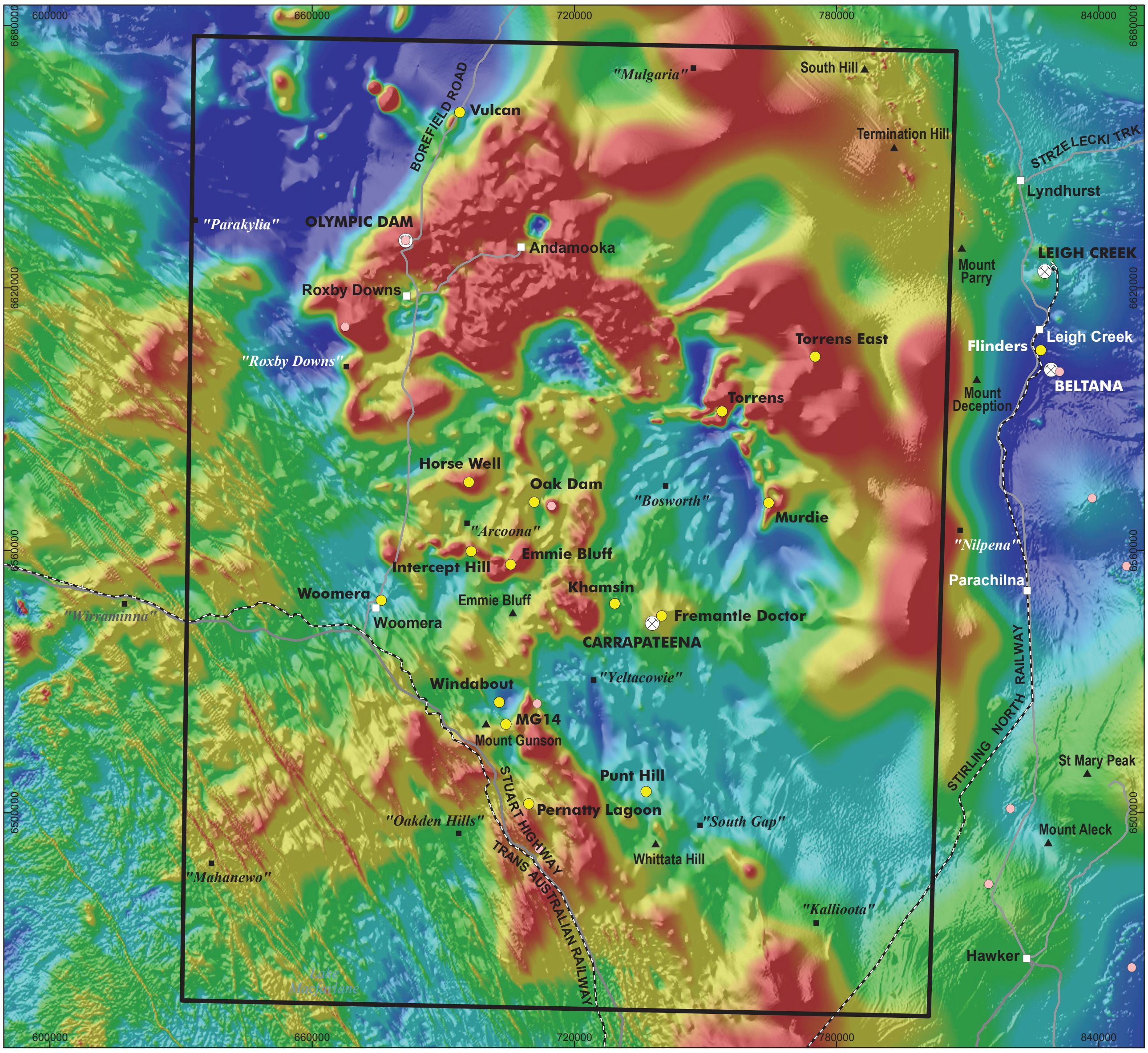
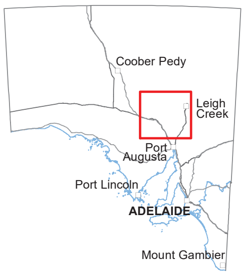
STUART SHELF
TOTAL MAGNETIC INTENSITY (TMI) – REDUCED TO POLE





Current as at May 2023

Study area

Iron ore occurrences

Mines and projects

Major mine

Mining project/deposit

Topographic information

Locality
Homestead
Hill or peak

Highway
Secondary road
Railway

0 25 50 km

GDA2020 Projection Zone 53

Total Magnetic Intensity (nT)

High: 628.907 Low: -351.293

Figure 3 *Stuart Shelf study area mineral resource occurrences shown over TMI image*

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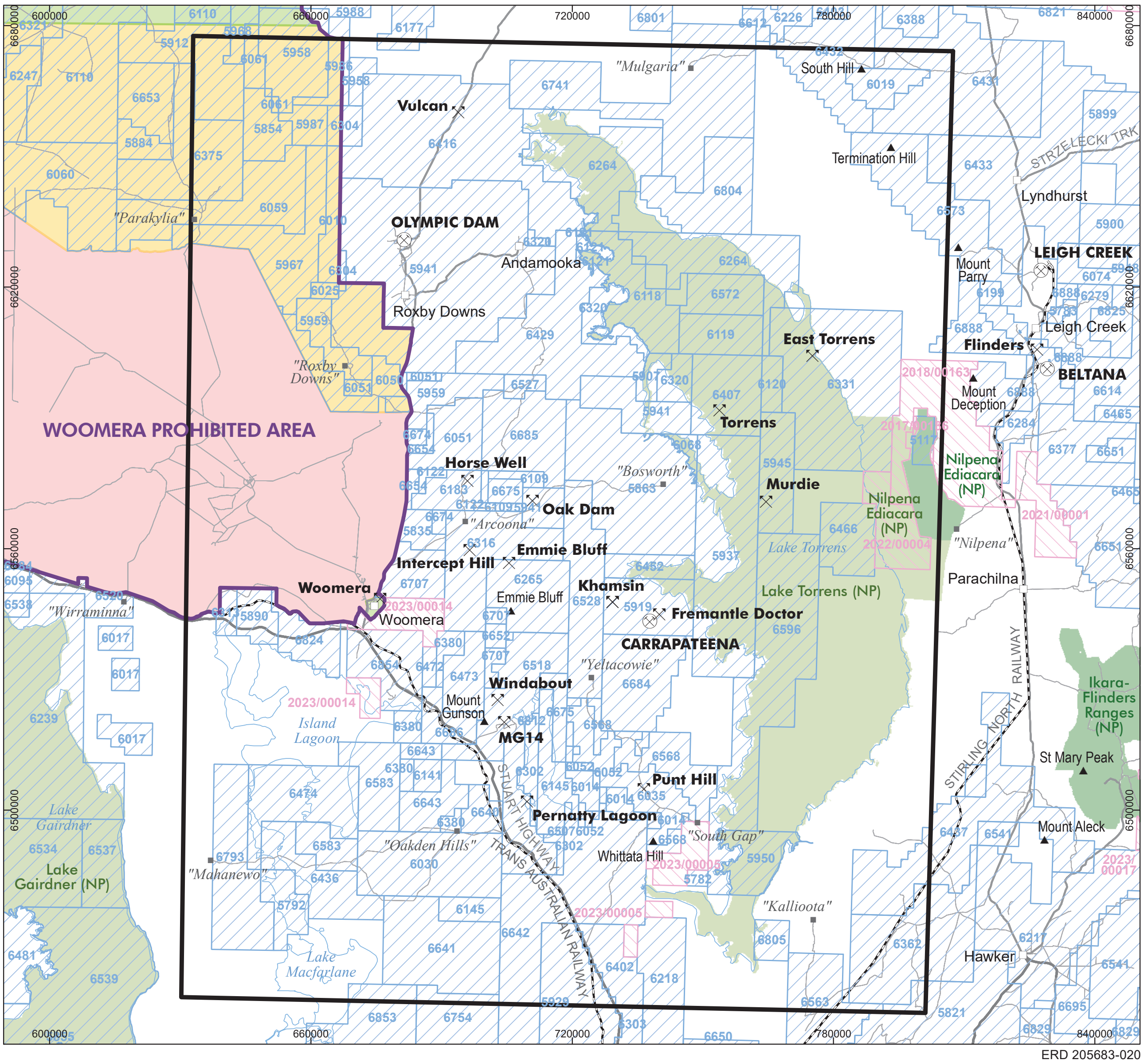
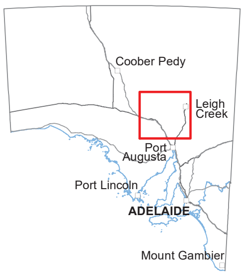
Government of South Australia
Department for Energy and Mining

STUART SHELF MINERAL EXPLORATION ACTIVITY





Current as at May 2023

- Study area

Mineral exploration licences

- Exploration licence (EL)
- Exploration licence application (ELA)

Mines and projects

- Major mine
- Mining project/deposit

Parks and reserves

- No mineral exploration access
- Mineral exploration access

Woomera Prohibited Area

- Outer boundary
- Defence Continuous Use Zone: 12 months exclusive access
- Defence Periodic Use Zone 1: 140 days exclusive access
- Defence Infrequent Zone: Up to 56 days exclusive access

Topographic information

- Locality
- Homestead
- Hill or peak
- Lake
- Highway
- Secondary road
- Minor road
- Railway

Figure 4 *Current exploration leases.*

3 Mine water demand

3.1 MINE WATER REQUIREMENTS

3.1.1 Quantity

Water is required for many aspects of a mining development which include but are not limited to:

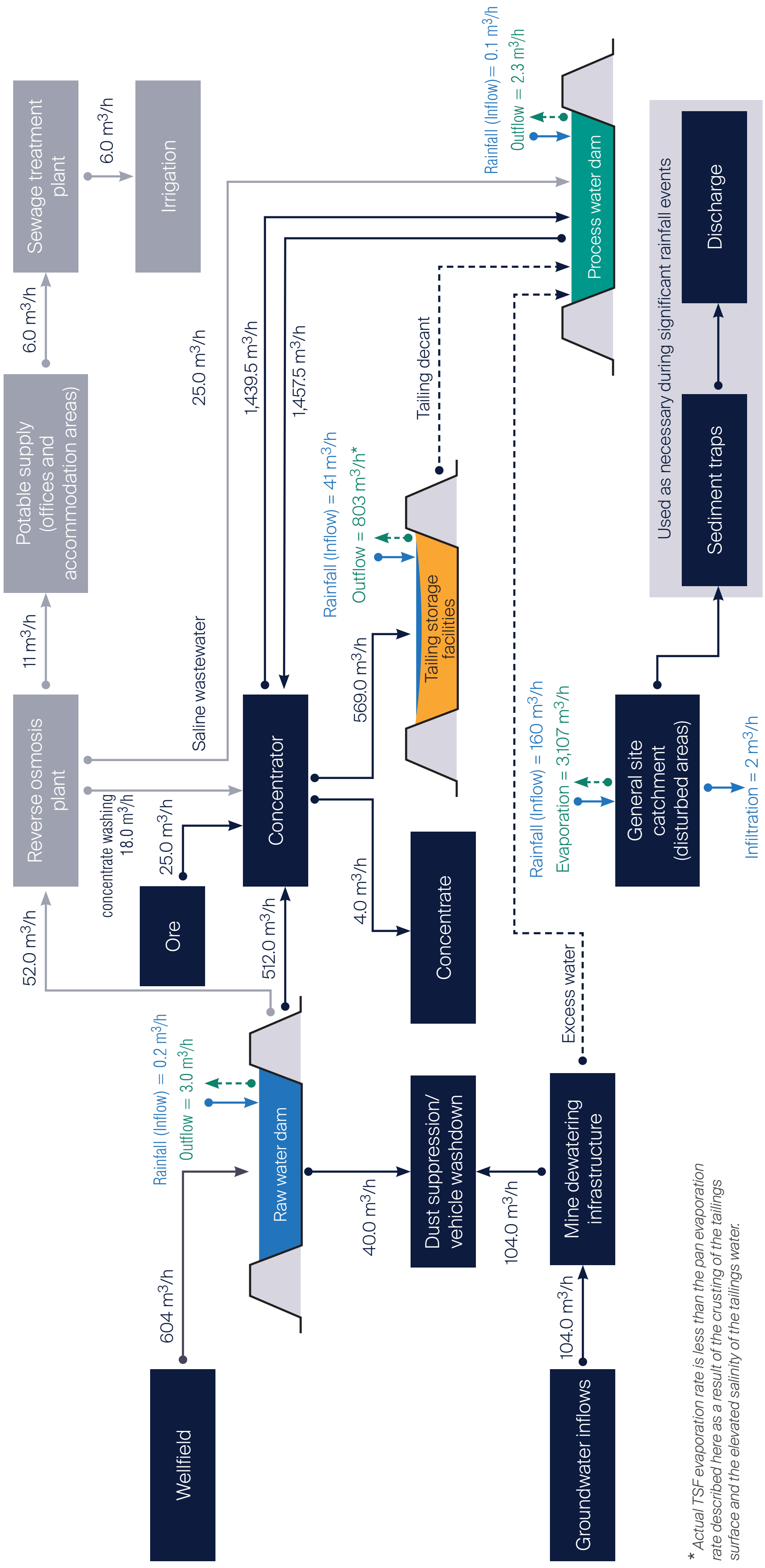
- Construction requirements (e.g. mine plant, mine camp, haul roads, infrastructure)
- Dust suppression (in-pit and ex-pit)
- Potable water for workforce, mine camp and workshops
- Mineral processing and tailings
- Product export
- Exploration drilling

Of these requirements, mineral processing and tailings are typically the most substantial component of the mine water balance. An example of a mine water balance for Prominent Hill (OZ Minerals, 2017) is shown in Figure 5 highlighting that water for processing is the largest component of the mine water balance. Similarly, the time series for water demand at Carrapateena also shows the dominance of water for processing (Figure 6, OZ Minerals 2020).

There is only limited public information available on water demand for mining in the region. OZ Minerals (2020) report that approximately 4 GL/y is required for the proposed expanded Carrapateena block cave mine (annual production at 4.25 Mt), which equates to approximately 1 GL for every Mt of ore milled and processed to produce a concentrate for export. This water is sourced from local saline groundwater supplies within 50 km of the mine.

Olympic Dam operations sourced approximately 12.2 GL/y (35.1 ML/d) of groundwater from the GAB (Wellfields A and B) in FY2021 to support production rates (milled tonnes) in the order of 11.5 Mtpa (BHP 2021a). Local saline groundwater resources are also used to support mining operations with 1.6 GL used in FY2021 (BHP 2021a). A water use efficiency target is set within the Olympic Dam Environmental Protection and Management Program (EPMP) which applies to GAB water use (BHP 2021b). The target states that GAB water use should be less than 1.16 kL for every tonne of ore milled (equating to 1.16 GL/Mt). In FY2021, a GAB water use efficiency of 1.11 kL/t (or GL/Mt) was achieved (BHP 2021b).

Ongoing demand for GAB water for Olympic Dam is projected to be around 12.8 GL/y (35.1 ML/d) to 2031 (BHP 2021).



** Actual TSF evaporation rate is less than the pan evaporation rate described here as a result of the crusting of the tailings surface and the elevated salinity of the tailings water.*

Figure 5 *Prominent Hill mine water balance (OZ Minerals 2017) Note: rainfall and evaporation flows are annual averages.*

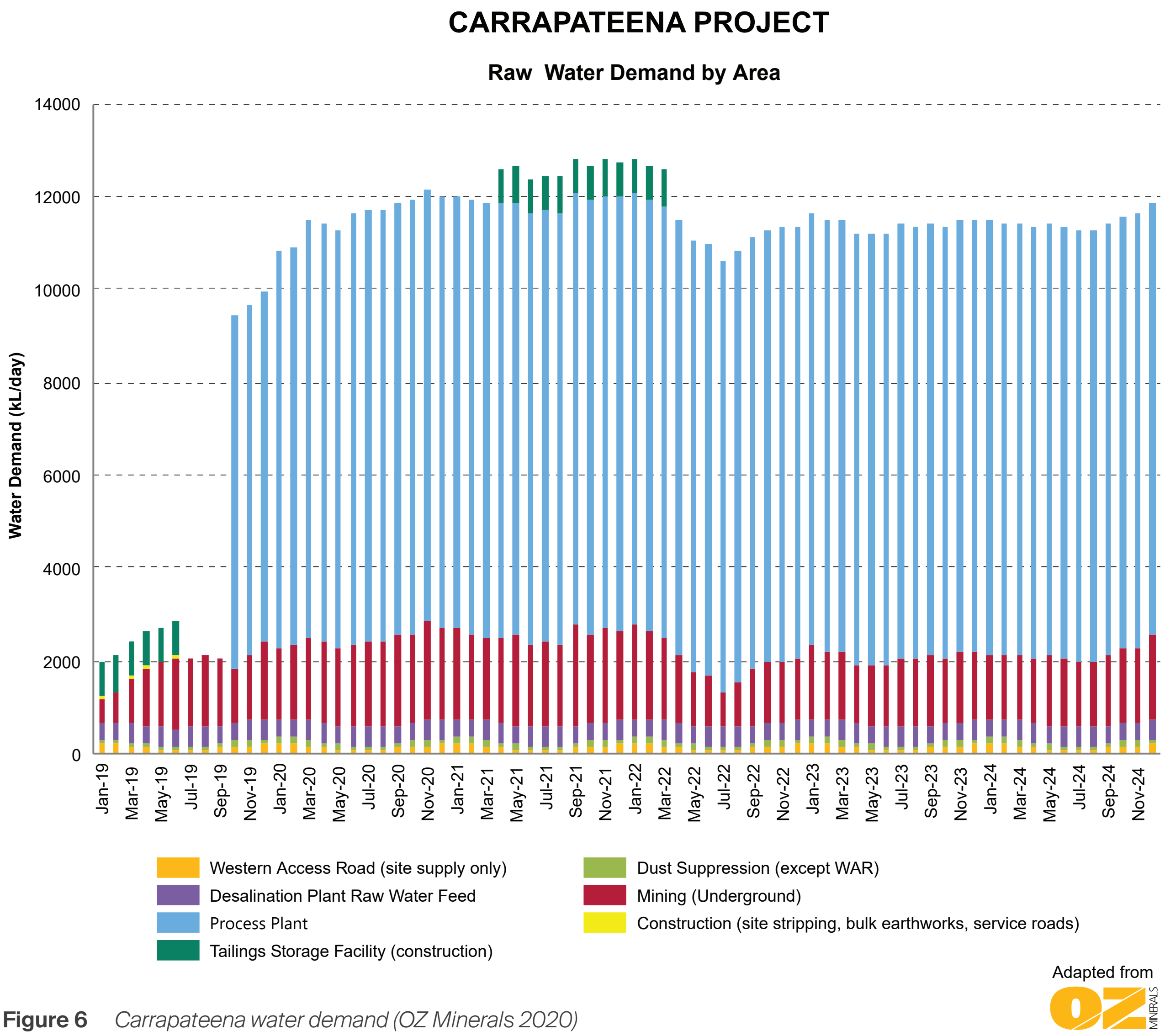


Figure 6 *Carrapateena water demand (OZ Minerals 2020)*

3.1.2 Quality

Processing water quality requirements vary from site to site based on the characteristics of the ore and the proposed metallurgical processes used. While low salinity water is preferable (highly saline water is also corrosive), many projects (e.g. Carrapateena) can tolerate the use of highly saline water for most processing requirements with a small quantity of fresh water used to wash the final product and remove impurities. However, it is understood that fresher water is needed for mineral processing at Olympic Dam due to the nature of the ore body and for uranium recovery.

Water supply salinity requirements are hard to define given the variables involved. It is likely that saline water (14,000 to 35,000 mg/L) and in some cases hypersaline water (>35,000 mg/L) is suitable to develop many of the mineral deposits in the study area. However, given the experience at Olympic Dam it would be prudent to assume that a reasonable portion of the total mine water demand in the study area (perhaps 25-50%) would need to be of low salinity. It is also assumed that each project would implement some level of desalination capacity (e.g. reverse osmosis [RO] treatment) to cover concentrate washing and potable needs.

3.2 PROJECTED REGIONAL WATER DEMAND

The Northern Water Supply (NWS) project (Infrastructure SA 2022) proposes to supply desalinated water to the Far North via a 400 km pipeline and a desalination plant in Upper Spencer Gulf. The NWS project has undertaken an evaluation of possible future water demand for current and future mines in the study area, which includes ongoing mining and expansion at Olympic Dam and Carrapateena, and assumes the development of:

- Elizabeth Creek (incl. MG14 and Windabout)
- Fremantle Doctor
- Oak Dam
- Khamsin, The Saddle and Carra Regional
- Emmie Bluff
- Murdie (or other deposits of this scale)

Table 3 presents a summary of the cumulative water demand in the study area projected for 2050 based on the analysis undertaken by the NWS project, which largely assumed 1 GL of water being required to produce 1 Mt of ore milled and processed.

Table 3 *Current and projected cumulative mine water demand for the Stuart Shelf study demand (Infrastructure SA 2022)*

Current use (GL/y)	**Future demand based on NWS projections at 2050**	
	Low case (GL/y)	**High case** (GL/y)
18.3	28.5	56.6

4 Hydrogeology and groundwater resources

4.1 REGULATORY CONTEXT

Mining operations in South Australia are regulated by the *SA Mining Act 1971* except for the Olympic Dam mine, which operates under the *Roxby Downs (Indenture Ratification) Act 1982* and the Olympic Dam and Stuart Shelf Indenture (the Indenture) that is a schedule to the Act and applies to the Special Mining Lease (SML) area and to Olympic Dam operations outside of the SML.

State legislation for land and water management is provided by the *Landscape South Australia Act 2019*. The study area occurs within the South Australia Arid Lands Region. The study area also includes part of the Woomera Prohibited Area, proclaimed under the *Defence Act 1903* and regulated by *Defence Force Regulations 1952* and the Woomera Prohibited Area Rule 2014; however, most of the known mineral deposits are outside of this zone. The Far North Prescribed Wells Area (PWA) overlaps a small part of the study area in the north, and the groundwater resources in this zone are managed by the Far North Water Allocation Plan (WAP).

Excluding the small zone which overlaps the Far North PWA, surface water and groundwater in the study area are non-prescribed water resources meaning they are not allocated nor managed in accordance with a WAP. They are, however, subject to several general protections provided by the *Landscape South Australia Act 2019* and Regional Landscape Plans (SA Arid Lands Landscape Board 2021).

The conditions of use of groundwater for mining are managed largely as a Program for Environment Protection and Rehabilitation, PEPR (under Part 10A, *Mining Act 1971*), which requires proponents to manage the environmental impacts associated with mining operations. The PEPR would require that a proponent associated with exploration or mineral lease development outlines an understanding of the groundwater resource, likely impacts, monitoring approach and strategies for mitigation of risks. In this case, the Minister could request a PEPR for development of a groundwater resource with an emphasis on:

- Benchmarking the understanding of the groundwater resource (e.g. recharge mechanisms).
- Describing a conceptual design for a wellfield with estimated extraction rates during the life-of-mine.
- Quantifying the cumulative impact of extraction on the resource and other users (consumptive and environmental) assuming multiple operators.
- Approach to monitoring and reporting of wellfield cumulative impacts.
- Approach to mitigation of risks.

For Olympic Dam operations, clauses 11 and 13 of the Indenture sets out the conditions and requirements for groundwater use. Water use from the remote wellfields to the north of the study area in the Great Artesian Basin (GAB) is managed in accordance with the Special Water Licence and Environment and Protection Management Plan for Olympic Dam.

4.2 CLIMATE AND HYDROLOGY

The study area is arid with potential evaporation (~2,200 mm/y[3]) exceeding rainfall (~180 mm/y[4]) by a factor of 12. The rainfall is very irregular and sporadic. In the rare events that it does rain, it can be localised and very heavy. Rainfall data from Woomera indicates around 30% of the total cumulative rainfall occurs from daily rainfall events in excess of 20 mm.

Surface water is highly ephemeral. Watercourses drain the Stuart Shelf plateau in a dendritic pattern and terminate within large salt lakes (playas) that include Lake Torrens, Pernatty Lagoon and Lake Windabout. Surface water flow only occurs for short periods following significant rainfall; however, some permanent pools are present along a few creeks (OZ Minerals 2018), indicating persistence of shallow groundwater discharge. These resources are finite and are not large enough to be developed into a reliable water resource but likely have some ecological value.

A series of small, farm dams have been constructed throughout the region to capture a portion of surface runoff for stock and domestic use, supporting pastoral land uses.

Lake Torrens is one of Australia's largest saline playa lakes and is a sacred site for Traditional Owners. Its catchment covers part of Stuart Shelf and is larger to the east of the lake, extending into the Flinders Ranges. The lake was formed within the depression created by the Torrens Hinge Zone, which created a rift extending through to the Spencer Gulf. It was regularly filled by water during wetter periods of the Pleistocene (when it was fresh to brackish), but the onset of hotter and more arid conditions has caused it to dry out and become hypersaline (when water is present). It is now rarely filled with water and is endorheic, meaning it has no outflow, and water is lost by evaporation, leaving salt behind. In 1989, extreme rainfall caused it to overflow into the Spencer Gulf, but this is the only time in recorded history that this has occurred.

The lake forms a regional groundwater discharge zone and springs are known to occur on the shore of Lake Torrens and on the lake itself, some which support refuge populations of Lake Eyre Hardyhead (BHP Billiton 2009; OZ Minerals 2018).

3 Based on average daily pan evaporation at Woomera Aerodrome (BOM Site 016001) multiplied by a factor of 0.7.

4 Based on average annual rainfall at Woomera Aerodrome (BOM Site 016001)

4.3 GEOLOGY

The study area is located on the eastern edge of the Gawler Craton (an Archean to Paleoproterozoic basement complex) where it is covered by the Stuart Shelf (a platform of Neoproterozoic to Cambrian sediments). The Torrens Hinge Zone and the edge of the Adelaide Geosyncline cover the eastern portion of the study area. Figure 7 shows the main geological domains and the surface geology is shown in Figure 8.

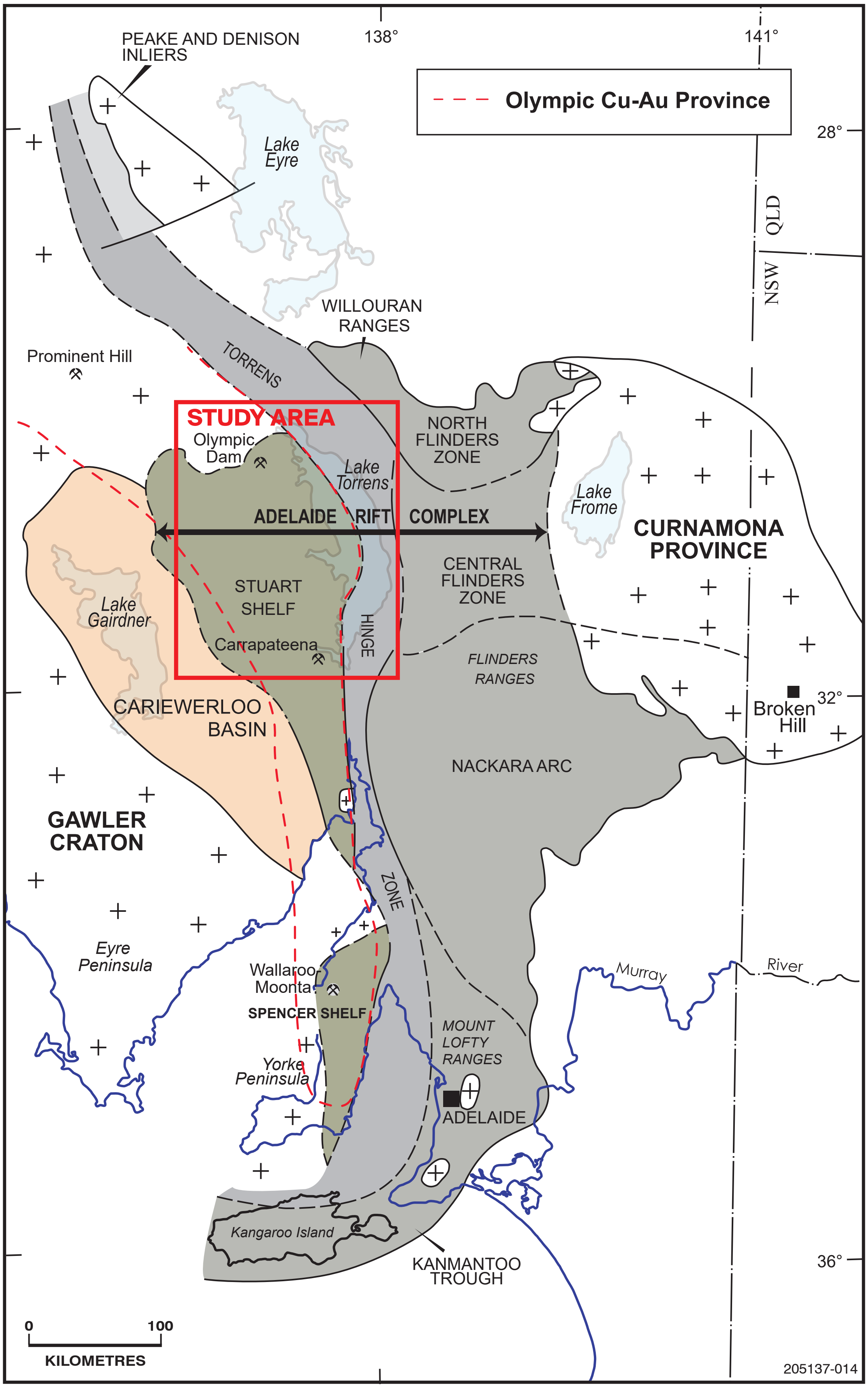


Figure 7 *Location of the study area relative to major tectonic subdivisions of the Adelaide Rift Complex and the Olympic Cu-Au province which hosts the IOCG deposits (after Reid 2019).*

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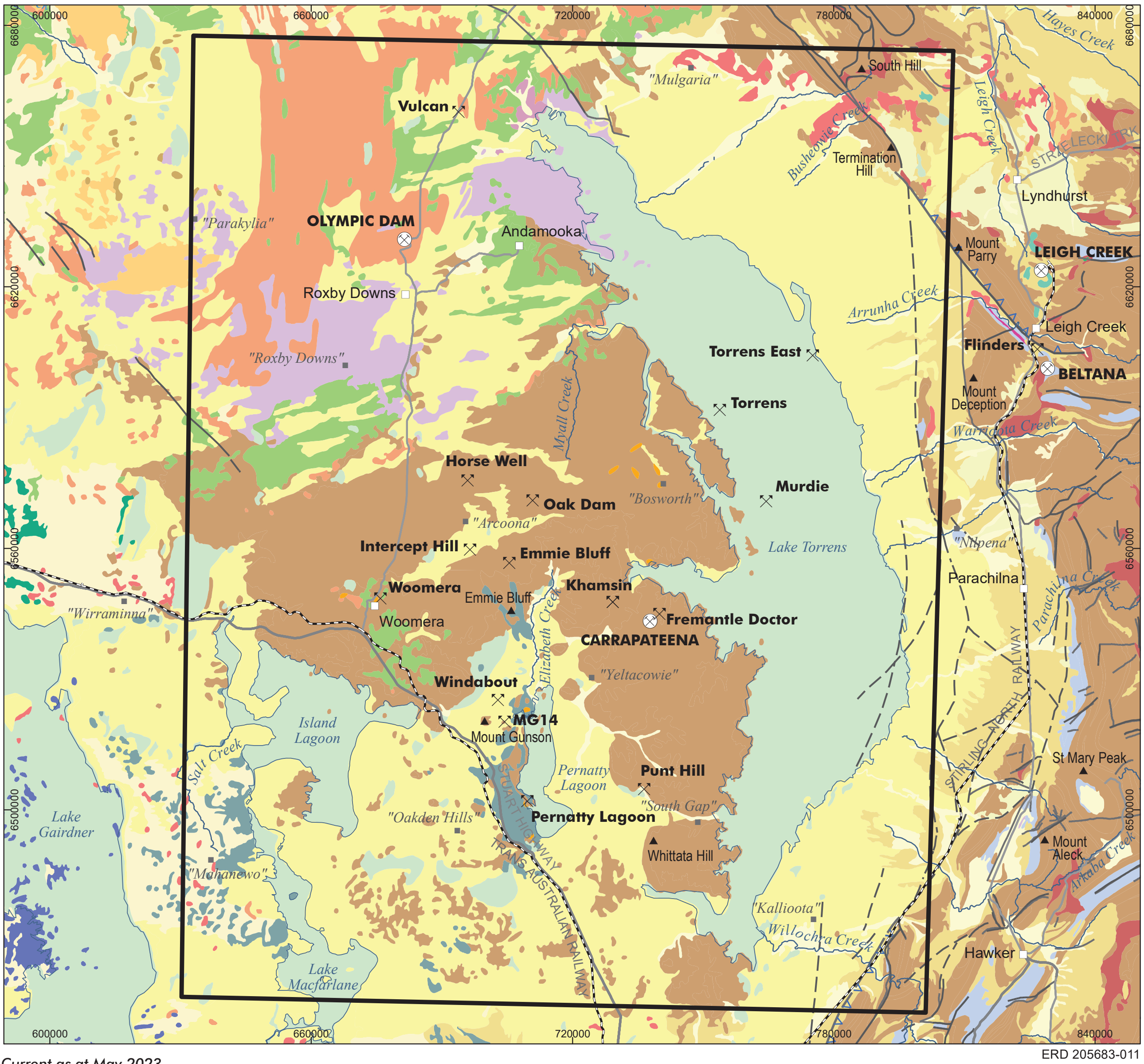
STUART SHELF SURFACE GEOLOGY



Current as at May 2023

0 25 50 km
GDA2020 Projection Zone 53

Surface geology (1M)

QUATERNARY
- Channel and flood plain alluvium; gravel, sand, silt, clay
- Dunes, sandplain with dunes and swales
- Pooraka Formation
- Arrowie Formation
- Lake and swamp deposits

CENOZOIC
- Undifferentiated consolidated Cenozoic sedimentary rocks
- Millers Creek Dolomite Member
- Ferruginous duricrust, laterite
- Sand or gravel plains, quartz sand sheets
- Silcrete, silicified gravel, siliceous duricrust, siliceous breccia

CRETACEOUS
- Bulldog Shale

JURASSIC-CRETACEOUS
- Algebuckina Sandstone

TRIASSIC-JURASSIC
- Leigh Creek coal measures

CARBONIFEROUS-PERMIAN
- Boorthanna Formation, Alpana Formation

CAMBRIAN-ORDOVICIAN
- Hawker Group

CAMBRIAN
- Andamooka Limestone
- Yarrawurta Shale
- Billy Creek Formation

NEOPROTEROZOIC
- Wooltana Volcanics
- Heysen Supergroup
- Breccia, diapiric, carbonate-cemented

MESOPROTEROZOIC
- Yardea Dacite
- Pandurra Formation

Fault structures
- Fault position accurate
- Fault position approximate
- Fault reverse approximate triangles upthrown side
- Fault reverse triangles upthrown side

Study area

Mines and projects
- Major mine
- Mining project/deposit

Topographic information
- Locality
- Homestead
- Hill or peak
- Watercourse
- Lake
- Highway
- Secondary road
- Railway

Figure 8 *Surface geology.*

The major stratigraphic groupings are as follows:

- The Gawler Craton (see Figure 9) contains Archaean to Paleoproterozoic granitic and volcanic basement complexes, overlain by Paleoproterozoic volcano-sedimentary expressions. The formation of these rocks was followed by periods of significant magmatism and metamorphism which saw the formation of the IOCG deposits in the Olympic Cu-Au province (Reid 2019).
- During the Mesoproterozoic, continental sediments were deposited in the Carriewerloo Basin (see Figure 10) to form the Pandurra Formation (mostly riverbed sediments featuring sandstone, conglomerate, mudstone and siltstone). This unit was subsequently intruded by the Gairdner Dolerite in the early Neoproterozoic.
- From the Neoproterozoic to the Cambrian (Figure 11), sediments were deposited in a fault-controlled basin forming the Adelaide Rift Complex. This includes:
  - The Umberatana Group, which hosts the Tapley Hill Formation (finely laminated siltstone and dolomite) and Whyalla Sandstone.
  - The Wilpena Group, which hosts the Tent Hill Formation (containing the Tregolana/Woomera Shale, the Corraberra Sandstone and Arcoona Quartzite).
  - Early Cambrian deposits of the Arrowrie basin, which hosts the Andamooka Limestone and Yarrawurta Shale.
- During the Jurassic–Cretaceous, sediments were deposited in the Eromanga Basin, which partially covers the northern extent of the study area. The Bulldog Shale is the main geological unit from the Eromanga Basin present in the study area.
- Tertiary sediments were deposited in the Torrens Basin and the Billa Kalina Basin.
- A veneer of Quaternary sediments covers much of the low-lying areas of land.

The Delamarian Orogeny occurred from the Cambrian to Ordovician and affected the Adelaide Rift Complex to the east of the Torrens Hinge Zone leading to the formation of the Flinders Ranges. This major structural and metamorphic event created three primary geological domains across the study area as follows:

- The Stuart Shelf platform which covers the eastern Gawler Craton and is flat lying and comparatively undeformed (albeit faulted).
- The Torrens Hinge Zone, a transitional zone up to 25 km wide (between the Stuart Shelf and Adelaide Geosyncline), which is a complex half-graben fault system that has formed a depocenter for Cenozoic sedimentation.
- The Adelaide Geosyncline made up of thick, folded Neoproterozoic sediments.

Several structural features occur within the Stuart Shelf itself (Tonkin and Wallace 2021). There is a north-trending basement high through the centre of Stuart Shelf (the Torrens Cratonic Uplift), a dome shaped basement high in the north of the Stuart Shelf (Andamooka Dome), and a north-trending uplift of the Pandurra Formation (the Pernatty Upwarp) that is adjacent to (west of) the Torrens Cratonic Uplift (see Figure 13). The Pernatty Upwarp causes the lower strata of the Neoproterozoic sequence (including the Whyalla Sandstone) to pinch out and be compartmentalised, and it appears to be responsible for faulting in the upper sequence of the Neoproterozoic sediments (Tonkin and Wallace 2021).

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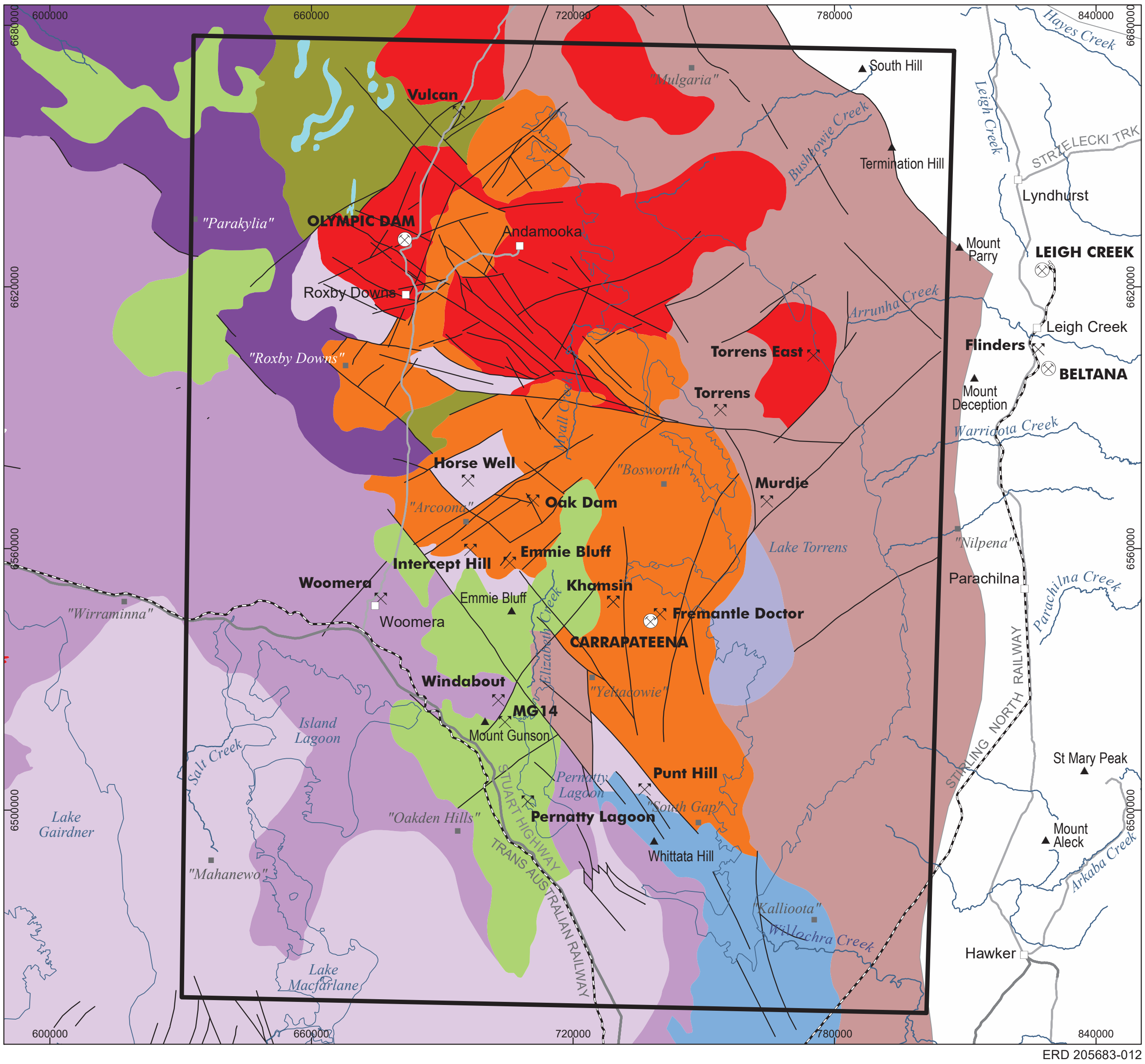
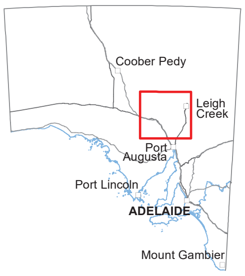
STUART SHELF
SOLID GEOLOGY – ARCHEAN TO MESOPROTEROZOIC





Current as at May 2023

Solid geology – Archean to Mesoproterozoic
- Undifferentiated mafic to felsic volcanic rocks
- Hiltaba Suite
- Gawler Range Volcanics (upper)
- Gawler Range Volcanics (lower)
- Dacite to rhyolite, andesite, basalt
- Donington Suite
- Hutchison Group equivalent
- Wallaroo Group
- Weetulta Formation
- Iron formation
- Mulgathing Complex
- Pre-Neoproterozoic basement

Archean to Mesoproterozoic faults
- Fault position accurate

- Study area

Mines and projects
- Major mine
- Mining project/deposit

Topographic information
- Locality
- Homestead
- Hill or peak
- Watercourse
- Lake
- Highway
- Secondary road
- Railway

Figure 9 *Solid Geology: Archaean to Early Mesoproterozoic time slice showing the Gawler Craton.*

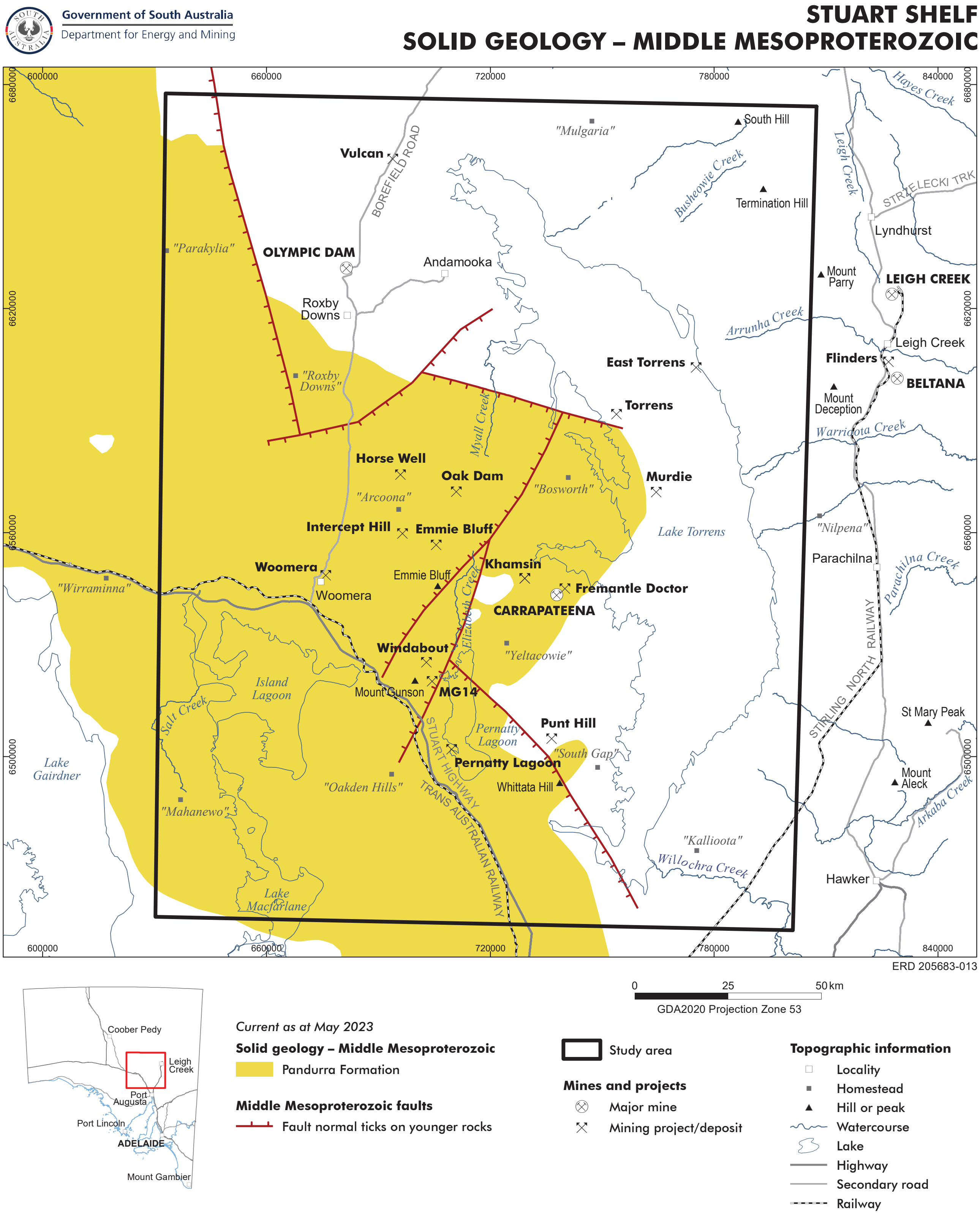


Figure 10 *Solid Geology: Middle Mesoproterozoic time slice showing the Cariewerloo Basin (the extent of the Pandurra Formation).*

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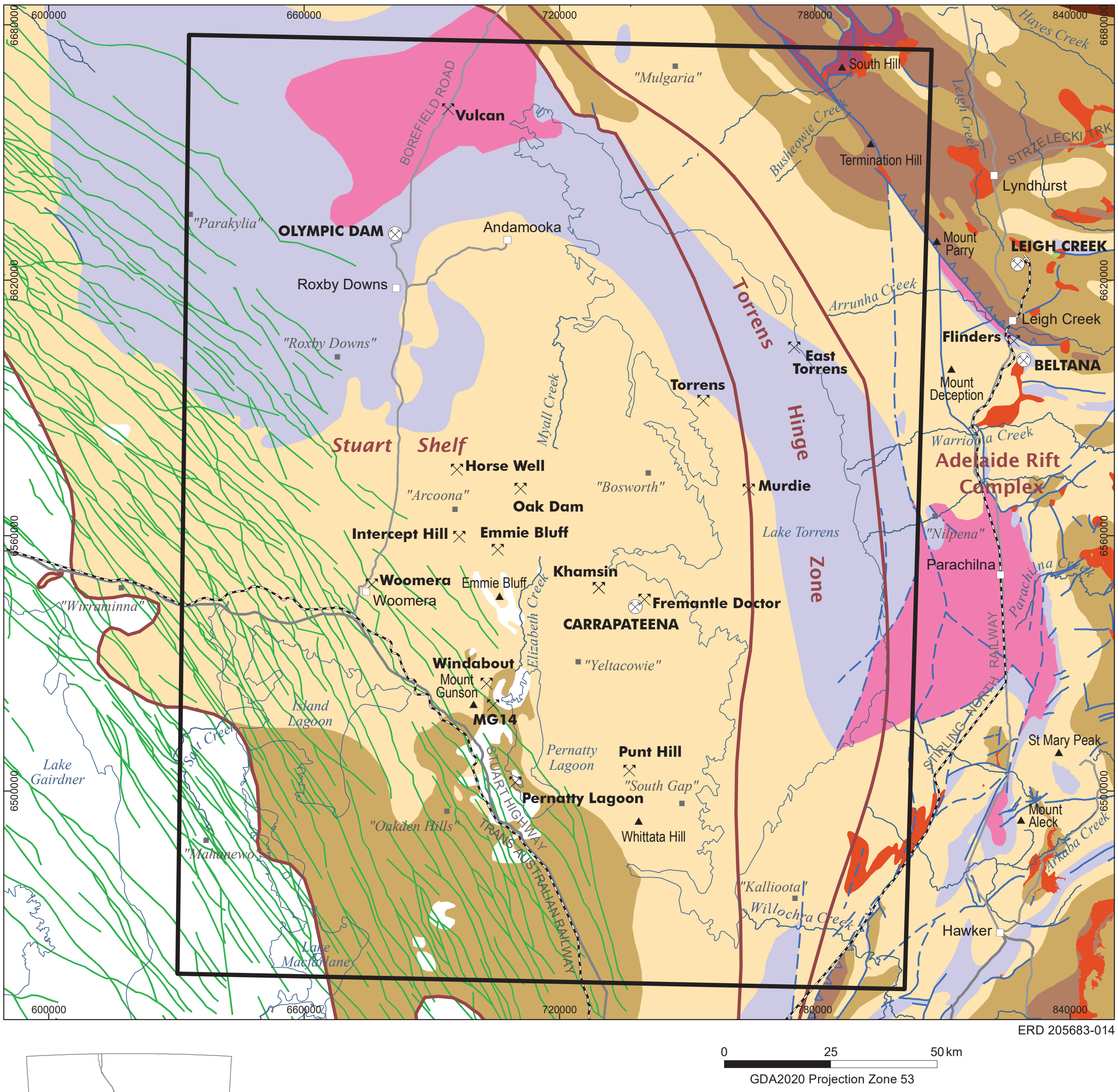
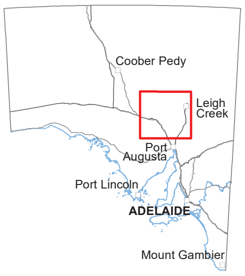
STUART SHELF
SOLID GEOLOGY – NEOPROTEROZOIC TO ORDOVICIAN





Current as at May 2023

Solid geology – Neoproterozoic to Ordovician

- Uratanna Formation, Hawker Group, Andamooka Limestone
- Billy Creek Formation, Wirrealpa Limestone, Lake Frome Group, Yarrawurta Shale
- Undifferentiated Neoproterozoic rocks
- Burra Group
- Callanna Group
- Umberatana Group
- Wilpena Group
- Diapiric carbonate-cemented breccia
- Gairdner Dolerite
- Includes Wooltana Volcanics, Beda Volcanics

Neoproterozoic to Ordovician faults

- Fault position accurate
- Fault position approximate
- Fault reverse approximate triangles upthrown side
- Fault reverse triangles upthrown side

Study area

Mines and projects

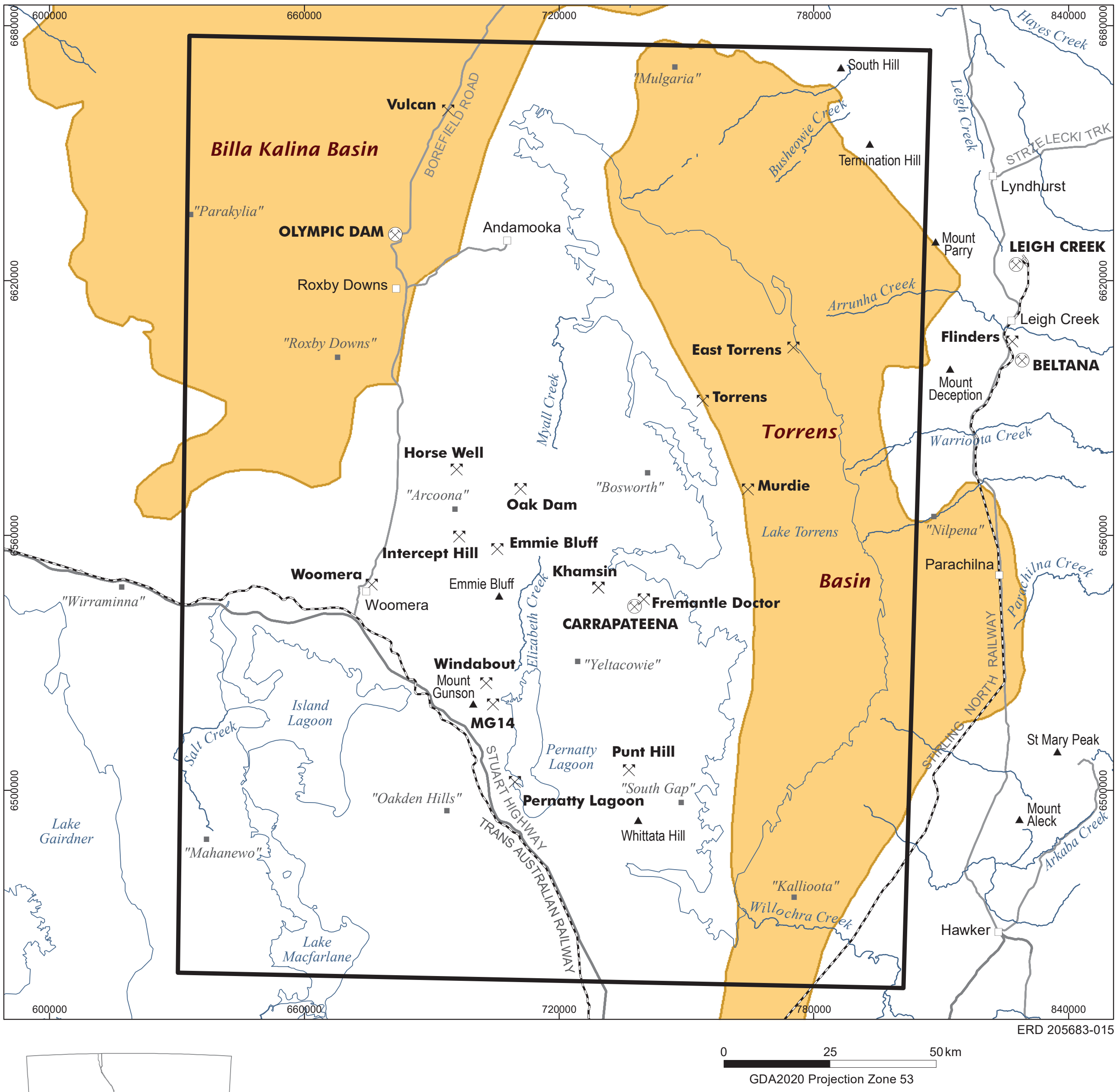
- Major mine
- Mining project/deposit

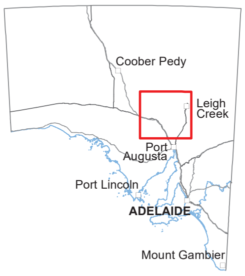
Topographic information

- Locality
- Homestead
- Hill or peak
- Watercourse
- Lake
- Highway
- Secondary road
- Railway

Figure 11 *Solid Geology: Neoproterozoic to Ordovician time slice showing the major groupings of the Adelaide Rift Complex.*

STUART SHELF CENOZOIC BASINS





Current as at May 2023

Cenozoic Basins

Study area

Mines and projects

Major mine

Mining project/deposit

Topographic information

Locality

Homestead

Hill or peak

Watercourse

Lake

Highway

Secondary road

Railway

Figure 12 *Cenozoic sedimentary basins.*

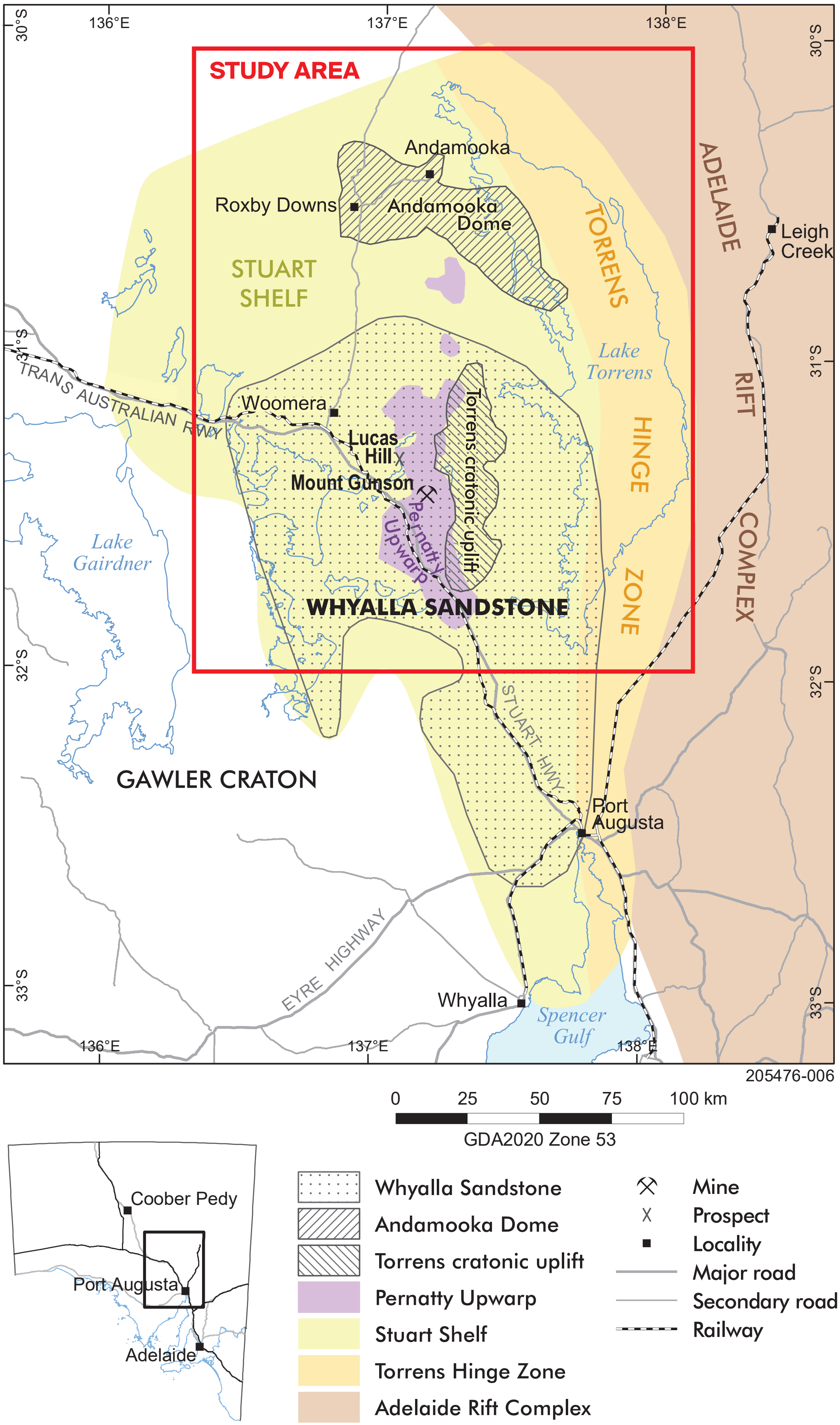


Figure 13 *Structural features within the Stuart Shelf (study area shown in red) (after Tonkin and Wallace 2021).*

4.4 GROUNDWATER RESOURCES

4.4.1 Existing datasets and knowledge base

The latest publicly available groundwater data has been obtained from WaterConnect (for SA data) (see Figure 14, Figure 15, Figure 16). Regional hydrogeological reviews have been undertaken for the non-prescribed areas of South Australian Arid Lands (Watt et al. 2012) and to broadly investigate groundwater supply options for mining development in the Far North (Houthuysen and Baird 2017). Several hydrogeological investigations and reviews have occurred for the Olympic Dam and Carrapateena mines in relation to groundwater supply and impact assessment studies to support various mining lease proposals and approval requirements. Much of this material is in the public domain (e.g. REM-SKM 2009; BHP 2011; OZ Minerals 2018). This work has concentrated on the Stuart Shelf and there is comparatively little data on the Torrens Basin. DEW is currently undertaking a drilling program in the Torrens Basin, but this data is not yet available.

4.4.2 Hydrostratigraphy and hydrogeological zones

Groundwater can be hosted in the pore spaces of porous rocks or sediments (as primary porosity), or in the fractures of consolidated rocks (secondary porosity). An aquifer is defined as "a (geological) formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs" (Lohman 1972). Applying this definition, the main stratigraphic units of the study area have been classified into aquifers and aquitards (Table 4).

The hydrogeology of the study area is complex due to:

- The variable distribution and thickness of the geological units hosting the aquifers and aquitards (which act as confining units).
- The occurrence of aquifers at different elevations which can affect their degree of saturation.
- The reliance of many of the aquifers on fractured porosity, which can be highly variable spatially.

The above factors have combined to create a compartmentalised and heterogeneous groundwater system. Within this complexity, three broad hydrogeological zones can be recognised as follows:

- **The Stuart Shelf-Carriewerloo Basin Zone** covers the southern and eastern portion of the Stuart Shelf, where the Pandurra Formation aquifer is overlain by aquifers of the Stuart Shelf facies—the Whyalla Sandstone to the south of this zone, and the Tent Hill Aquifer to the north. The zone is approximated by the extent or the Carriewerloo Basin (see Figure 10). Groundwater resources within this zone are used by the Carrapateena mine.
- **The Stuart Shelf-Arrowie Basin Zone** covers the northern portion of the Stuart Shelf, where the Tent Hill Aquifer is overlain by the Andamooka Limestone Aquifer of the Arrowie Basin. The zone is approximated by the extent of the Arrowie Basin (Figure 11). Groundwater resources within this zone are used by the Olympic Dam mine.

- **The Torrens Basin Zone** extends across the Torrens Hinge Zone to the foothills of the Flinders Ranges in the east of the study area. There is minimal development and limited knowledge of groundwater resources in this zone.

A description of the groundwater resources in each of these zones is provided in the following sections.

Table 4 *Hydrostratigraphy of the study area. The main aquifer systems are highlighted. The Tertiary units of the Billa Kalina Basin have not been included because they are unsaturated in the study area, occurring above the water table.*

Age		Geological Domain	Stratigraphic Unit	Aquifer/Aquitard
Cenozoic	Pleistocene to Holocene	Various	Undifferentiated alluvial, lacustrine & aeolian sediments	Aquitard (local aquifer in places)
	Eocene	Torrens Basin	Neuroodla Formation	Aquitard
	Miocene		Cotabena Formation	Aquifer (sedimentary)
Mesozoic	Cretaceous	Eromanga Basin	Bulldog Shale	Aquitard
Paleozoic	Cambrian	Arrowie Basin	Yarrawurta shale	Aquitard
			Andamooka Limestone	Aquifer (karstic sedimentary)
Neoproterozoic	Marinoan	Stuart Shelf	Arcoona Quartzite (upper)	Aquitard
			Arcoona Quartzite (lower)	Tent Hill Aquifer (fractured sedimentary)
			Corraberra Sandstone	
			Woomera/Tregolana Shale	
			Woomera/Tregolana Shale	Aquitard
			Nuccaleena Formation	Thin basal aquifer
			Whyalla Sandstone	Aquifer (fractured)
	Sturtian		Tapley Hill Formation	Aquitard
Mesoproterozoic		Cariewerloo Basin	Pandurra Formation	Aquifer (fractured)
Paleoproterozoic		Gawler Craton	Crystalline Basement	Aquitard

4.4.3 Existing wells

Figure 14 shows the distribution of groundwater wells in the study area, classified by purpose. Figure 15 shows the distribution of well yields reported at the time of drilling (which may not be representative of yields that can be sustained by pumping over long periods). Figure 16 shows the distribution of groundwater salinity measured in wells. Groundwater salinity is generally saline to hypersaline throughout the study area. The following trends are noted:

- Regionally, higher yields typically coincide with poor quality (i.e. more saline) groundwater and are found in aquifers such as the Andamooka Limestone, Tent Hill Aquifer, Pandurra Formation and Whyalla Sandstone.
- Sites that record comparatively better quality water (i.e. less than 5,000 mg/L) coincide with lower yields (less than 0.25 L/s) which is likely a factor of shallow occurrence.
- The regionally variable salinity distribution may reflect a variety of well depths, yields, local recharge conditions as well as a complex distribution of salinity in three dimensions.
- Better water quality sites typically occur around pastoral stations, the locations of which may have been originally sited by the availability of better quality of water sources. These sources of better water quality are likely represented by local groundwater flow systems associated with higher-than-normal recharge (at outwash colluvial slopes or creek beds) that form perched groundwater tables/aquifers.

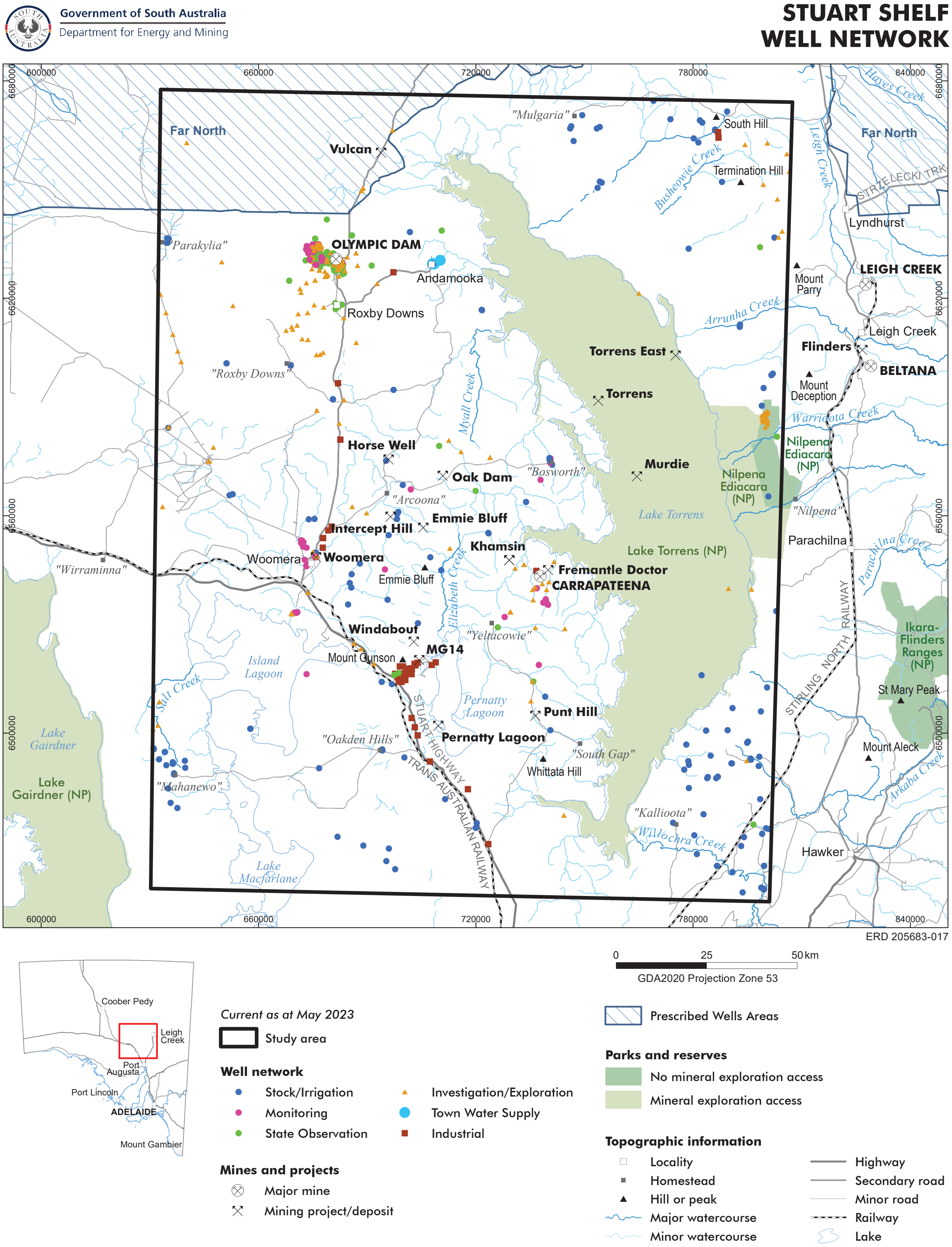


Figure 14 *Listed wells in study area (WaterConnect).* www.waterconnect.sa.gov.au/Systems/GD/Pages/Default.aspx

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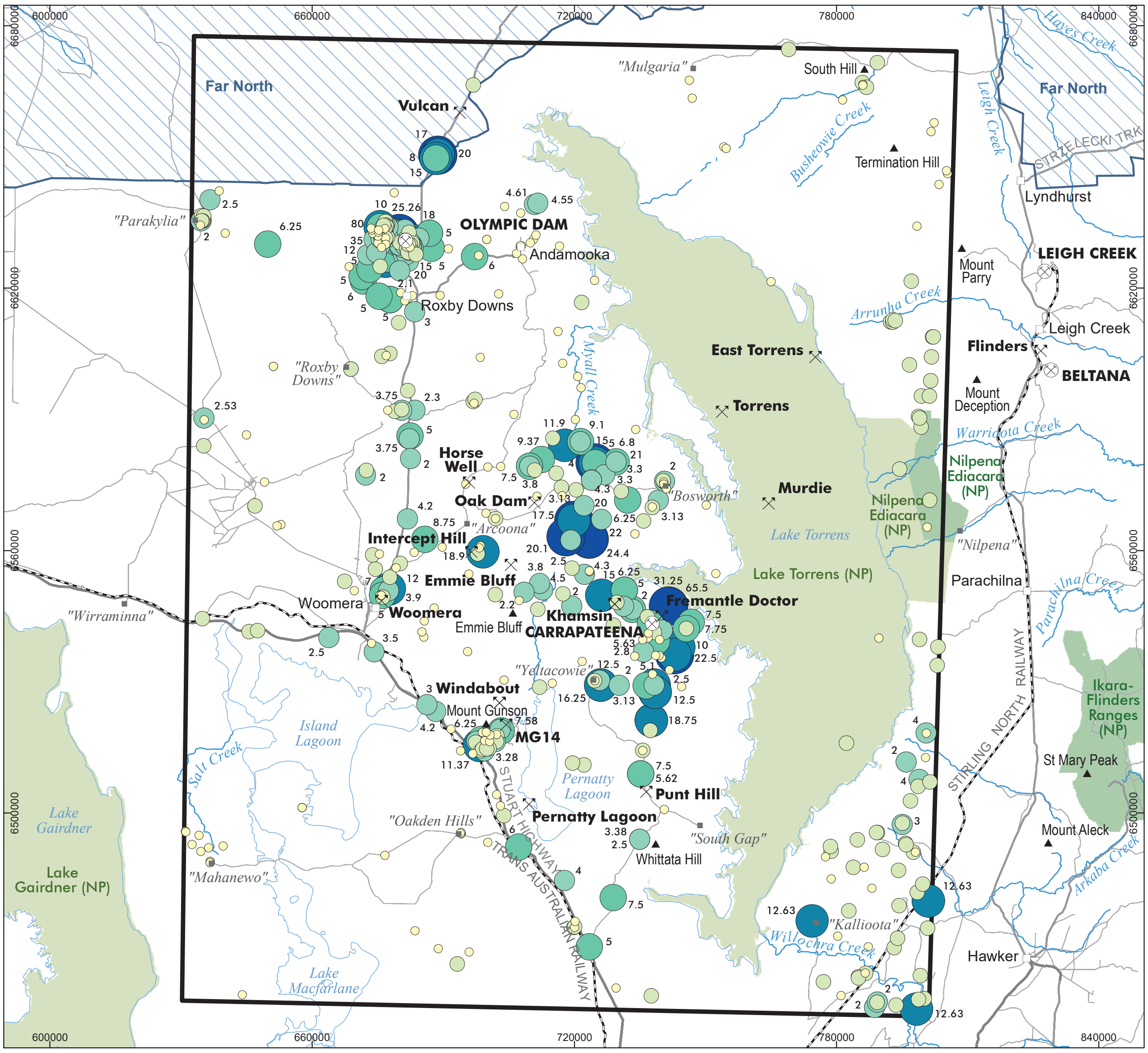
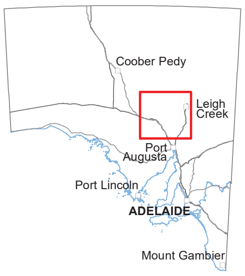
STUART SHELF GROUNDWATER YIELDS





Current as at May 2023

Study area

Yield (L/s)
- Less than 0.5
- 0.5 - 1.9
- 2 - 4.9
- 5 - 9.9
- 10 - 19.9
- Greater than 20

Prescribed Wells Areas

Mines and projects
- Major mine
- Mining project/deposit

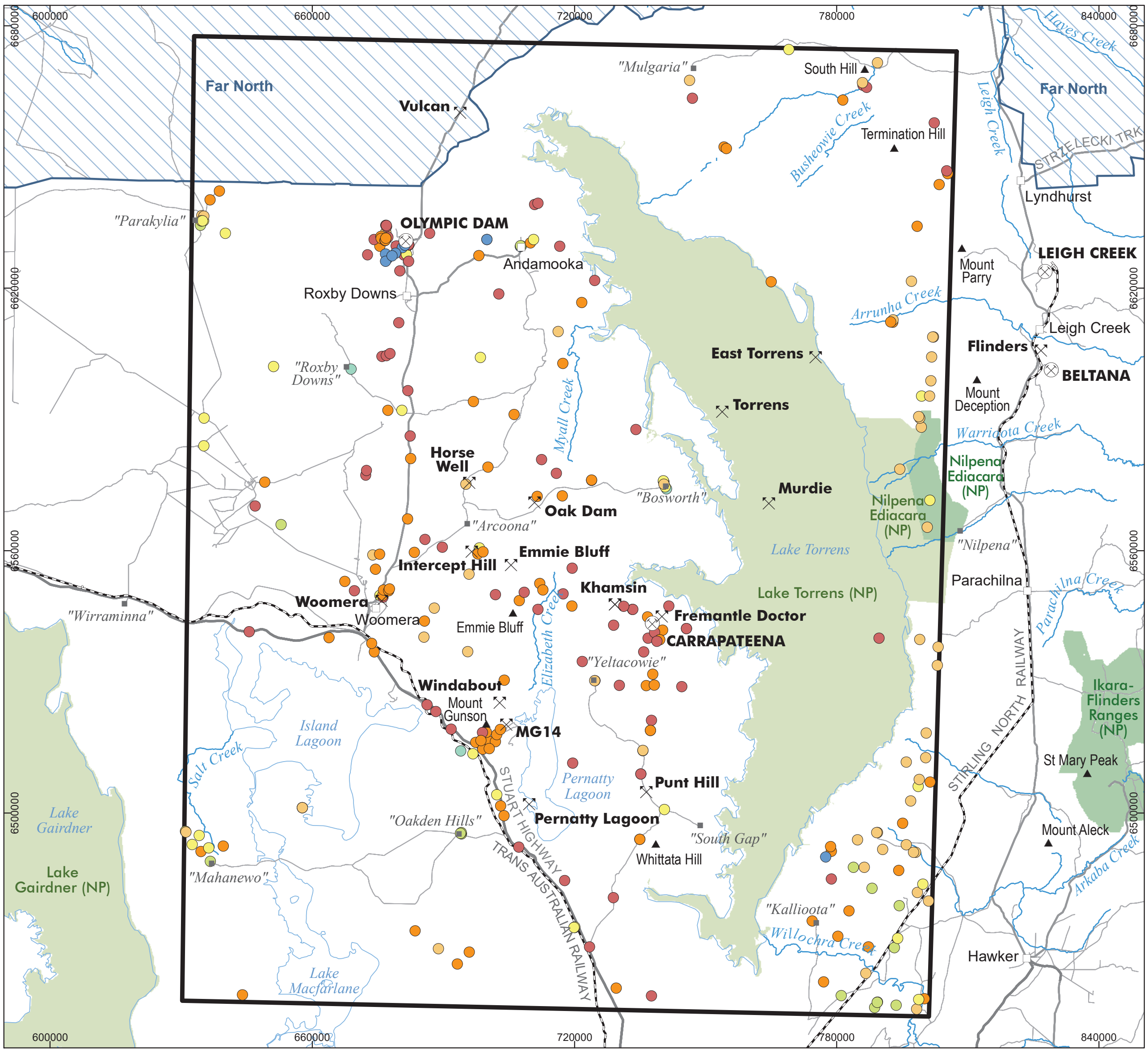
Parks and reserves
- No mineral exploration access
- Mineral exploration access

Topographic information
- Locality
- Homestead
- Hill or peak
- Major watercourse
- Highway
- Secondary road
- Minor road
- Railway
- Lake

Figure 15 *Reported well yields at the time of drilling in study area*

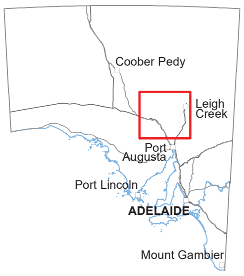
Government of South Australia
Department for Energy and Mining

STUART SHELF
SALINITY (ELECTRICAL CONDUCTIVITY)



0 25 50 km

GDA2020 Projection Zone 53



Current as at May 2023

Study area

Electrical conductivity (uS/cm)

- Less than 500
- 500 - 999
- 1000 - 2999
- 3000 - 6999
- 7000 - 13999
- 14000 - 35000
- Greater than 35000

Prescribed Wells Areas

Mines and projects

- Major mine
- Mining project/deposit

Parks and reserves

- No mineral exploration access
- Mineral exploration access

Topographic information

- Locality
- Homestead
- Hill or peak
- Major watercourse
- Highway
- Secondary road
- Minor road
- Railway
- Lake

Figure 16 *Reported groundwater salinity in listed wells (WaterConnect).*
www.waterconnect.sa.gov.au/Systems/GD/Pages/Default.aspx

4.4.4 Groundwater resources in the Stuart Shelf-Cariewerloo Basin Zone

A description of the groundwater resources in this zone is provided by Jacobs (2016) and OZ Minerals (2018) which is summarised here.

Figure 17 presents an east to west cross-section of the hydrogeological zone. The main aquifers and aquitards are:

- Shallow quaternary aquifers (not shown in Figure 17) are hosted in sandy silts along ephemeral creek lines. These are local, shallow groundwater lenses recharged episodically during stream flow. They are low-salinity/brackish and low yielding but can provide water for stock and support riparian vegetation (e.g. large trees) where present. Some shallow wells have been installed by pastoral stations to use this water.
- The Upper Red Arcoona Quartzite outcrops over much of the Stuart Shelf. It consists of quartzite with shale interbeds and forms an aquitard over the Tent Hill Aquifer.
- The Tent Hill Aquifer (a composite of the lower (white) Arcoona Quartzite, the Corraberra Sandstone and the transitional facies of the Woomera/Tregolana shale) is present over the northern half of the zone. It is unsaturated over the south half of the zone where it occurs at higher elevations. The aquifer is primarily fracture controlled with some limited primary porosity, with yields being highly variable spatially. In studies undertaken to support the Carrapateena Mining Lease Proposal (MLP), aquifer testing provided estimates of aquifer transmissivity ranging between 1 and 80 m2/day and sustainable pumping yields in completed wells ranging from 0.5 to 10 L/s. It is 50 to 150 m thick and hosts saline to hypersaline groundwater. It is one of the two main aquifers used to supply water for the Carrapateena mine.
- The Tapley Hill Formation acts predominately as an aquitard being composed of finely laminated siltstone but may host local resources in dolomitic zones.
- The Whyalla Sandstone acts as aquifer and an aquitard. It tends to be more transmissive towards the southwest of the zone, near the Pernatty Upwarp, where it occurs at shallower depths. It is 50 to 150 m thick and hosts hypersaline groundwater.
- The Pandurra Formation is a thick geological unit (500 m or more) composed of poorly sorted sands and congolmerates. Its extent is constrained to the Cariewerloo Basin (Figure 10). It acts primarily as a fractured rock aquifer. Zones of enhanced permeability have developed on the flanks of the Pernatty Upwarp, where the Pandurra Formation has been intensively silicified making it prone to brittle fracturing (Kellett et al, 1999), but it can be low yielding outside of fracture zones. The Pandurra Formation aquifer hosts saline to hypersaline groundwater and is generally more saline than the Tent Hill Aquifer. It is one of the two main aquifers used to supply water for the Carrapateena mine.

Figure 18 presents the distribution of wells in the zone by aquifer and the water table elevations and flow paths. The effect of the Pernatty Upwarp is evident, creating a groundwater flow divide.

A conceptual hydrogeological model (OZ Minerals 2018) is shown in Figure 19 for pre-mining conditions near the Carrapateena mine site. It highlights:

- Low recharge rates (in the order of 0.1 mm/y) due to low rainfall and high evaporation rates but is likely to vary considerably with some areas capable of accumulating rainfall runoff, and where fractured rocks outcrop/subcrop experiencing higher infiltration rates.

- Some transfer of water occurs between hydrostratigraphic units by leakage and fractures, particularly in faulted zones.
- Groundwater discharge occurs either via evaporation from shallow water tables or to the salt (playa) lakes as diffuse or point source discharge (i.e. spring discharge), with flow Lake Torrens being the largest discharge mechanism.

Groundwater users in this zone include:

- Pastoralists have installed some shallow wells (less than 30 m deep) for stock use, accessing water from shallow alluvial / weathered Proterozoic aquifers along creek lines linked to perched groundwater flow systems.
- Groundwater Dependent Ecosystems (GDEs) linked to groundwater fed pools or springs.
- Carrapateena mine water supply.

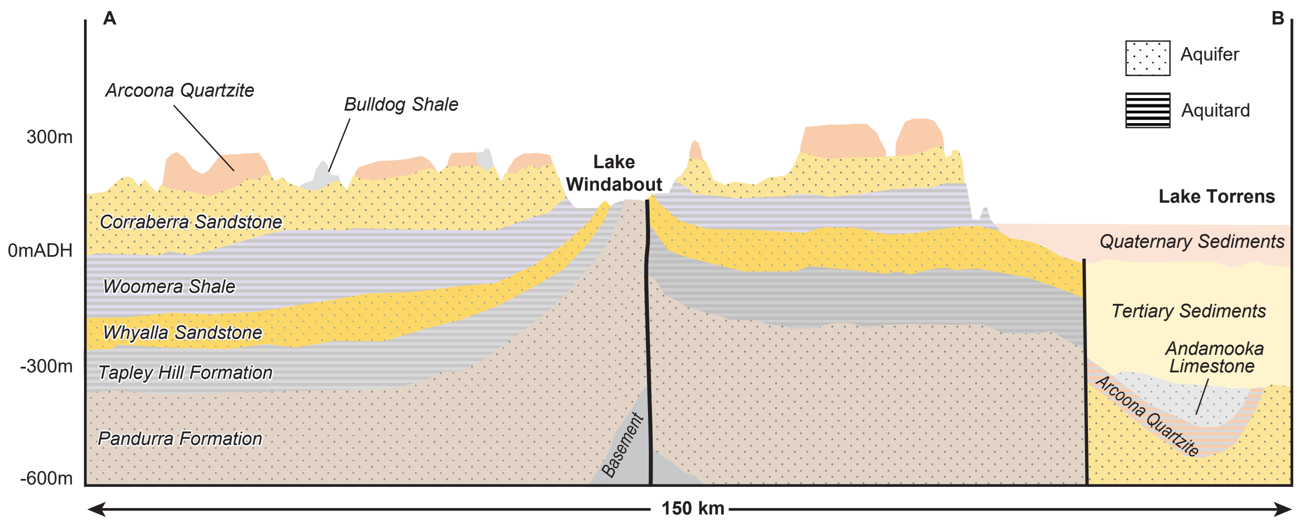


Figure 17 *West to east hydro-stratigraphic cross-section through the Stuart Shelf-Cariewerloo Basin Zone.*

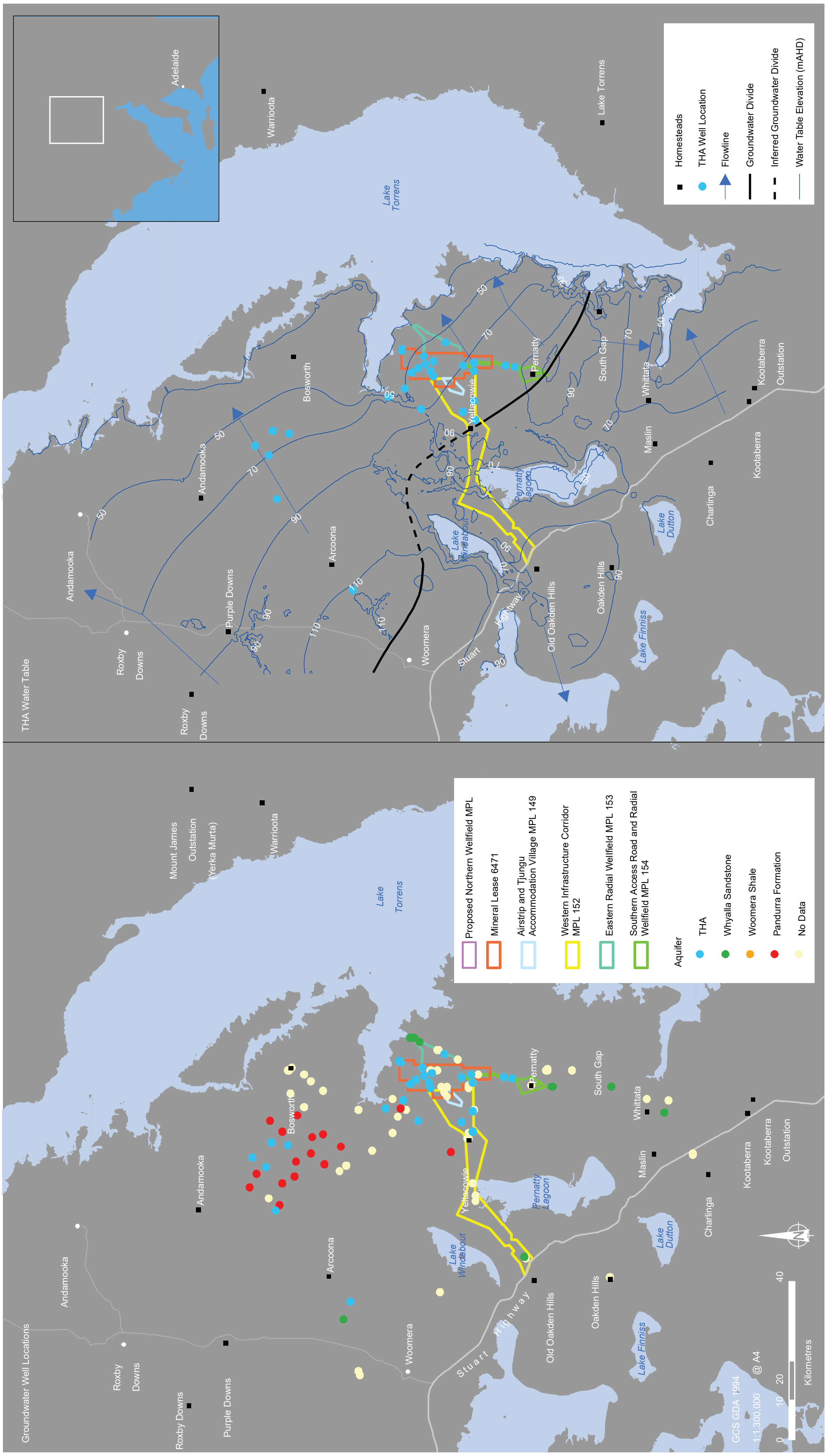


Figure 18 *Existing wells, aquifer completions, and water table elevations and flow paths in the Stuart Shelf-Cariewerloo Basin Zone (OZF Minerals 2018)*

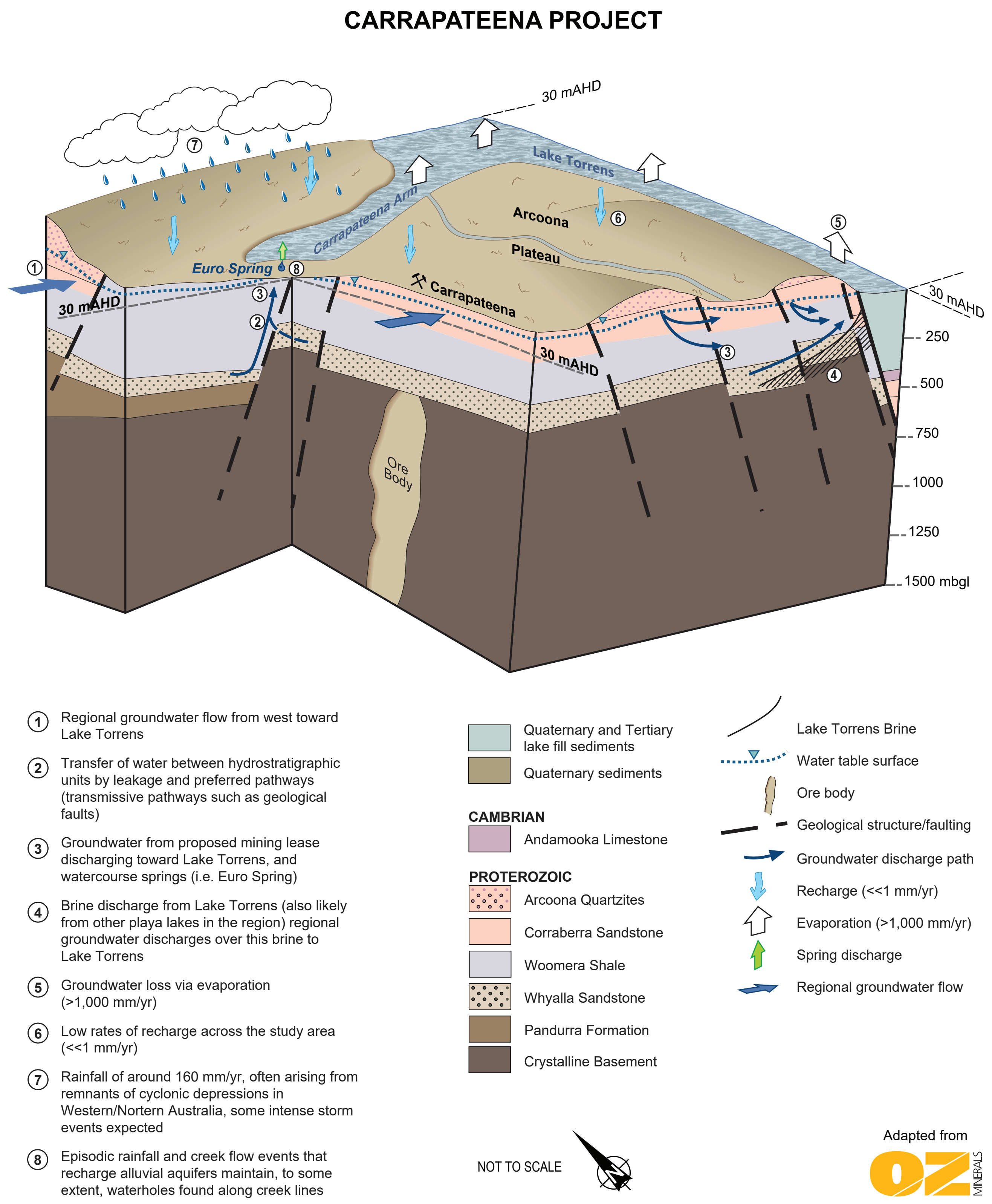


Figure 19 *Conceptual hydrogeological model for pre-mining conditions at the Carrapateena Mine (OZ Minerals 2018)*

4.4.5 Groundwater resources in the Stuart Shelf-Arrowie Basin

Figure 20 presents a south to north cross-section of the Stuart Shelf-Arrowie Basin hydrogeological zone. The main aquifers and aquitards are as follows:

- The Bulldog Shale, where present, is an aquitard overlying the Andamooka Limestone aquifer.
- The Yarrawurta Shale is an aquitard overlying the Andamooka Limestone Aquifer to the north of Olympic Dam.
- The Andamaooka Limestone is an unconfined-confined aquifer with significant transmissivity at the regional scale, associated with karst and (possibly fracture) related secondary porosity. At the Olympic Dam SML, which is close the edge of the Arrowie Basin, it can be unsaturated or have limited saturated thickness and be unconfined. However, its saturated thickness increases to the north of Olympic Dam (see Figure 20) and it can be confined by the Yarra Wurta Shale or the Bulldog Shale. Typically, groundwater is saline to hypersaline, with brines sitting at the base beneath and adjacent to Lake Torrens. It is generally undeveloped due to its high salinity.
- Upper (red) Arcoona Quartzite unit is a low permeability but leaky aquitard that confines the underlying Tent Hill aquifer and limits exchange between the Tent Hill Aquifer and the Andamooka Limestone where it is present. It can yield water where significant secondary porosity is induced by fracturing.
- The Tent Hill Aquifer is a composite of the Corraberra Sandstone and lower (white) Arcoona Quartzite units, as well as transition zone in the upper Tregolana Shale and equivalents. Moderate permeability aquifer with variable degree of secondary porosity. Can be high yielding in association with major structures and high heads. It behaves as a well-connected system with connectivity increased locally by structure through the Arcoona Quartzite. Typically hosts saline to hypersaline groundwater. It is currently used as a saline water supply at Olympic Dam.
- Tregolana Shale transitions into the overlying Tent Hill Aquifer in many areas. It is a leaky confining unit that separates the Tent Hill Aquifer and basement rocks.

Figure 21 shows a map of the regional water table elevation and interpreted flow paths. Flow towards the centre of the Arrowie Basin and Lake Torrens is clearly indicated.

Groundwater recharge over much of the zone is likely very low (<1 mm/y) due to low rainfall and high evaporation rates. Groundwater discharge occurs either via evaporation from shallow water tables or to Lake Torrens as diffuse or point source discharge (i.e. spring discharge).

Other than the Olympic Dam mine, there are few groundwater users in this zone owing to the salinity of available groundwater. However, the groundwater flow system does support several springs at Lake Torrens and associated GDEs, including Yarra Wurta Springs.

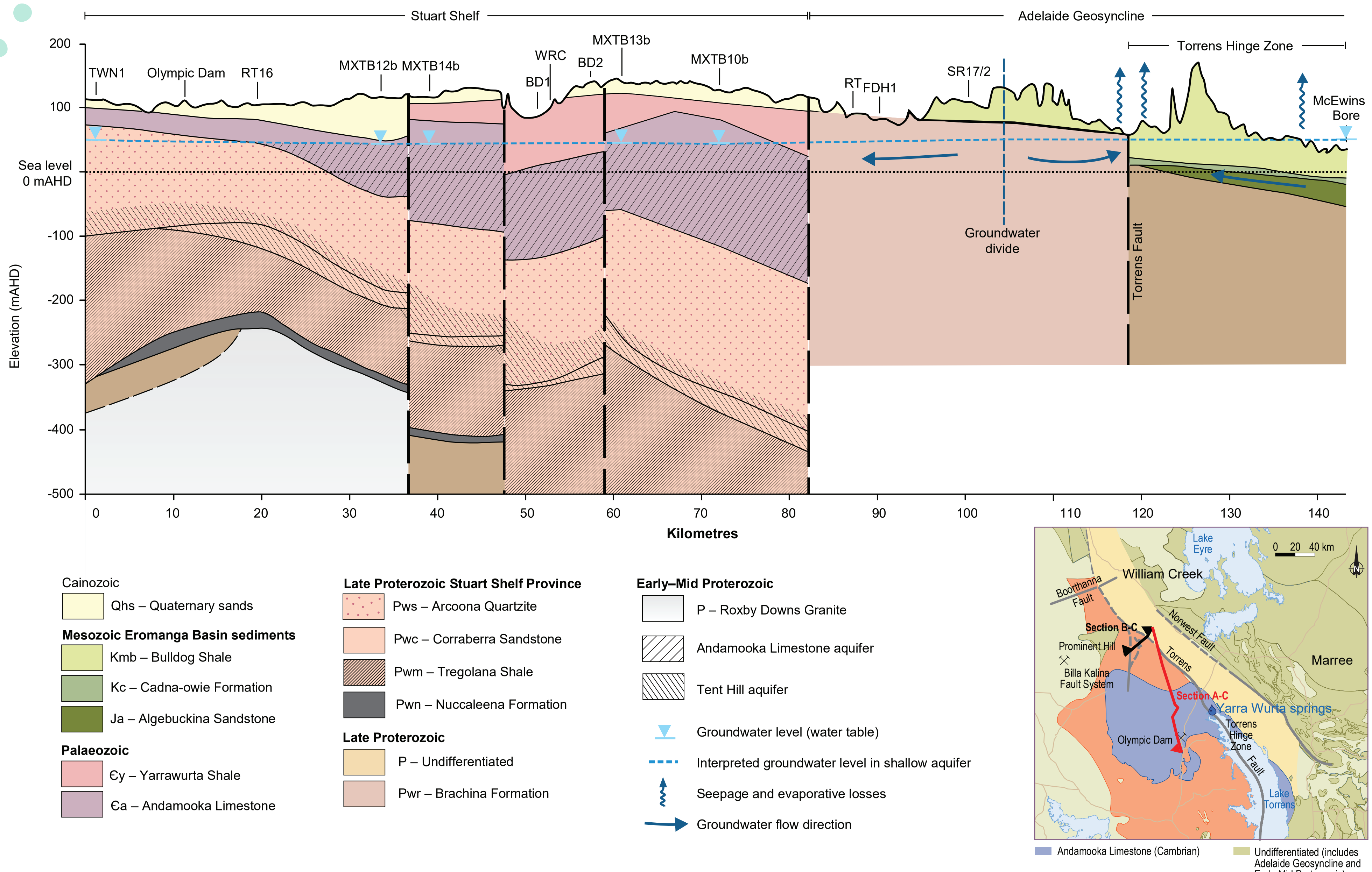


Figure 20 Hydrogeological section through the Stuart Shelf-Arrowie Basin Zone (BHP 2011). The northern boundary of the zone (and the study area) is defined by the edge of the Andamooka limestone.

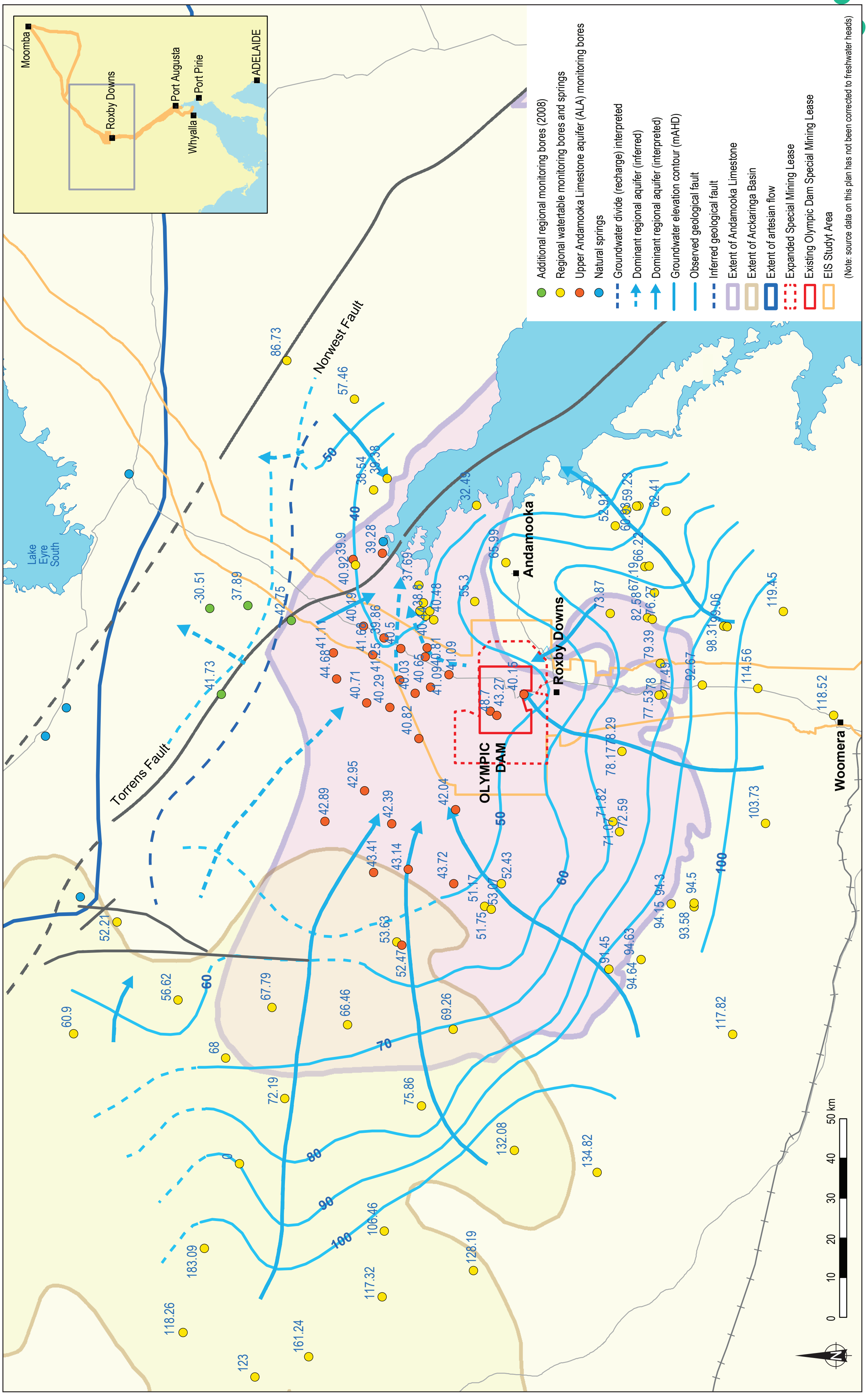


Figure 21 Interpreted regional water table contours in the Stuart Shelf-Arrowie Basin Zone (BHP 2011)

4.4.6 Groundwater resources in the Torrens Basin Zone

The Torrens Basin (see Figure 12) represents a relatively unexplored groundwater resource. It contains fluvio-lacustrine sediments of Eocene and Miocene age and overlies Precambrian and Cambrian rocks (Watt et al. 2012). It is spatially extensive (~10,000 km2) and quite deep (up to 250 m) with the sediments thickening towards the east.

Figure 22 presents a cross-section of the Torrens Basin. Two geological formations are indicated, with the lower unit (Cotabena Formation), composed of fine to coarse-grained sand, silt and sandstones with clay interbeds, being the more prospective groundwater resource. The Cotabena Formation is confined by the mudstones of the Neuroodla.

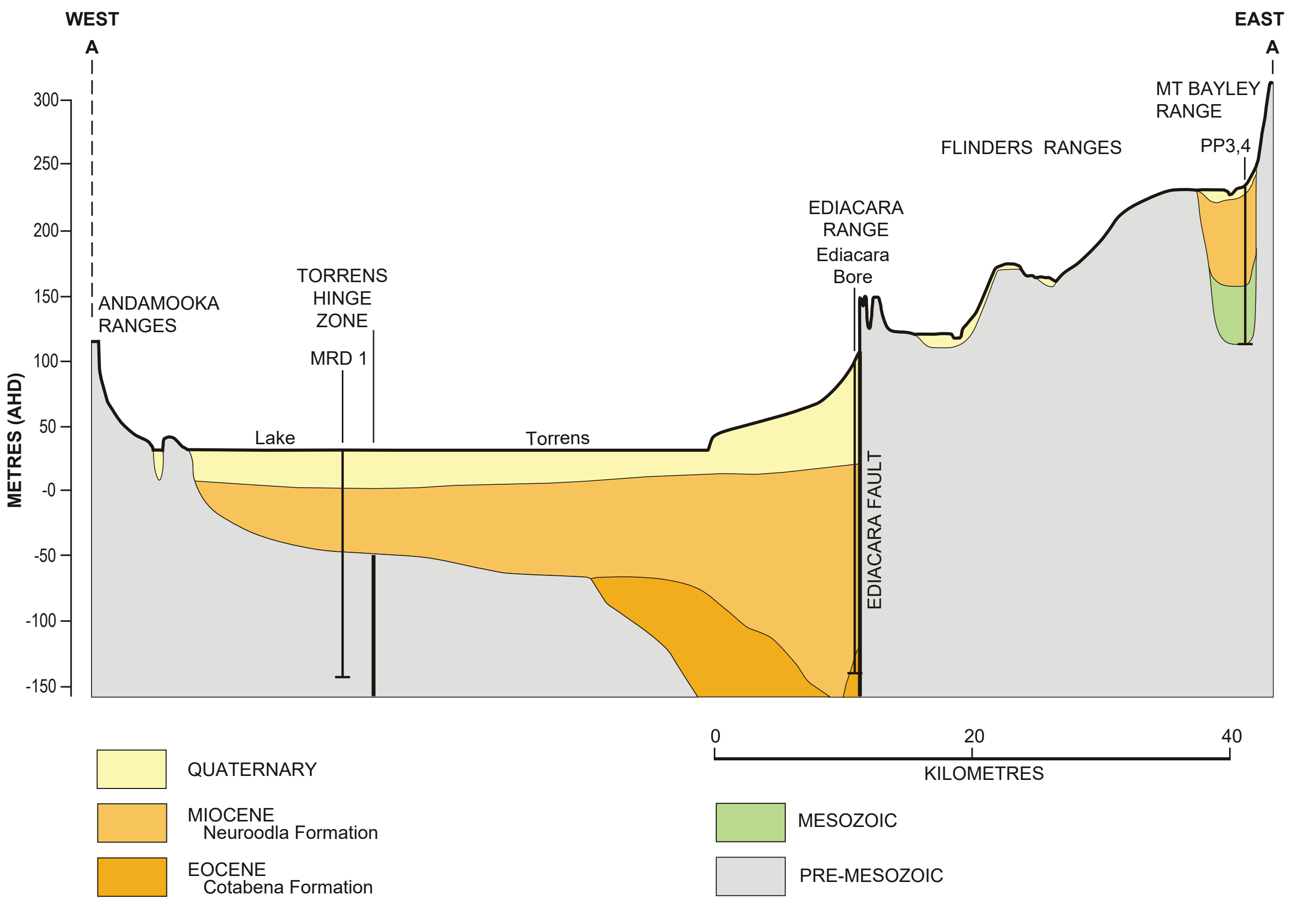


Figure 22 *Cross-section through Tertiary sediments in the Torrens Basin (Alley and Benbow 1995)*

It is speculated that the Cotabena Formation could be recharged by runoff from the Flinders Ranges as it passes the faulted zones at the eastern limit of the Basin (e.g. Chebotarev 1952), much like what occurs in the Adelaide Plains sedimentary aquifers where runoff from the Mount Lofty Ranges is a significant recharge source. This process has also been confirmed in the Pirie Basin in hydrogeological studies of the Baroota Reservoir (Clarke 1989). It follows too, that the Torrens Basin aquifers could be source of groundwater discharge to several of the springs present at Lake Torrens, and the springs themselves are indicative of artesian heads within the Torrens Basin aquifers. There is, however, limited data to support these theories.

Mapped springs within the Lake Torrens surface water catchment are shown in Figure 23. The springs in east of the catchment occur outside of the study area and are linked to groundwater discharge from fractured rock aquifers in the Finders Ranges. However, several springs have been mapped within the study area, particularly within the Torrens Basin zone, and several occur within Lake Torrens itself.

Lewis and McConchie (1994) present a conceptual model of spring discharge within playa settings (like Lake Torrens) which indicates variable mineralisation and ion exchange (due to the evapo-concentration of salts) can drive the location of spring discharge points. It is probable that these processes are occurring on Lake Torrens as well. However, in relation to potential groundwater resource development, the most significant factor is the groundwater flow systems driving the artesian pressures which create spring discharge. If the development of groundwater resources were to lower these pressures, then spring discharge could be affected and associated GDEs could be impacted. Understanding which groundwater flow systems are responsible for the spring discharge (and their relative influence) is therefore important as it will dictate the sensitivity of spring discharge to the development of a particular resource. This has been studied in some detail in relation to the proposed BHP expansion for the northern section of Lake Torrens at Yarrawurta springs (REM-SKM 2009), and in relation to the springs adjoining the Carrapateena development; but is not well known elsewhere and role of the Torrens Basin hydrogeology is uncertain.

4.5 KNOWLEDGE GAPS AND UNCERTAINTIES

Several knowledge gaps and uncertainties constrain the current understanding of groundwater resources in the study area. These include:

- Hydrogeology of the Torrens Basin, including well yields, salinities, recharge and discharge processes.
- Vertical connectivity between aquifers in the Stuart Shelf.
- Aquifer extents and thicknesses as they are important determinants of the overall capacity of the groundwater resources.
- Hydraulic parameters (conductivity and storage), which control the responsiveness of the aquifer to pumping and support estimates of sustainable rates of extraction, are known reasonably well at local to sub-regional scales (around existing developments) but are not as well known regionally and the available storage is uncertain.
- Characterisation of potential GDEs, particularly springs within and surrounding Lake Torrens have been studied in relation to existing developments; however, the relationship between spring discharge and Torrens Basin hydrogeology is less clear.
- Recharge and discharge processes.

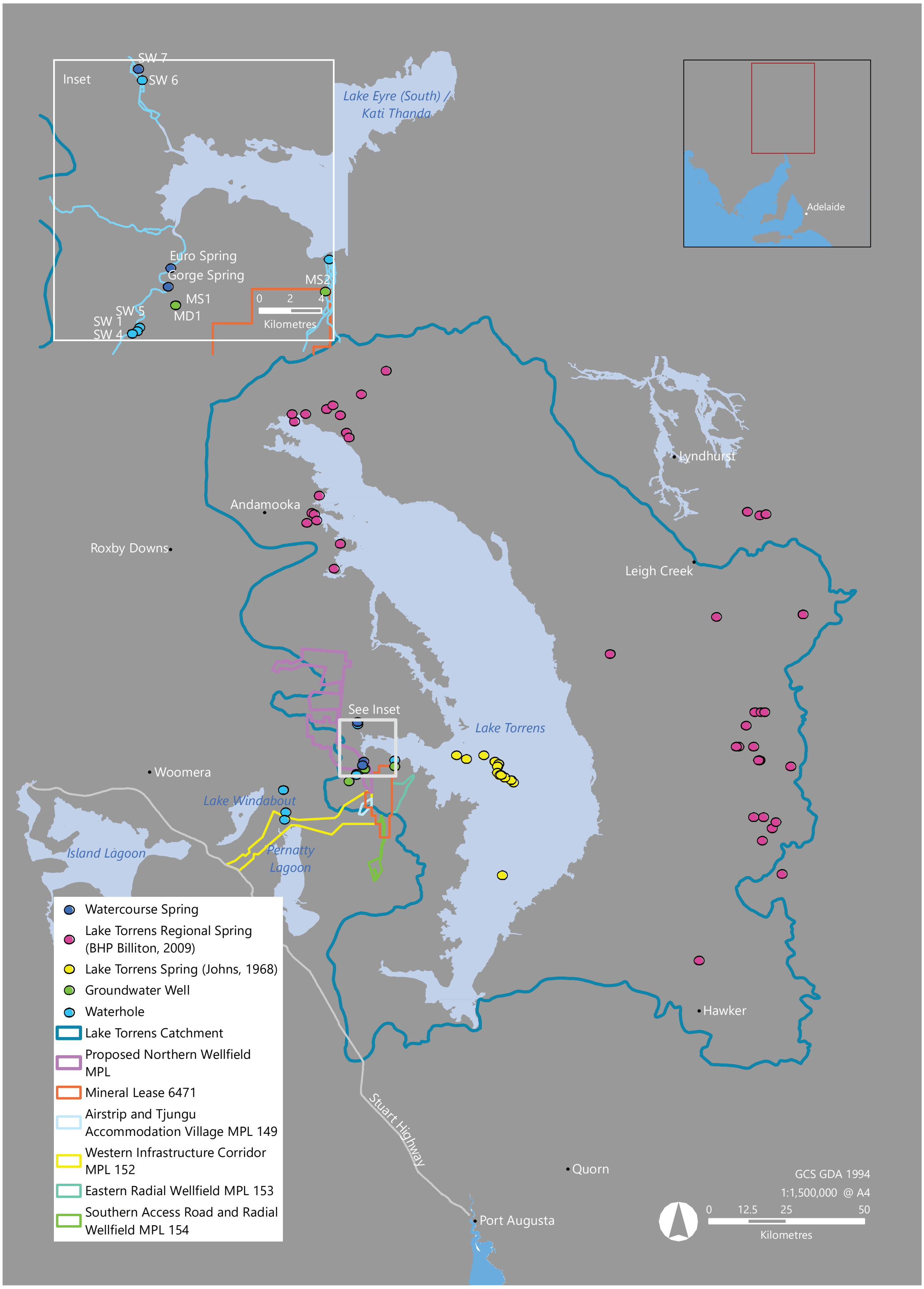


Figure 23 *Mapped springs within the Lake Torrens surface water catchment (OZ Minerals 2018)*

5 Groundwater resource assessment to support mining

5.1 CAPACITY OF GROUNDWATER RESOURCES TO MEET WATER DEMAND

- The capacity of groundwater resources is related to several factors which include recharge, responsiveness to pumping, aquifer storage and the requirements of other water users (including GDEs). While the concept of groundwater resource capacity is relatively simple, it is challenging to quantify and relies on robust modelling approaches supported by data, which may not be available. Qualititative approaches can, however, provide some initial guidance.
- Howe (2011) developed a framework for the National Water Commission to qualitatively assess the capacity of aquifer systems (termed robustness) in relation to mining development (Figure 24). The framework measures robustness using three factors. Climate provides an indicator of recharge rates. Aquifer type provides an indicator of aquifer storage, with sedimentary aquifers typically having much higher storage volumes than fracture rock aquifers. The scale of the groundwater flow system provides an indicator of the spatial extent of the aquifer system (Walker et al 2003) and its total storage volume, with regional flow systems (>50 km) having substantially higher volumes than local flow systems (<5 km).

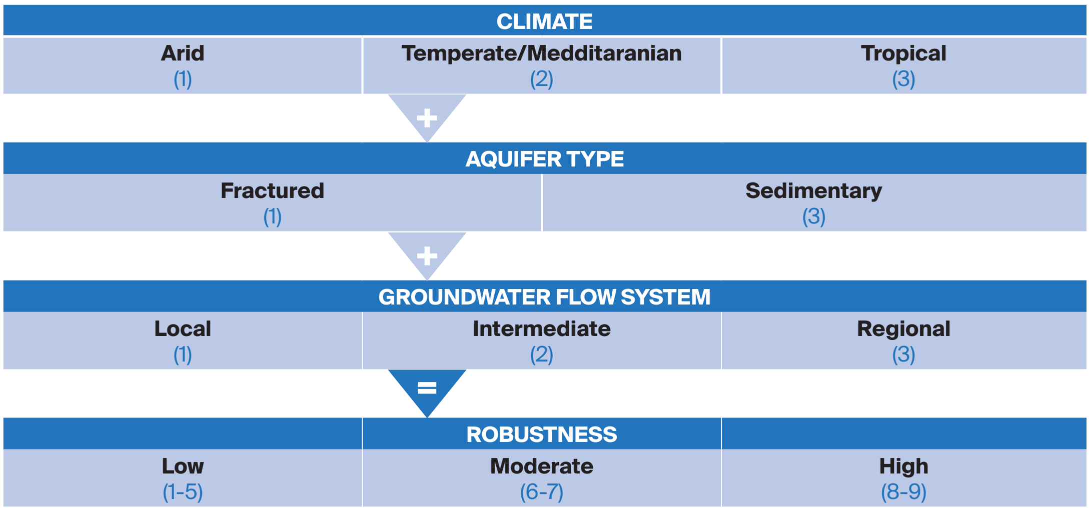


Figure 24 *Qualitative aquifer robustness calculation (Howe 2011)*

This framework can be applied to the groundwater resources in the study area as follows:

- Groundwater resources of the Stuart Shelf-Cariewerloo Basin Zone are classified as having a low level of robustness (total score of 4) based on,
  - Arid climate (1) of where recharge occurs.
  - Aquifer type is fractured-rock (1).
  - Intermediate groundwater flow systems (2).
- Groundwater resources of the Stuart Shelf-Arrowie Basin Zone are classified as having a low level of robustness (total score of 5) based on,
  - Arid climate (1) of where recharge occurs.
  - Aquifer type is fractured-rock (1).
  - Regional groundwater flow system (3).
- Groundwater resources of the Torrens Basin Zone are classified as having a moderate level of robustness (total score of 7) based on,
  - Arid climate (1) of where recharge occurs.
  - Aquifer type is sedimentary (3).
  - Regional groundwater flow system (3).

The low-moderate robustness scores from this assessment support the notion that these resources are reasonably constrained particularly, by available (accessible) storage and general heterogeneity.

In the absence of a thorough modelling assessment that is supported by field studies outside the main areas of existing groundwater development (Olympic Dam and Carrapateena), it is difficult to quantify the capacity of the resources in terms of a sustainable rate of groundwater extraction and the period over which this could apply, but the following sources provide some guidance:

- The development of the groundwater supply for Carrapateena indicates well spacings in the order of 3-5 km or more are needed to minimise well interference (noting that tighter well spacings may be possible in certain locations). Given these spacing requirements, and current overall pumping rate of ~4 GL/y over the EL areas, the sustainable pumping rate per unit area is equivalent to ~0.002–0.003 GL/y/km2. Extrapolating this over the zone indicates that total pumping rates over 12-20 GL/y would be hard to sustain, and maintenance of heads to support spring discharge along the western margins of Lake Torrens may also be a constraint.
- Investigations conducted for Olympic Dam Expansion EIS found very high yields in the Andamooka Limestone Aquifer (>50 L/s) and it is possible this resource could support high rates of extraction. However, aquifer storage and recharge are limited and the salinity of the resource is a constraint. It contains hypersaline brine (>35,000 mg/L) near Lake Torrens that is likely unsuitable as a resource and pumping would need to target the comparatively lower salinity groundwater (~35,000 mg/L) away from Lake Torrens. Maintenance of heads and the northern end of Lake Torrens to support spring discharge in Lake Torrens may also be a constraint. To the north, the aquifer overlaps the Far North Prescribed Wells Area and abstractions would need to be managed in accordance with the WAP.
- There are limited data and hydrogeological information for the Torrens Basin to make any assessment of capacity for groundwater resources in that zone.

Using the current information, Table 5 has been prepared which outlines the likelihood of groundwater resource capacity meeting the regional mine water demand scenarios outlined in Section 3.2. The assessment indicates that the groundwater resources in the study area are unlikely to have sufficient capacity to meet the cumulative mine water demands projected; particularly so when water quality requirements are factored in, which dictate that a reasonable portion of the total water demand needs to be of low salinity (see Section 3.1) and all of the groundwater resources identified are saline to hypersaline.

Table 5 *Likelihood of groundwater resources meeting mine water demand.*

Water demand scenario	Likelihood of groundwater resource capacity meeting water demand*			
	Stuart Shelf – Carriewerloo Basin Zone	Stuart Shelf – Arrowie Basin Zone	Torrens Basin Zone	All zones combined
Current	**~4 GL/y**	**~2 GL/y**	**Negligible**	**~6 GL/y**
Low (30 GL/y)	Unlikely	Unlikely	?	Possible
High (60 GL/y)	Remote	Remote	?	Remote

*Probable: high probability of meeting demand (>80%);
Likely: reasonable probability of meeting demand (60-80%);
Possible: intermediate probability of meeting demand (10-60%);
Unlikely: low probability of meeting demand 1-10%;
Remote: very low probability of meeting demand (<1%)

5.2 GROUNDWATER SUPPLY OPTIONS

Given there is a low likelihood of groundwater resources in the study area being able to meet the projected water demands, this indicates that an external source of water (e.g. NWS) would be required to achieve this level of mining development.

However, even if an additional external water supply is developed, groundwater will likely play a significant ongoing role as a primary water resource. Furthermore, some future projects may not have ready access to an external water supply (e.g. due to capital costs) and may need to rely on local groundwater resources. Based on these considerations, there will be continued demand for groundwater resources, with the following groundwater supply options being the most prospective:

- Development of a saline water supply in the Andamooka Limestone and ongoing development of the Tent Hill aquifer in the Stuart Shelf-Arrowie Basin Zone.
- Ongoing development of a saline water supply in the Stuart Shelf-Cariewerloo Basin Zone from the Tent Hill and Pandurra aquifers to the north and the Pandurra and Whyalla Sandstone aquifers to the south.
- The Torrens Basin aquifers subject to further groundwater exploration.

The location of the resources relative to the mineral deposits is quite disparate and water demands of projects targeting large IOCG-type deposits are significant. As a result of these factors, the development of a common (shared) groundwater resource and associated infrastructure (including wells, pipelines and power) is unlikely to be feasible, with the possible exception of a significant groundwater resource being identified in the Torrens Basin. The development of the groundwater resources and associated infrastructure would, therefore, likely continue to be developed on a project-by-project basis.

5.3 SWOT ANALYSIS

The assessment of groundwater resources in the study area to support mining is framed around strengths, weaknesses, opportunities and threats (SWOT). All groundwater resources in study area are considered in the assessment.

Strengths

- Proven as a mine water supply option with the development of the Carrapateena Mine and the saline water supply at Olympic Dam.
- Proximity of the water resources relative to mining projects.
- Minimal existing use by third parties (e.g. stock and domestic users) due to the salinity of water.

Weaknesses

- Resource capacity unlikely to be sufficient to meet large cumulative projected water demands.
- Well spacing requirements to avoid well interference in the Stuart Shelf-Cariewerloo Basin Zone are likely significant giving rise to large wellfield footprints.
- High salinity of groundwater resources
- Low-to-moderate success rate for exploration drilling in many parts of the study area (particularly the Stuart-Shelf Cariewerloo Basin Zone) due to the reliance on intercepting fractures to access transmissivity and storage.
- Low recharge rates mean that groundwater pumping to support industrial-scale water demands involves mining of the resource, and pumping will lead to diminished aquifer storage over time, mitigated by induced leakage from aquitards in the case of leaky confined aquifers.
- Land access issues related to development of water resources in Torrens Basin Zone, given cultural significance of Lake Torrens—it is a sacred site to five First Nations and is also a National Park.
- There are several important knowledge gaps relating to:
  - Groundwater resources and hydrogeology of the Torrens Basin
  - Springs (and associated GDEs) within and surrounding Lake Torrens, and the groundwater flow systems that drive the spring discharge given the complexity in hydrogeology beneath Lake Torrens
  - Inter-aquifer connectivity and leakage

Opportunities

- Potential for further development of the groundwater resources, particularly in the high yielding Andamooka Limestone Aquifer (noting it overlaps the Far North PWA and abstractions from this area would be subject to the WAP) and the extensive Pandurra Formation Aquifer.
- Development of groundwater resources to support mining activity on a case-by-case basis; recognising that while groundwater may not be able to support all projected mining activity in the study area at the one time, and it may prove to be suitable for individual projects.
- Water resource development for mining could be extended to local landholders and communities as additional water for stock and domestic supplies.
- Exploration in the Torrens Basin could discover a significant groundwater resource that may be relatively more sustainable than other aquifer regions (due to recharge arising from Flinders Ranges stream flows).

Threats

- Competition for groundwater resources (e.g. well interference) from multiple mining developments, with well interference effects extending across tenement boundaries.
- Impacts to existing users (stock and domestic users) and GDEs via groundwater development and possible associated drawdown of shallow potable / brackish water tables. Such impacts (if uncontrolled) could limit the capacity of the aquifer to supply water.
- Cumulative impacts to existing users (stock and domestic users) and GDEs via groundwater development and associated drawdown from incremental development of multiple mining projects leading to overlapping impacts. These cumulative impacts (if uncontrolled) could limit the capacity the aquifer to supply water and can be problematic from a management perspective if there is uncertainty around responsibility and accountability of impacts.
- Management of salinity and other water quality considerations.
- Uncertainty related to:
  - Projected mine water demand leading to under- or over-investment in infrastructure.
  - Sequencing of mining developments with later developments possibly having reduced access to groundwater.
  - Hydrogeological knowledge base leading to under- or over-estimation in capacity of groundwater resources.
  - Existing users and GDEs leading to unexpected impacts from groundwater resource development.

6 Road map

6.1 OBJECTIVES, CONSTRAINTS AND ISSUES ARISING

The SWOT analysis undertaken in Section 5.3 has revealed several opportunities and threats in relation to developing groundwater resources for mining development. The overall objective of the road map is to realise these opportunities by addressing the threats and their inherent challenges, constraints and knowledge gaps.

The key opportunities in developing groundwater resources to assist mining development include:

- Economic growth and development associated with mining development.
- Water to communities as an extension of mining and groundwater resource development.

The constraints include:

- Limited capacity of groundwater resources relative to projected cumulative long-term water demands.
- Management of salinity and other potential water quality considerations
- Uncertainties related to:
  - Groundwater resource estimation and long-term sustainability of supply.
  - Mine planning: timing, demand quality and quantity, costs of developing resources, water supply security.

The issues arising include:

- Competition for water resources (e.g. well interference across tenement boundaries).
- Potential impacts (and cumulative impacts) of groundwater resource extraction.

6.2 ACTION PLAN

The action plan is framed around addressing the above knowledge gaps, constraints and developing pathways to navigate the issues arising. The objective is to then realise the opportunities presented in an efficient manner. The effort entailed will be a mix of industry and government-led initiatives, with the government led actions highlighted as a means to prioritise government investment in the short to medium-term (<5 years).

6.2.1 Better understanding the capacity of the resources

Objective: Quantify the capacity of the groundwater resources to meet demand

1. In consultation with existing project proponents design and implement a regional-scale pilot drilling and testing program to understand aquifer hydraulic properties and potential accessible storage in target areas and to provide input data to a regional conceptual and numerical model (see below).
2. Liaise with existing groundwater users in the target area (stock and domestic) to better understand their water access requirements so that future operators of the water supply are aware of the need to maintain these requirements.
3. Identify and characterise potential GDEs to assess their sensitivity to changes in groundwater quantity (e.g. level and flux) and quality.
4. Develop a regional-scale numerical groundwater flow model to quantify the cumulative impact of groundwater abstraction from multiple developments (the existing modelling platforms have been focussed on individual developments) and to assess the capacity of the resource to meet demand for a range of development scenarios (refer below).
5. Use the model to assess impacts (including cumulative impacts) to other environmental and consumptive users

6.2.2 Better understand demand scenarios

Objective: Quantify required volume and quality of water supply over life of mine

1. Maintain dialogue with project proponents to update demand scenarios for mine construction and operations.
2. Liaise with local groundwater users (stock and domestic) to determine current water requirements and potential opportunities for the provision of additional water.
3. Identify and promote water saving initiatives (recycling/re-use)

6.2.3 Develop groundwater management framework

Objective: Create a framework agreement for groundwater resource management

1. Working with industry develop a conceptual approach to co-ordinated groundwater resource management. This framework would recognise:
   - Competing impacts (e.g. well interference) would need to be managed
   - Joint responsibility of cumulative impacts of groundwater extraction (e.g. to springs on Lake Torrens)

6.2.4 Data sharing with mineral exploration

Objective: Develop water data protocol for future mineral exploration in the study area

1. Develop a protocol that describes how water data can be collected and collated as part of future mineral exploration in the study area.

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As guests here on Kaurna land, the Department for Energy and Mining (DEM) acknowledges everything this department does impacts on Aboriginal country, the sea, the sky, its people, and the spiritual and cultural connections which have existed since the first sunrise. Our responsibility is to share our collective knowledge, recognise a difficult history, respect the relationships made over time, and create a stronger future.
We are ready to walk, learn and work together.

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