GROUNDWATER 12

12.1 INTRODUCTION

Olympic Dam is located in an area of low rainfall, low rates of groundwater flow and recharge, and low topographic relief. As a consequence, most groundwater within 50 km or more of the current operation is saline (i.e. salty) and little-used. Olympic Dam currently uses less than 1 ML/d of local groundwater for dust suppression, and there are three known shallow groundwater wells within 50 km that use saline groundwater for stock (all three are within pastoral leases held by BHP Billiton).

The primary water supply for the existing Olympic Dam operation is groundwater extracted from Wellfields A and B located in the Great Artesian Basin (GAB), about 120 and 200 km north of Olympic Dam, respectively. These wellfields supply an average of 37 ML/d to the existing operation. The extraction of groundwater is monitored extensively to demonstrate compliance with licence conditions and to prevent impact to the GAB springs.

The proposed Olympic Dam expansion would require an additional 183 ML/d (peak requirement). The primary water supply for the proposed expansion is a desalination plant located at Point Lowly, not groundwater from the GAB. No new water would be obtained from the GAB beyond that which is available under approvals from the South Australian Government.

A supplementary, low-quality water supply, primarily for dust suppression, would be sourced from saline aquifers close to the current operation.

This chapter describes the local and regional groundwater systems of the wider Olympic Dam region and identifies activities to be undertaken as part of the Olympic Dam expansion that may have the potential to affect groundwater during operations and post closure. The assessment identifies the extent of the area likely to be affected by these activities and the potential impact on users of the groundwater resources and other sensitive receptors.

No groundwater affecting activities would occur as a result of construction or operation of the proposed concentrate handling facilities at the Port of Darwin. These facilities would be constructed within the reclaimed area of the East Arm where groundwater is not naturally occurring. Consequently, the local and regional groundwater systems of the Darwin area are not discussed here. Information relating to the risk to groundwater from accidental spills or leaks is discussed in Appendix E4.

Groundwater in the vicinity of the desalination plant would not be used and the proposed expansion would not affect the natural interactions between groundwater and seawater.

The potential for, and implications of, water accumulating in the bottom of the open pit after mine closure are discussed in Chapter 11, Surface Water. The rehabilitation and decommissioning of the wellfields after the mine has closed are discussed in Chapter 23, Rehabilitation and Closure.
The existing management and monitoring programs, and the requirements for the proposed expansion are discussed in Chapter 24, Environmental Management Framework.

12.2 ASSESSMENT METHODS

12.2.1 GEOLOGICAL SETTING

Groundwater systems and the associated water resources are closely linked to geology and rock properties. A summary of the geology and geochemical properties of subsurface materials is presented in this chapter and further detail is provided in Appendix K1.

Geological maps and soil descriptions were sourced from various publications, including the Geological Survey of South Australia map sheets (Geological Survey of South Australia 1981, 1982 and 1992), Atlas of Australian Soils map sheets and explanatory data (CSIRO 1960 and 1968), and assessments undertaken as part of the 1982 and 1997 Olympic Dam EIS (Kinhill-Stearns Roger 1982; Kinhill 1997).

In addition, a sampling and analytical program has been established since mining began at Olympic Dam and data have been compiled into an extensive geology, hydrogeology and geochemistry database. Figure 12.1 provides an indication of the resource drilling that has been undertaken in order to identify the extent of the Olympic Dam ore body and its properties. The database of borehole logs and the analytical results from around 2.5 million samples provided an important resource for understanding the geology of the mine site and wider region.

12.2.2 REGIONAL GROUNDWATER DATA COLLECTION

Numerous regional groundwater studies have been undertaken in the EIS Study Area, including assessments presented in the two previous Olympic Dam EIS (Kinhill-Stearns Roger 1982; Kinhill 1997). Groundwater data used in these assessments were largely obtained from borehole drilling records kept by the Department of Water, Land and Biodiversity Conservation (DWLBC) and WMC Limited drilling programs that focused on the GAB. While this database represents an important resource, particularly in the area of the GAB, data have been collected over more than 100 years and the completeness, consistency and integrity of historic records varies.

For the current assessment, the existing data were supplemented by an extensive hydrogeological drilling and testing program over a broader area, as outlined below and detailed in Appendices K1 and K2. The area studied for the regional groundwater assessment is shown in Figure 12.2 (to avoid confusion with the EIS Study Area, this broader area is termed 'project area' hereafter).

Groundwater levels and water quality

Groundwater levels, flow and quality on and around the existing SML are well understood through a groundwater monitoring program that has been operating for 25 years and is documented in the annual Environmental Management and Monitoring Report (see BHP Billiton 2007 for latest). However, limited data were available for the wider region around Olympic Dam and the proposed infrastructure corridors.

Desktop and field investigations were undertaken to collect regional groundwater level data. Groundwater well locations were obtained by searching the DWLBC database and consulting with landholders. Seventy-four wells (including mechanically drilled 'bores' and hand-dug 'wells') were located, inspected and surveyed with a differential GPS (see Plate 12.1). Where possible, a water sample was collected and analysed in the field for temperature, electrical conductivity, pH, dissolved oxygen and reduction/oxidation (redox) potential (see Appendix K2 for details).

It was apparent that there were no drill holes (and therefore no groundwater data) in the north-east region of the project area, between the SML and Lake Torrens, and further beyond to the GAB. To fill this gap, nine additional, multi-nested groundwater monitoring wells, ranging from around 70 m to more than 600 m deep, were drilled to assess the horizontal and vertical hydraulic gradients, aquifer parameters, the potential for inter-aquifer connection and regional groundwater discharge processes (see Figure 12.2 for location of groundwater monitoring wells).

A desktop review of baseline groundwater conditions associated with both the gas pipeline corridor options and the southern infrastructure corridor was also undertaken (see Appendices K1 and K3 for details). In addition to the desktop assessment, a field investigation was undertaken along the southern infrastructure corridor. Groundwater samples could not be collected from the gas pipeline corridor options because most of these areas are accessible only by helicopter. The baseline groundwater parameters for wells located along the corridors have been summarised from drilling records.

As part of the field investigation, drilling records from the DWLBC were reviewed and 46 sites were chosen for field inspection, and groundwater samples were obtained from 21 of these wells (see Figure 12.2, Plate 12.2). The groundwater sampling and water quality results are presented in Appendix K3.

Plate 12.1 Differential GPS equipment

Plate 12.2 Groundwater wells being sampled

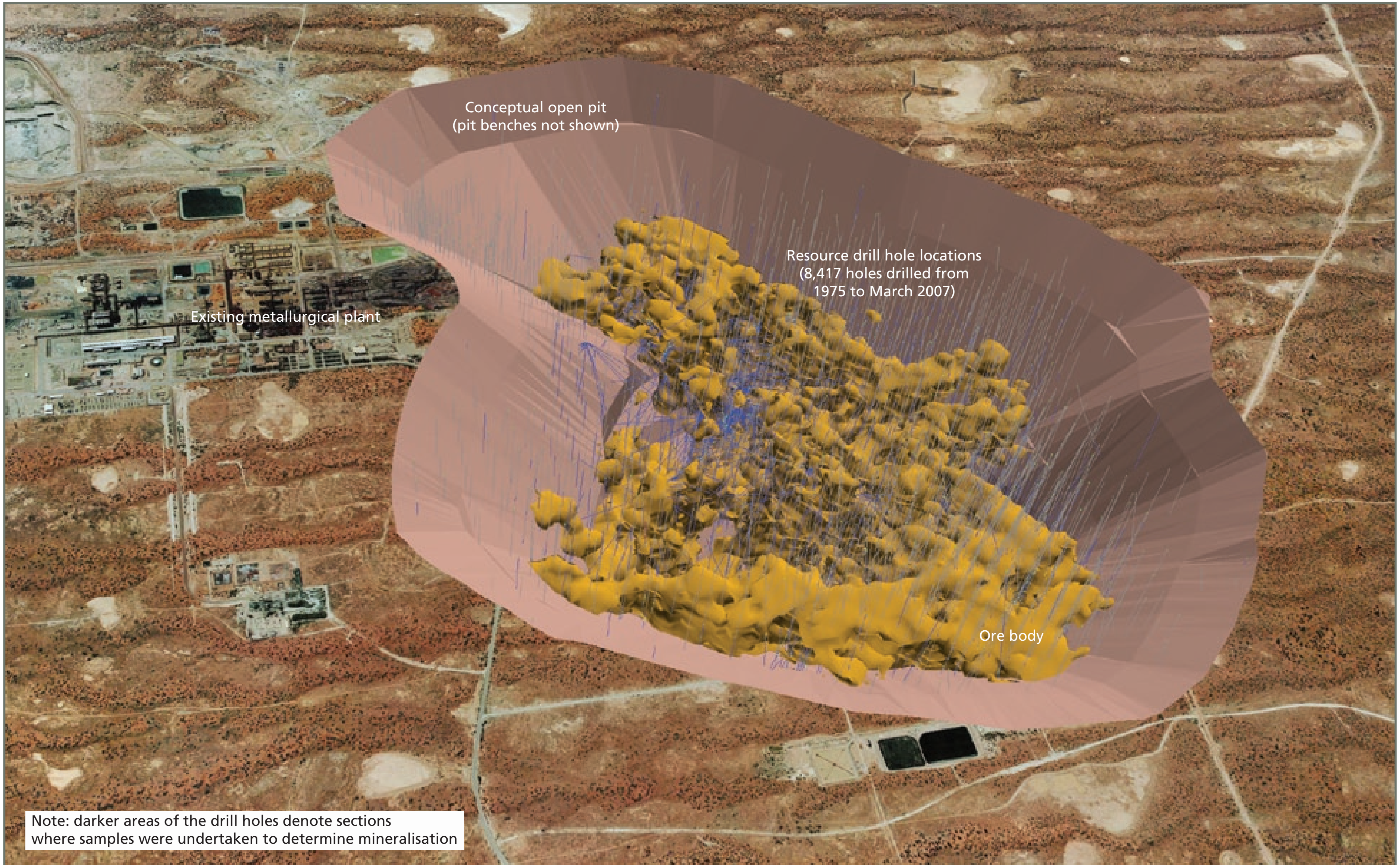


Figure 12.1 Resource drilling of the proposed open pit

Figure 12.2 Regional groundwater study area and groundwater sampling locations

Groundwater users survey

During the regional groundwater assessment, pastoralists in the project area were consulted to establish current groundwater use. Of the 16 pastoral stations consulted, eight were able to provide details on the following information relating to groundwater use (see Appendix K2):

- purpose (e.g. stock or domestic use)
- number of stock supported
- number of days used per year
- depth to groundwater
- well depth
- pumping equipment
- pump depth and typical pump rate
- geological and drillers logs, where available.

12.2.3 GEOCHEMISTRY ASSESSMENT

Tailings storage facility

A conceptual geochemical model was developed to assess the potential for solutes to be released from the TSF into the underlying groundwater systems. As the processing methods and the geochemical properties of the ore are not expected to be significantly different between the expanded and existing operations, the model was based on the observed conditions within and below the existing TSF. Results from supplemental geochemical laboratory testing were also considered.

The overall objective of the TSF geochemistry assessment was to develop estimates of solute concentrations in the seepage from the tailings into the underlying sediments and aquifers. The conceptual model addressed the release and mobility of acidity, heavy metal contaminants and radionuclides to the extent that the data allowed.

It is noted, that in this chapter, the term 'seepage' refers to liquid percolating from the base of the facility into the underlying sediments and does not refer to expression of liquid at the ground's surface.

The general approach adopted to develop the conceptual geochemical model was as follows (see Appendix K4 for details):

- Available geochemical information from the tailings and underlying soils and substrates was reviewed and summarised.
- Geochemical speciation modelling (i.e. MINTEQ and PHREEQC) and supplementary calculations were undertaken to support the conclusions from the initial review of the tailings geochemistry. The calculations included preliminary estimates of the potential overall acidity that may be released from the tailings.
- Geotechnical drill logs were reviewed to understand the near-surface geological conditions below the existing and future footprint of the TSF. Simplified but conservative overall acid-neutralisation calculations were also completed for the subsoils, and estimates were made of the potential for limestone dissolution within the Andamooka Limestone Formation.
- Seepage rates were used to establish the potential short- and medium-term effects for these calculations. Geochemical speciation modelling (i.e. MINTEQ and PHREEQC) was undertaken to understand the interaction between the subsoils and the seepage from the tailings.
- The groundwater quality monitoring results were reviewed to understand the potential interaction with the basement rock, particularly for evidence of changes in concentrations over time and to determine current effects.

More recently, holes were drilled in the existing TSF to obtain tailings samples for geochemical characterisation, and pore water was collected to determine water quality within the tailings. Soil and sediment samples were also obtained from beneath the TSF base to determine interaction with seepage from the tailings.

Rock storage facility

The geology and geochemistry database was evaluated as part of the Draft EIS assessments, and supplementary sampling and analytical test work was undertaken to characterise the mine rock that would be generated during the proposed expansion. The review and analytical test work targeted the sedimentary layers above the ore body (overburden) and the basement rocks that contain the ore body. The detailed methodology is presented in Appendix K5, and comprised geochemical testing and modelling to predict potential solute concentrations in the seepage from the RSF. The analytical geochemical testing included:

- geochemical assays – to determine the elemental composition, particularly the metals content, of each of the rock types present at Olympic Dam
- acid-base accounting – to evaluate the balance between acid generation processes and acid neutralising processes
- kinetic testing – time-based laboratory testing of the rock types to assess sulphide reactivity, weathering rates, metal solubility, metal loads and potential leachate composition
- contact tests – to assess solute attenuation reactions that may occur within the soils underlying the RSF.

Solute release modelling was also completed. The modelling included conversion of solute release rates from the laboratory tests to field conditions expected in the RSF and geochemical speciation modelling (i.e. PHREEQC) to understand the controls within the RSF on solute release to seepage from the base of the RSF. Assessment of the interaction between the subsoils and the percolate from the RSF was based on the contact test results as well as using the TSF as an analogue (i.e. a working example) for seepage and subsoil interaction.

12.2.4 REGIONAL GROUNDWATER MODEL

Numerical groundwater flow model

A regional numerical groundwater flow model has been developed to simulate historical groundwater behaviour at Olympic Dam and as a tool to aid in the prediction of a groundwater response from groundwater-affecting activities during operations and post closure.

The regional numerical model was constructed using a finite element groundwater model (FEFLOW) and consists of three main simulations. A steady state model was developed to represent groundwater conditions prior to mine development at Olympic Dam; transient calibrations were used to simulate the historical groundwater response from 1993 through to 2007; and a predictive model was used to simulate (predict) future groundwater behaviour in relation to the groundwater-affecting activities of the proposed expansion. These latter activities include:

- open pit mining
- groundwater extraction from depressurisation of the open pit
- seepage from the TSF and RSF
- extraction of groundwater from primary and satellite saline wellfields
- underground mining and operation of the raise bores.

The groundwater modelling needed to cover a large temporal and spatial range. Given the inherent uncertainties with modelling of this scale and complexity, sensitivity analysis was undertaken to define limits of prediction (i.e. data may only be suitable for predicting outcomes over a 500-year period) and to provide a conservative approach to predicting and managing impacts. The results of the groundwater modelling are presented in this chapter and detailed modelling methods and results of the sensitivity analysis are provided in Appendix K6.

12.2.5 IMPACT AND RISK ASSESSMENT

The assessment of impacts and risks for the proposed expansion has been undertaken as two separate, but related, processes (see Section 1.6.2 of Chapter 1, Introduction, and Figure 1.11).

Impacts and benefits are the consequence of a known event. They are described in this chapter and categorised as high, moderate, low or negligible in accordance with the criteria presented in Table 1.3 (Chapter 1, Introduction). A risk assessment describes and categorises the likelihood and consequence of an unplanned event. These are presented in Chapter 26, Hazard and Risk.

12.3 EXISTING ENVIRONMENT

This section summarises the geology and hydrogeology of the Olympic Dam region and the wider project area (including the proposed infrastructure corridors; see Figure 12.2). It also describes possible interactions with, and the influence of, neighbouring groundwater flow systems (see also Appendix K1).

12.3.1 REGIONAL GEOLOGICAL SETTING

Australia is divided into a number of geological provinces that describe the significant stages of geological formation from a spatial and temporal perspective. The geological provinces of southern South Australia and the corresponding surface geology are presented in Figures 12.3 to 12.5. Although the groundwater systems most likely to be affected by operations at Olympic Dam occur within the rocks of the Stuart Shelf, other geological provinces are relevant to Olympic Dam in the context of regional groundwater interactions and potential environmental issues. These are summarised below and detailed in Appendix K1.

Stuart Shelf

The Olympic Dam mine and the southern infrastructure corridors are located within the Stuart Shelf geological province, a relatively thin sequence of sedimentary rocks that lies above the Gawler Craton. The basement rocks of the Gawler Craton contain the Olympic Dam ore body (see Chapter 2, Existing Operation, for a geological description of the ore reserve).

The most significant sedimentary rocks of the Stuart Shelf include the Andamooka Limestone and the Tent Hill Formation, which comprises the Arcoona Quartzite, Corraberra Sandstone and Tregolana Shale. Beneath the Special Mining Lease (SML) these layers are relatively shallow and thin, but further away from Olympic Dam they become deeper and thicker (see Figure 12.6).

Adelaide Geosyncline

East of the Stuart Shelf are the highly folded sedimentary rocks of the Adelaide Geosyncline. These units are geologically equivalent to the rocks of the Stuart Shelf but have been separated by a zone of extensive faulting and deformation known as the Torrens Hinge Zone, which is bounded by the Torrens and Norwest faults (see Figure 12.3). Figure 12.7 shows a schematic geological cross-section of the Stuart Shelf and the westerly extent of the Adelaide Geosyncline.

Eromanga Basin

Eromanga Basin is the largest of three sedimentary basins that together form the Great Artesian Basin (GAB, see Section 12.3.2). The important units of the Eromanga Basin in South Australia in relation to groundwater are the Cadna-owie Formation, Algebuckina Sandstone and Bulldog Shale. Of these, only remnants of Bulldog Shale are present around Olympic Dam. Figure 12.6 presents a conceptual cross-section of the Stuart Shelf and the south-westerly extent of the Eromanga Basin.

Arckaringa Basin

West of Olympic Dam, the rocks of the Stuart Shelf are overlain by the younger sediments of the Arckaringa Basin, which covers an area of around 80,000 km^2. The formations of the Arckaringa Basin are largely restricted to the subsurface, due to the presence of even younger sediments above, such as the Eromanga Basin (see Figure 12.3).

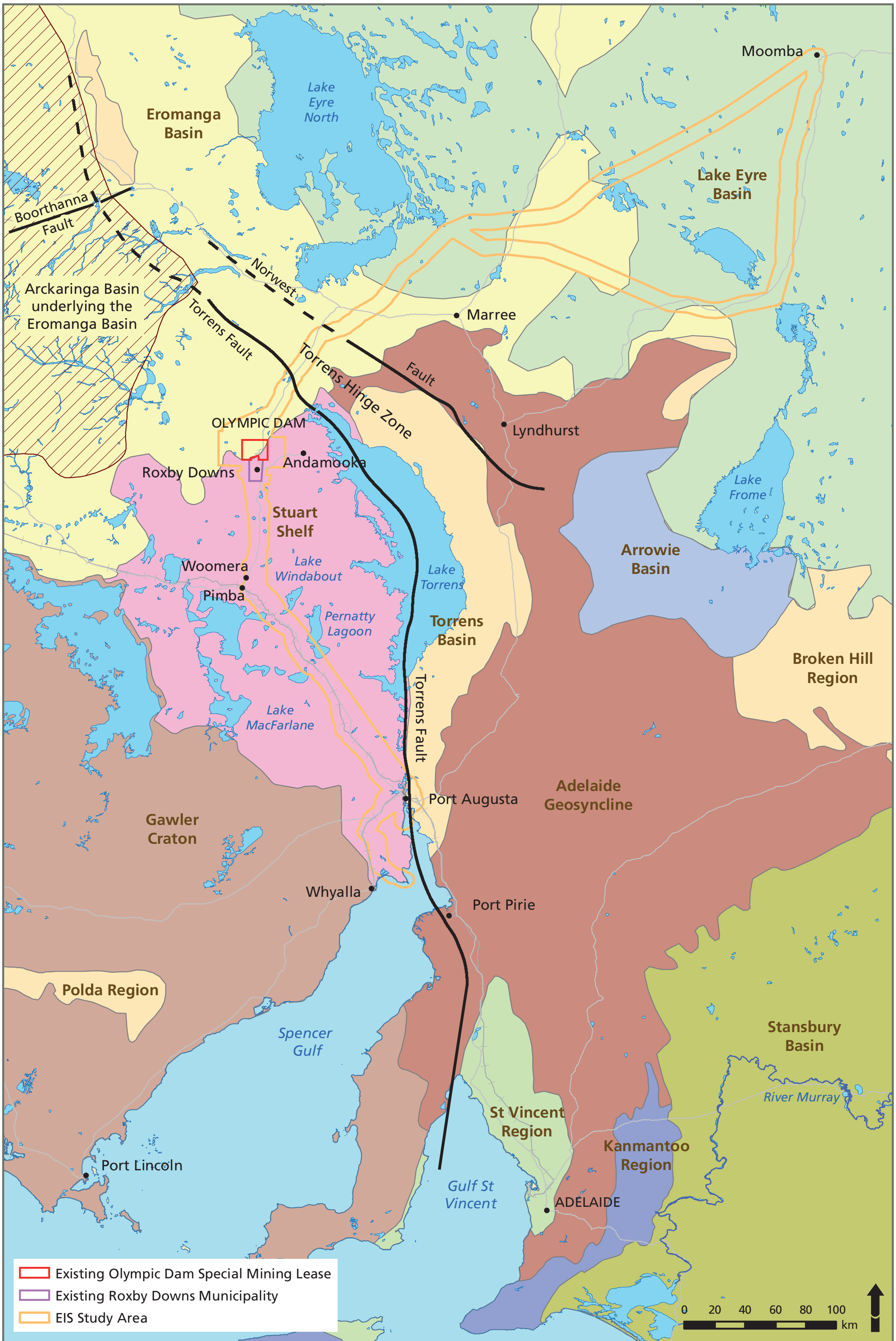


Figure 12.3 Geological provinces and basins of South Australia

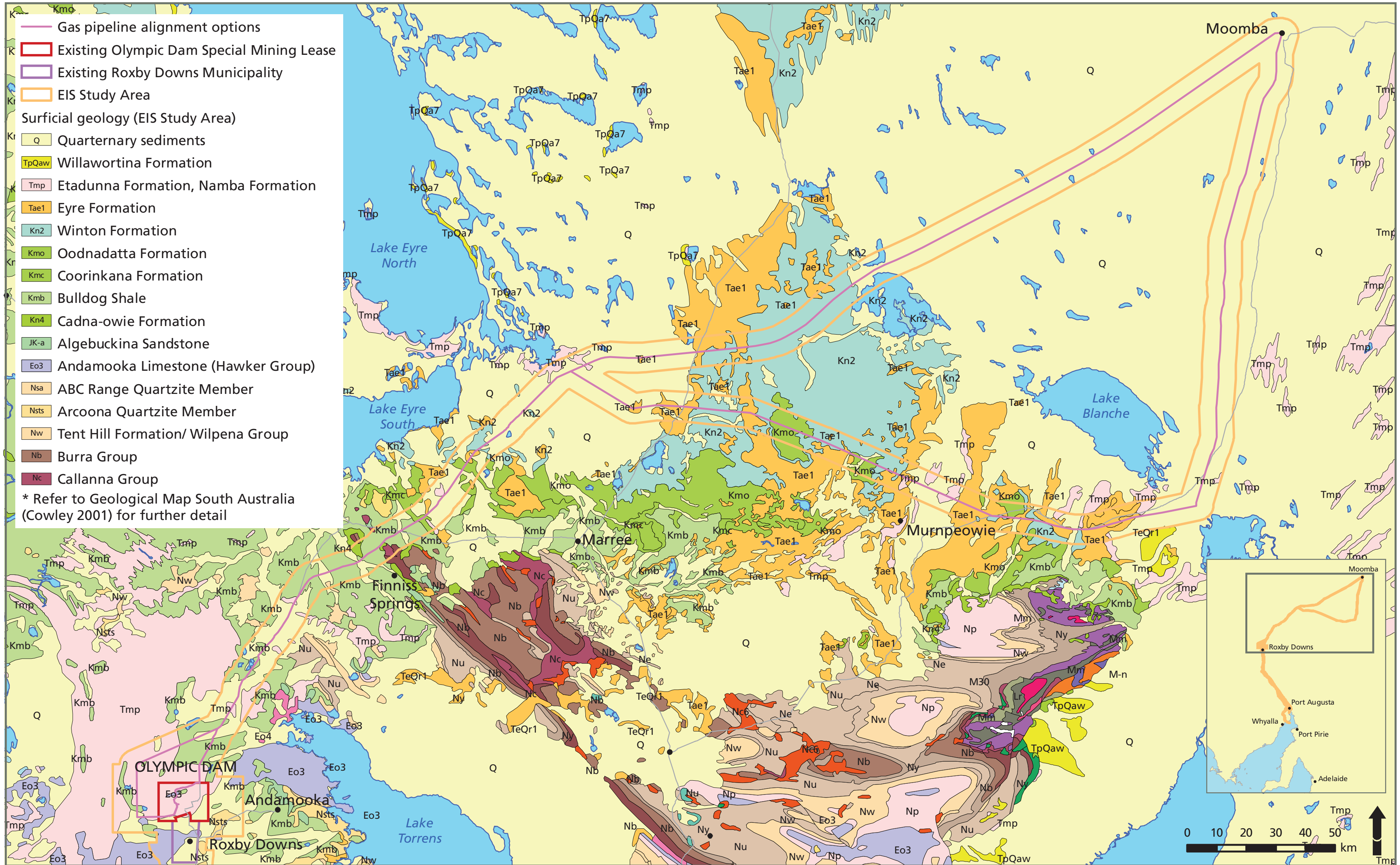
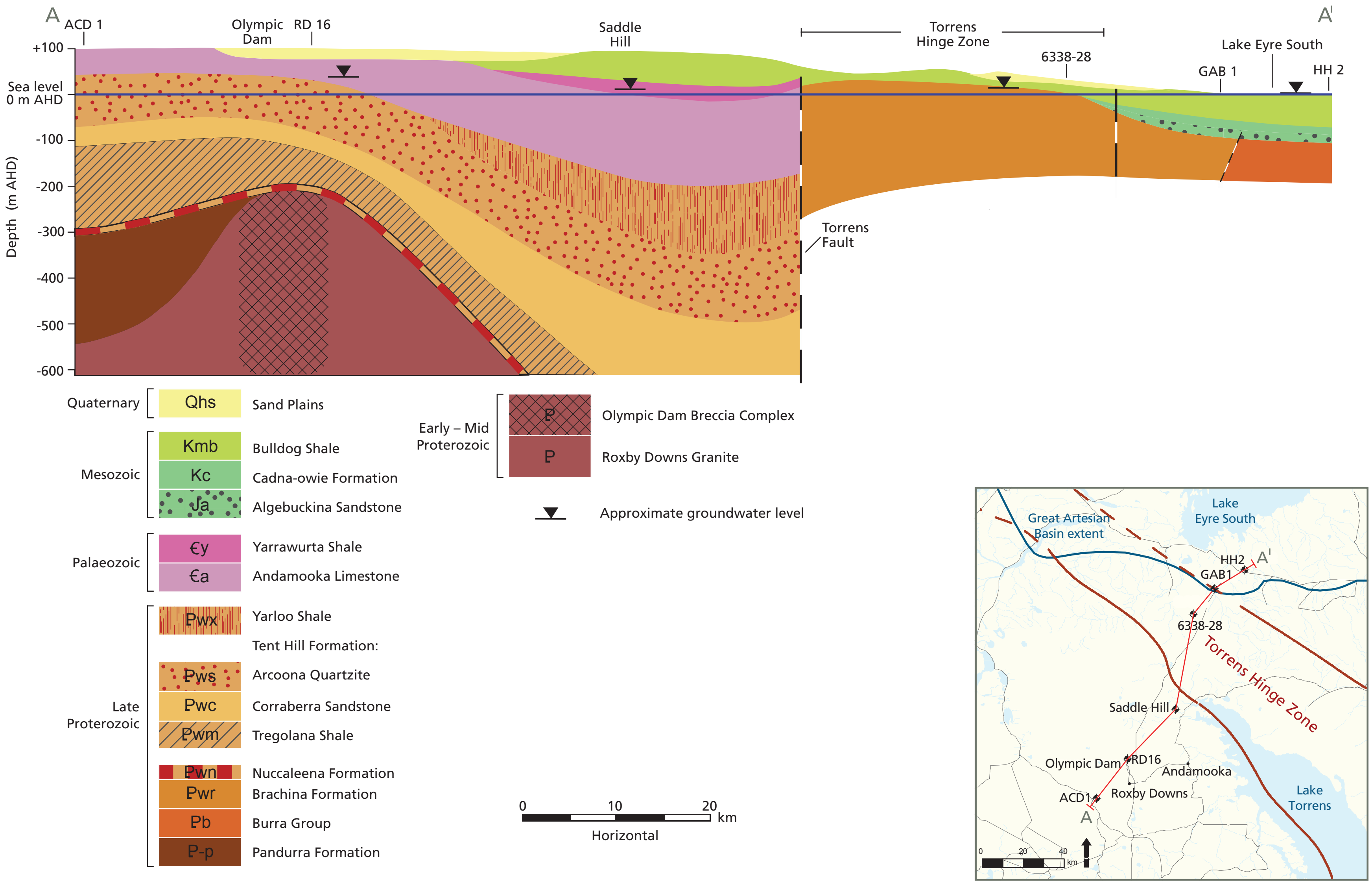


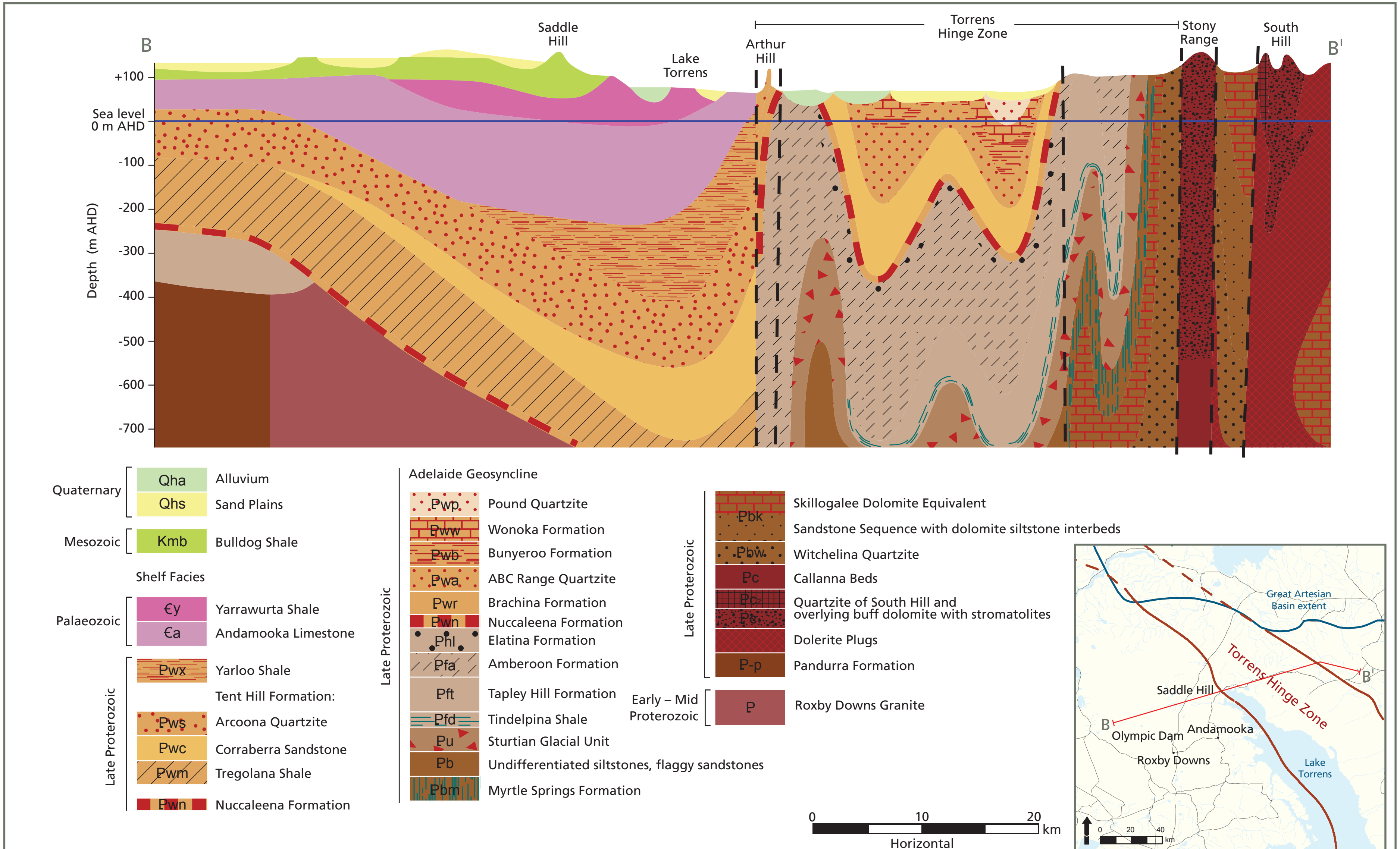
Figure 12.4 Surficial geology of the gas pipeline corridor options

Figure 12.5 Surficial geology of the Special Mining Lease and southern infrastructure corridor



Source: Adapted from Geological Survey of South Australia, Andamooka Map Sheet SH53-12

Figure 12.6 Schematic geological cross-section of northern Stuart Shelf and southern Great Artesian Basin



Source: Adapted from Geological Survey of South Australia, Andamooka Map Sheet SH53-12

Figure 12.7 Schematic geological cross-section of northern Stuart Shelf and westerly extent of the Adelaide Geosyncline

Torrens Basin

The Torrens Basin is an elongated structural depression that is coincident with the Torrens Hinge Zone and bordered on the west by the Torrens Fault. The basin has been in-filled with Tertiary-aged sediment to depths of up to 300 m.

12.3.2 GROUNDWATER FLOW SYSTEMS

Groundwater in the Olympic Dam region generally occurs in fractured rocks tens of metres below the surface. It moves very slowly (<1 m per year) from a west to east direction and ultimately discharges to Lake Torrens, an evaporative sink (Golder Associates 1995; REM 2007). It is estimated that it would take thousands of years for groundwater at Olympic Dam to reach Lake Torrens. Other groundwater flow systems in the region are also present in the rocks of the Eromanga and Arckaringa basins.

Stuart Shelf

Although the Olympic Dam ore body is located within rocks of the Gawler Craton, it is the Stuart Shelf that is important hydrogeologically and in relation to activities to be undertaken as part of the proposed expansion that would affect groundwater.

There are two important groundwater systems in the Stuart Shelf: the Andamooka Limestone aquifer and the Tent Hill aquifer. The general characteristics of these aquifers and the units that separate them are summarised below (see also Appendix K1). Figure 12.8 shows a conceptual cross-section of these units as they occur beneath the current operation.

Andamooka Limestone aquifer

Where it is saturated, the Andamooka Limestone is the shallowest of the aquifers in the Stuart Shelf, and forms the regional 'water table' aquifer to the north of Olympic Dam. It covers an area of approximately 14,500 km^2, extending from around 50 km south and 80 km north-west of Olympic Dam, to around 35 km north of the top of Lake Torrens. South of Olympic Dam the base of the Andamooka Limestone becomes shallower and the aquifer becomes unsaturated (i.e. it does not contain water).

The water table typically occurs about 50 m below ground in the area of the mine (i.e. 50 m Australian Height Datum (AHD) as Olympic Dam is at 100 m AHD). Groundwater in the aquifer moves from the west of the Stuart Shelf to the northern end of Lake Torrens, where the water table typically occurs less than 10 m below ground.

To the north of Olympic Dam the Andamooka Limestone aquifer has a high secondary porosity and permeability that is associated with dissolution features. Recent investigations undertaken by BHP Billiton during water supply studies show high transmissivity (i.e. 100 to 4,000 m^2/d) and groundwater yields from wells drilled in this area (see Appendix K1 for details).

Towards the southern limits of the Andamooka Limestone, the transmissivity decreases considerably (i.e. 4 to 120 m^2/d), suggesting that dissolution features, which have been observed in drill samples in the unsaturated portion of the limestone unit, are absent or rare beneath the natural water table level.

Groundwater salinity typically ranges between 20,000 mg/L and 60,000 mg/L (Golder Associates 1995; Kellett et al. 1999; REM 2007), but the groundwater salinity increases to as much as 200,000 mg/L closer to Lake Torrens. This compares with the salinity of seawater, for example, which is about 36,000 mg/L.

Tent Hill aquifer

The Tent Hill aquifer is extensive and forms the most important aquifer over the southern portion of the Stuart Shelf, where the Andamooka Limestone aquifer is either very thin or absent. It includes the lower parts of the Arcoona Quartzite and the Corraberra Sandstone units of the Tent Hill Formation and is therefore sometimes referred to as the Arcoona Quartzite aquifer or the Corraberra Sandstone aquifer. The aquifer occurrences reduces to the north of the SML due to a deepening of the unit and reduction in permeability.

At Olympic Dam, this aquifer typically occurs 160–200 m below ground level (about –60 m AHD to –100 m AHD). The depth increases moderately to the north, west and south, with the base of the unit occurring at around 225 m below ground level (–125 m AHD) near the existing underground mine (see Figure 12.6) and more than 400 m below ground to the north of Olympic Dam.

A high degree of variability is reported for the Tent Hill aquifer parameters across the Stuart Shelf. Reported groundwater yields are highest in the vicinity of the SML and consistent with the inferred alignment of a major structural zone referred to as Mashers Fault (see Figure 12.9).

Groundwater salinity in the Tent Hill aquifer is generally higher than the Andamooka Limestone, with reported concentrations ranging from about 35,000 mg/L to more than 100,000 mg/L in the vicinity of Olympic Dam, and ranging to around 200,000 mg/L closer to Lake Torrens.

The upper section of the Arcoona Quartzite unit forms an aquitard. This is a low permeability layer that acts to restrict the movement of groundwater between the Andamooka Limestone aquifer and the Tent Hill aquifer.

Eromanga Basin

The Eromanga Basin, together with the Surat Basin and the Carpentaria Basin, form the Great Artesian Basin (GAB) (see Figure 12.10), which contains one of the largest groundwater systems in the world. The GAB underlies almost 1.7 million km^2 of central and north-eastern Australia.

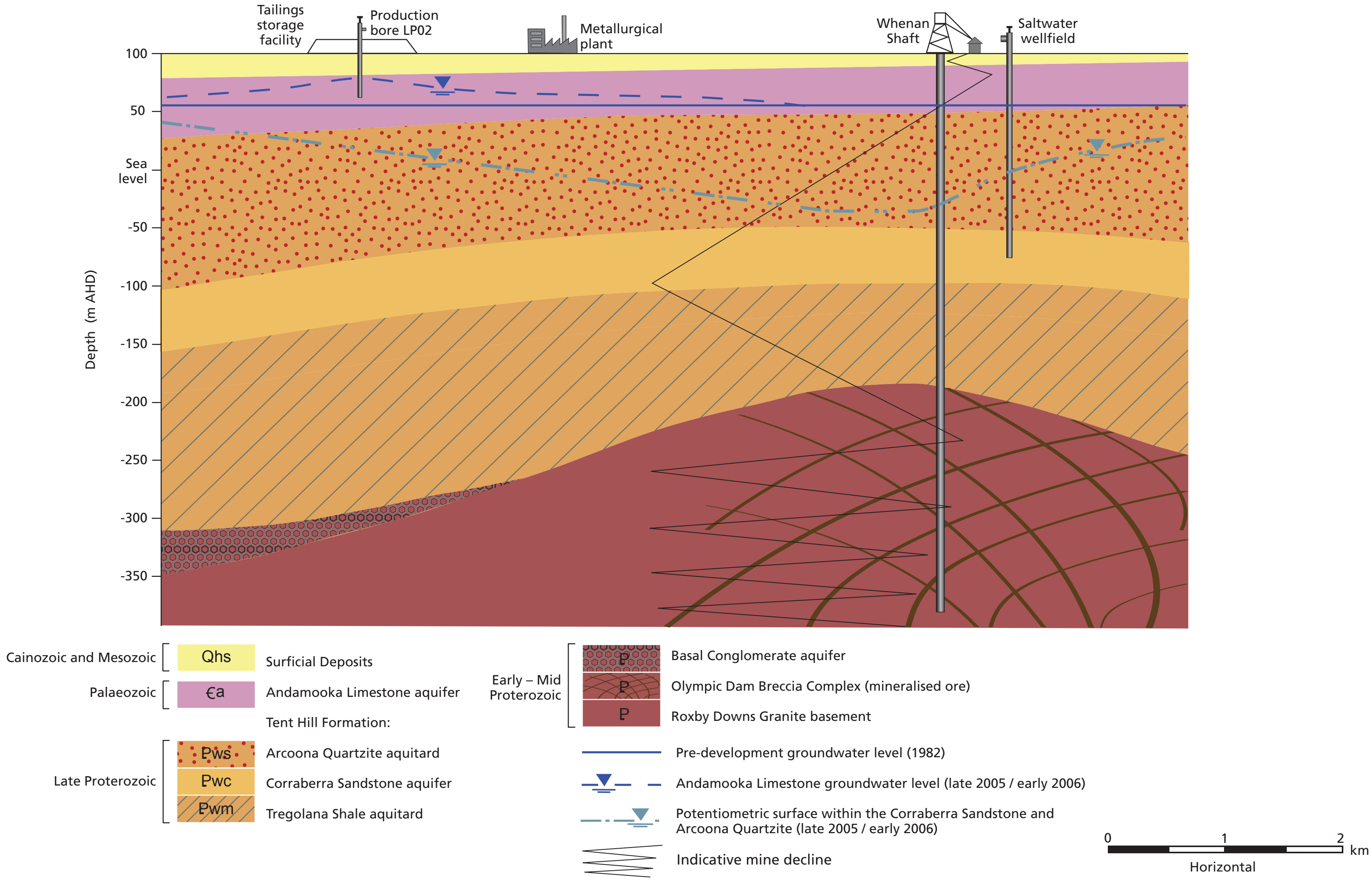


Figure 12.8 Schematic hydrostratigraphic cross-section of the Olympic Dam mine site

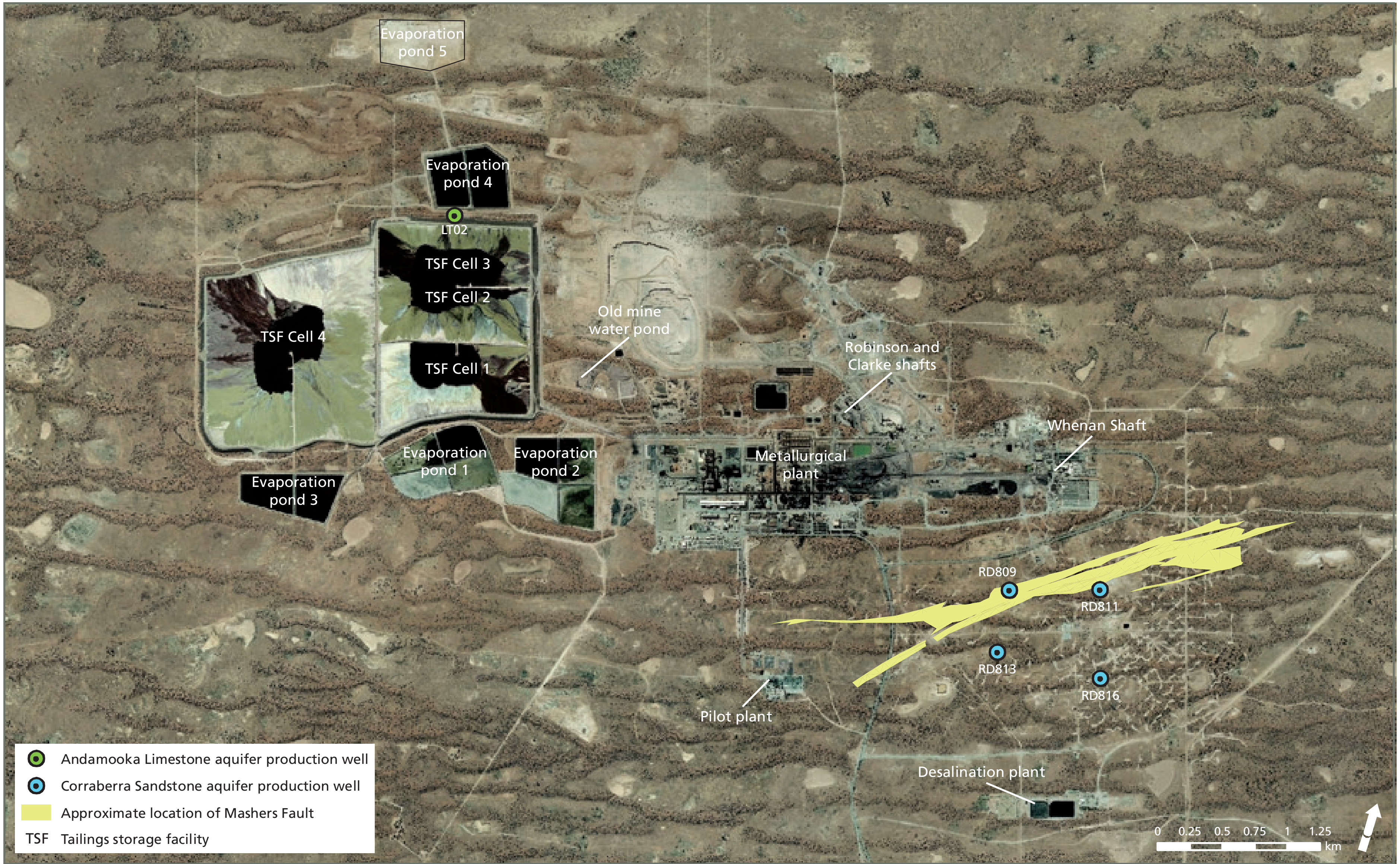


Figure 12.9 Existing wellfields on the Special Mining Lease

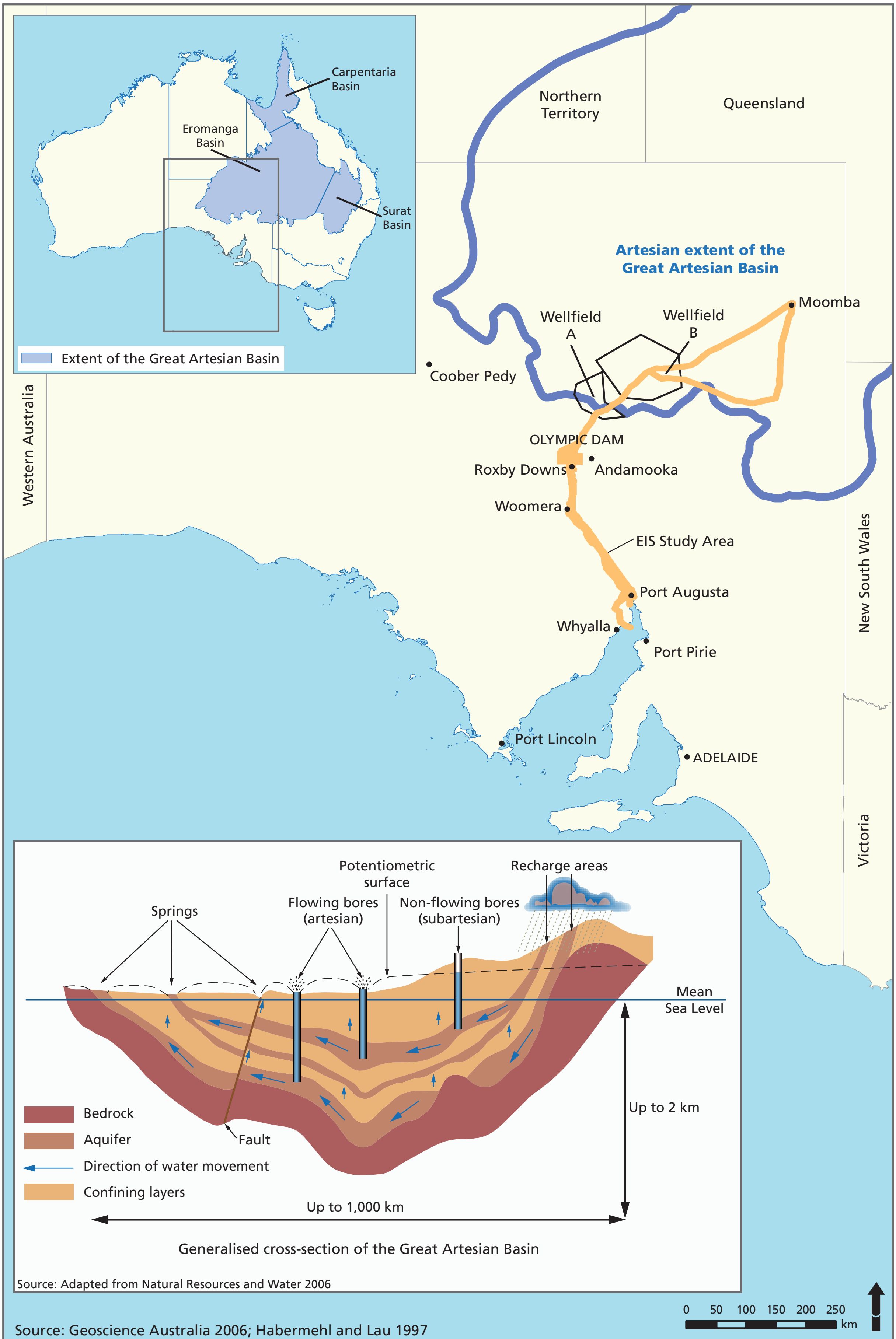


Figure 12.10 Locality plan of the Great Artesian Basin

In South Australia, there are two types of aquifers associated with the Eromanga Basin – artesian GAB aquifers and non-artesian aquifers – and there is very little, if any, hydraulic connection between the two (Kellett et al. 1999), or between the artesian GAB aquifers and the Stuart Shelf.

Artesian GAB aquifers

Artesian aquifers have a 'potentiometric surface' that is above ground level. This means the pressure within the aquifer would cause the water to rise above the ground surface if a hole was drilled into the aquifer (see Plate 12.3). The artesian GAB aquifers extend from Queensland through northern New South Wales to the north-eastern section of South Australia (see Figure 12.10). No artesian GAB aquifers occur within 95 km of Olympic Dam.

The artesian pressures observed in the GAB aquifers are derived primarily from rainfall recharge along the Queensland portion of the Great Dividing Range (Habermehl 1980). Near the edge of the artesian GAB aquifers, where they are close to the surface, natural geological structures such as faults provide a path for groundwater to express at the surface and form GAB springs (see Chapter 15, Terrestrial Ecology, for further detail of GAB springs). The nearest GAB spring is around 95 km north of Olympic Dam and is not in hydraulic connection with the primary Stuart Shelf groundwater flow aquifers.

Plate 12.3 GAB groundwater pressure

Plate 12.4 GAB production bore in Wellfield A

The salinity of groundwater in the artesian GAB aquifers is low, generally ranging from less than 1,000 mg/L to around 2,500 mg/L, providing an important resource for communities in the Far North of South Australia, as well as for the mining, and oil and gas industries. Olympic Dam currently sources most of its mine and process water from the groundwater resource of the artesian GAB aquifers (see Plate 12.4).

Non-artesian Eromanga aquifers

Non-artesian aquifers in the Eromanga Basin do not have potentiometric surfaces above ground level and, consequently, do not produce free-flowing wells or natural springs. These are present in a relatively small area to the south and south-west of the artesian GAB aquifers, and typically form shallow water table aquifers that do not support GAB springs. These aquifers are isolated in their extent, are recharged from local rainfall and are not in connection with the primary GAB aquifers.

Arckaringa Basin

The Arckaringa Basin occurs around 100 km to the north-west of Olympic Dam (see Figure 12.3). Historically, its groundwater system has not been investigated in detail, probably as a result of the ability to more easily develop groundwater supplies from the shallower non-artesian Eromanga Basin aquifers and the previous absence of mining operations in the area west of Olympic Dam. The Prominent Hill mine is now in this area and sources water from the Arckaringa Basin.

Two main groundwater systems have been identified in the Arckaringa Basin: the Mount Toondina aquifer and the Boorthanna aquifer. The Mount Toondina aquifer is a sub-artesian aquifer that occurs primarily north of the Boorthanna Fault (see Figure 12.3), at relatively shallow depths. Its salinity is variable (but mostly above 5,000 mg/L) and it may have an hydraulic connection to the overlying artesian GAB aquifers. South of the Boorthanna Fault, the Boorthanna Formation is known to form an extensive confined aquifer, with varying salinity (<10,000 mg/L to >30,000 mg/L) and moderate transmissivity.

Infrastructure corridor groundwater systems

Gas pipeline corridor options

Between Olympic Dam and Lake Torrens, the gas pipeline corridor options traverse the Stuart Shelf geological province (although Eromanga Basin sediments overly the Stuart Shelf in this area), and the groundwater systems are as described above.

To the north of Lake Torrens, where the Stuart Shelf is not present, the occurrence of shallow groundwater is dominated by the typically artesian GAB aquifers of the Eromanga Basin. Some discrete aquifers are also common within the overlying Bulldog Shale.

In the far north-east section of the gas pipeline corridor options, the Eromanga Basin is overlain by the Lake Eyre Basin. Shallow groundwater occurs in the Eyre and Namba Formations of the Lake Eyre Basin (see Figure 12.4) which ranges from fresh to saline across the project area – typically from around 1,000 mg/L to up to 34,000 mg/L.

The main groundwater discharge zones along the gas pipeline corridor options are GAB springs, saline lake systems, such as Lake Eyre and the larger ephemeral watercourses such as Cooper Creek.

Southern infrastructure corridor

Groundwater occurrence along the infrastructure corridor is mainly characterised by fractured rock aquifer systems similar to those occurring in the Olympic Dam area.

Apart from a small number of water supply development studies for road and rail construction works, there is little information available relating to the groundwater resources along the proposed infrastructure corridors. Some extraction wells have been developed in these areas to supply water for livestock, but these are small and undocumented.

Groundwater can be expected to be of poor quality, being saline (more than 10,000 mg/L), to hypersaline (more than 100,000 mg/L), especially in the deeper fractured rock aquifers. However, fresh to brackish groundwater has been recorded where localised recharge takes place, for example along creek lines.

12.3.3 REGIONAL GROUNDWATER INTERACTIONS

Stuart Shelf

Groundwater level data from recent surveys and drilling investigations (see Figure 12.11) have been used to interpret groundwater flow paths across the Stuart Shelf. The data suggest that there is no interaction between the artesian GAB aquifers and the primary Stuart Shelf groundwater flow systems (Andamooka Limestone and Tent Hill aquifers). The data also suggest that interactions occur between the Stuart Shelf groundwater systems and those of the Arckaringa Basin and Adelaide Geosyncline. These interactions form a regional groundwater system.

The main characteristics of the regional groundwater flow systems are as follows:

- Olympic Dam lies at the southern edge of the regional groundwater system.
- The groundwater catchment extends south of Woomera and west into the Arckaringa Basin. It is bounded to the north by the Adelaide Geosyncline rocks and to the east by Lake Torrens.
- Recharge occurs to the south from the Arcoona Plateau and west via through-flow from the Arckaringa Basin. Recharge also occurs from rainfall over the entire Stuart Shelf, which is estimated at 0.1 to 0.2 mm/y (see Appendix K1; Golder Associates 1995; Kellett et al. 1999).
- Low hydraulic gradients (which affect how fast and in what direction groundwater moves) occur north of Olympic Dam, where the regional system is dominated by the Andamooka Limestone aquifer. This is a result of higher aquifer transmissivity.
- Lake Torrens has generated high density brines that have migrated west from the lake to form a high salinity groundwater zone in the base of the Andamooka Limestone aquifer.
- Steep hydraulic gradients occur to the south and west of Olympic Dam, suggesting that low permeability, due to a reduction in the Andamooka Limestone aquifer thickness and dominance of the Tent Hill aquifer, occurs in these areas.
- Groundwater moves towards the northern end of Lake Torrens where it discharges via evaporative processes. Some groundwater flow and evaporative discharge also occurs along the northern boundary of the Stuart Shelf.

Great Artesian Basin

Figure 12.12 presents a conceptual model of the interaction between the Stuart Shelf and GAB groundwater systems (also see Appendix K1). Most importantly, Figure 12.12 shows that:

- the artesian GAB aquifers are separated by geological and structural controls associated with the low permeability rocks of the Adelaide Geosyncline and Torrens Hinge Zone
- groundwater discharges at the edge of each groundwater system, via evaporation, and does not flow laterally between systems
- GAB springs are supported by groundwater flow from the artesian GAB aquifers to the north-east and are not supported by groundwater flow from the Stuart Shelf.

The conceptual model is also supported by hydrogeochemical and isotope data, which show that the composition of groundwater sampled from the GAB aquifers is significantly different to groundwater from the Stuart Shelf (see Appendix K1 for details), and the outputs of the numerical groundwater flow model (see Appendix K6).

12.3.4 GROUNDWATER QUALITY AND BENEFICIAL USE

Groundwater was sampled from wells across the Stuart Shelf and the southern infrastructure corridor to determine baseline groundwater quality and whether it may have a beneficial use. A summary of results and sampling locations is shown in Figure 12.13, with further details provided in Appendix K3.

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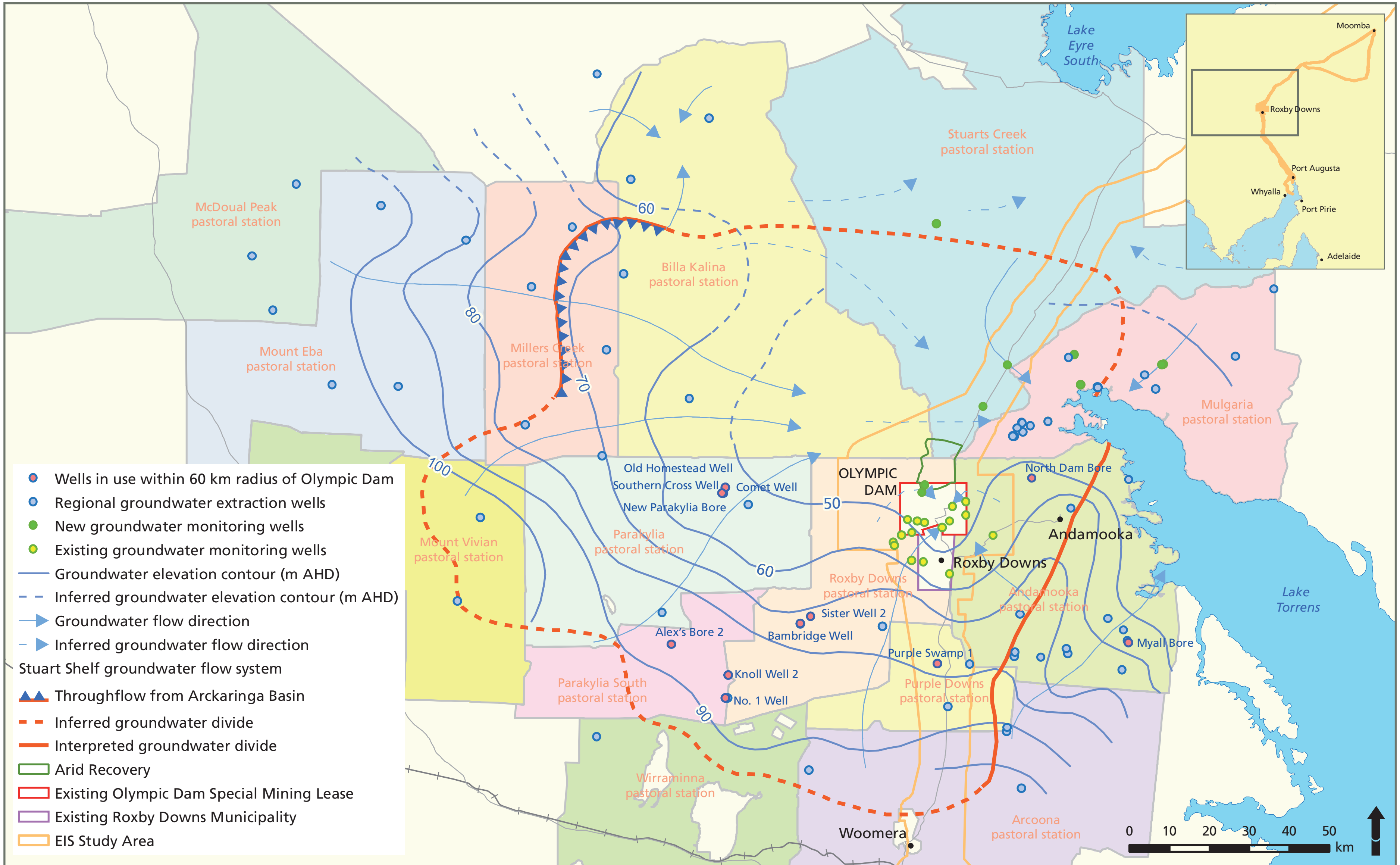
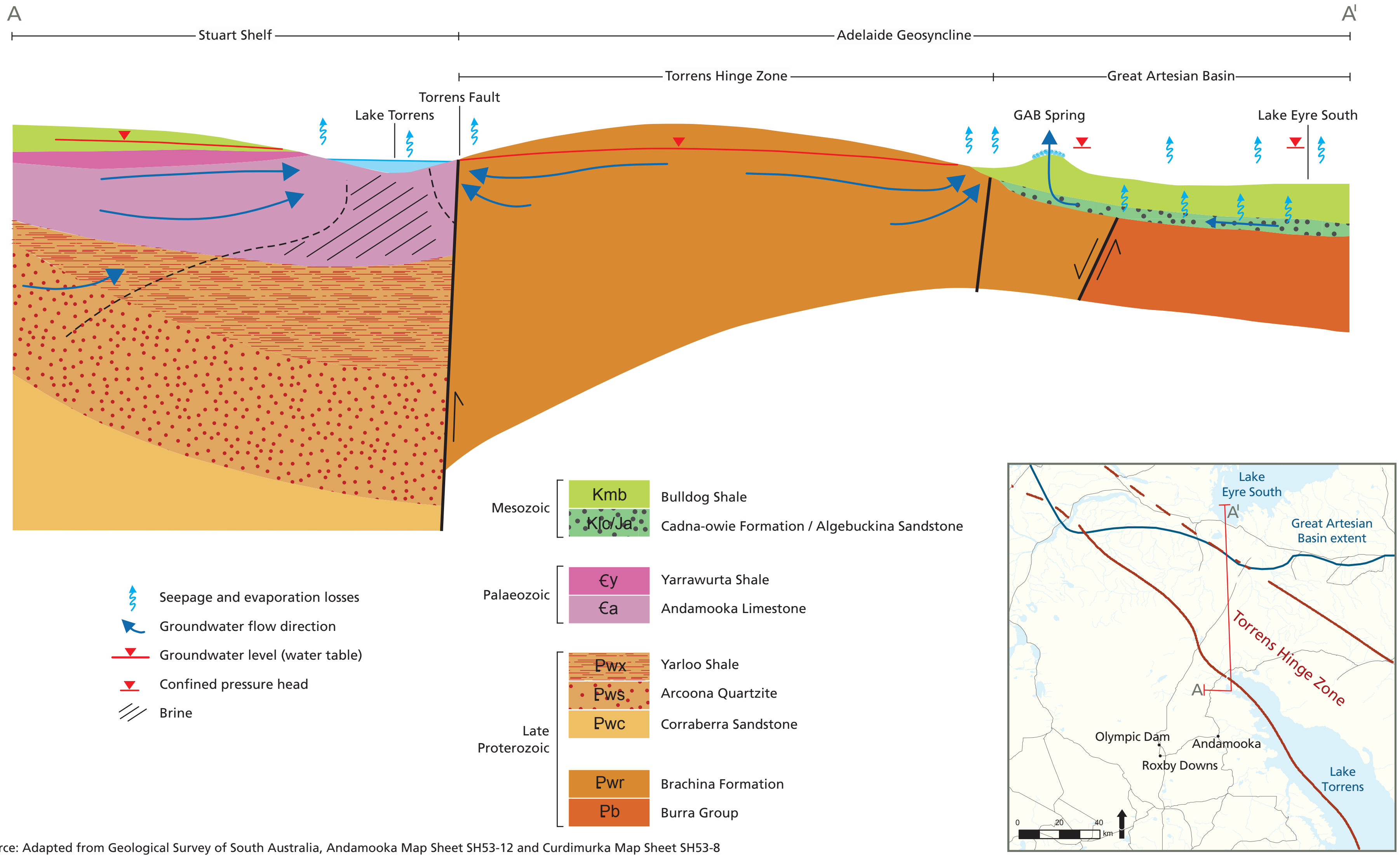


Figure 12.11 Groundwater elevation contours for western Stuart Shelf



Source: Adapted from Geological Survey of South Australia, Andamooka Map Sheet SH53-12 and Curdimurka Map Sheet SH53-8

Figure 12.12 Conceptual model illustrating the separation between the Stuart Shelf and Great Artesian Basin

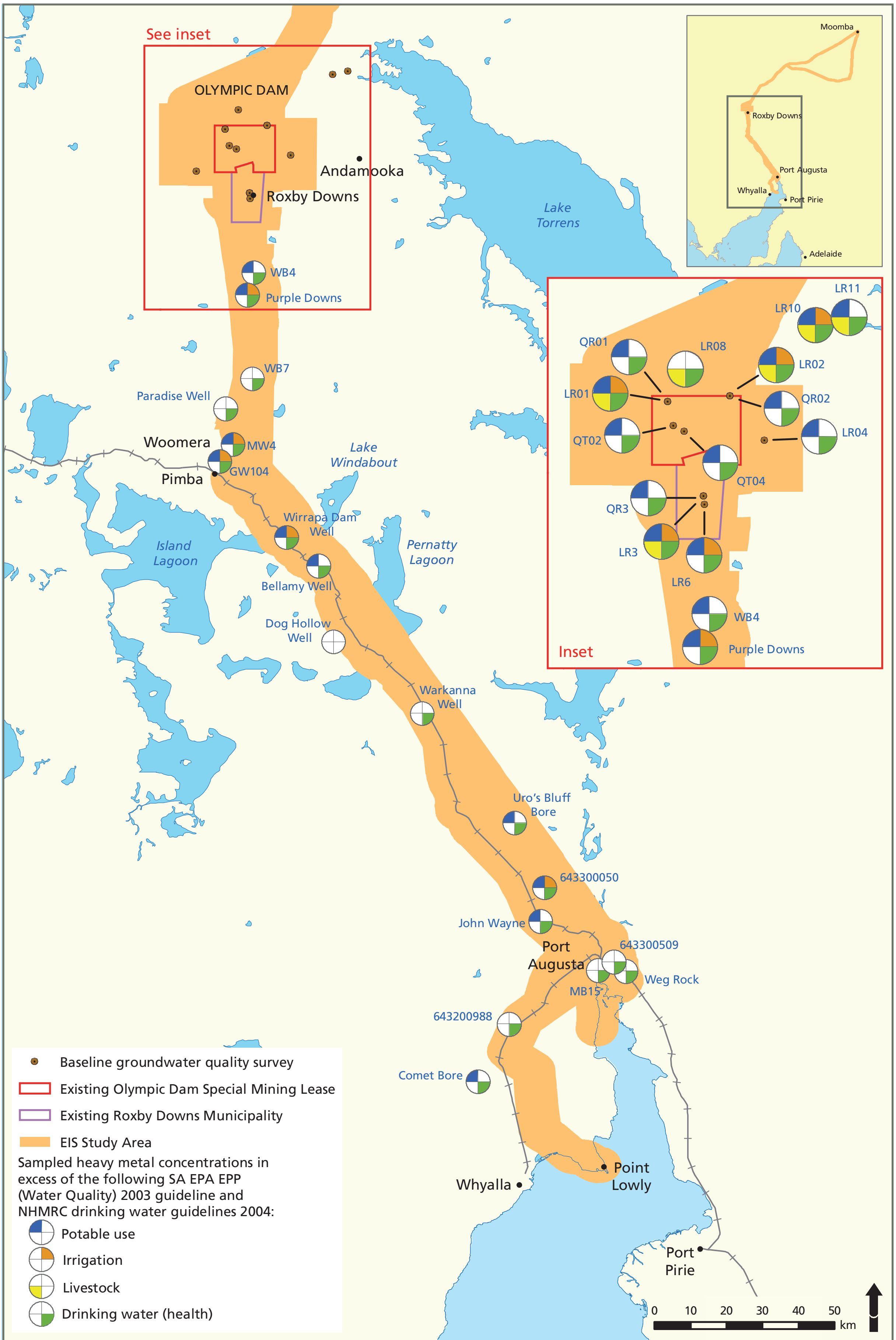


Figure 12.13 Water quality survey showing groundwater guideline exceedances

As mentioned above, most of the groundwater across the Stuart Shelf ranges from saline to hypersaline (greater than 10,000 mg/L and 100,000 mg/L, respectively). Based on guidelines of the Australian and New Zealand Environment and Conservation Council (ANZECC/ARMCANZ 2000), and the South Australian Environment Protection (Water Quality) Policy 2003 (SA EPA 2003), most groundwater does not meet the criteria for freshwater aquatic ecosystems, drinking water, stock water or recreational use. Some groundwater suitable for stock use (less than 5,000 mg/L) was identified along the southern infrastructure corridor and is likely to be associated with localised recharge and limited in extent.

Background metal concentrations in both the Andamooka Limestone and Corraberra Sandstone are relatively low, although concentrations can exceed one or more water quality criteria. Specifically, in terms of uranium, groundwater concentrations are typically between 0.01 and 0.03 mg/L. The South Australian potable water quality criterion for uranium is 0.02 mg/L (SA EPA 2003).

12.3.5 GROUNDWATER USERS

Stuart Shelf

Even though the salinity of groundwater in the project area is generally high, the absence of permanent surface water and the sporadic nature of rainfall means that, although limited, most pastoral stations use groundwater to some degree.

A survey undertaken for the Draft EIS identified 14 groundwater wells that are currently in use within a 60 km radius of the existing Olympic Dam (see Figure 12.11 and Plates 12.5 and 12.6). Of these, seven are located on pastoral leases held by BHP Billiton (Andamooka, Purple Downs and Roxby Downs), four are located on Parakylia Station and three are located on Parakylia South Station.

Local groundwater is not currently used in Andamooka Township (G Murray, President Andamooka Progress and Opal Miners Association, pers. comm., 2006). Water is now piped to Andamooka from the desalination plant at Olympic Dam, which is supplied by water from the GAB.

Gas pipeline corridor options

Several pastoral stations along the gas pipeline corridor options rely on groundwater from the artesian GAB or Lake Eyre aquifers to meet some or all of their stock and domestic water needs. Although the active use of groundwater wells could not be confirmed, government database records indicate that more than 100 potentially operational wells are located in the vicinity of the corridors. The majority of these wells are constructed to abstract water from depths greater than 20 m, with salinities likely to be less than 10,000 mg/L (see Appendix K1 for details).

Plate 12.5 Southern Cross Well at Parakylia Station

Plate 12.6 Groundwater well with pump on Arcoona Station

Southern infrastructure corridor

About 80 wells or water points are located on pastoral stations along the southern infrastructure corridor. Some of these wells are used for stock water. It is not known whether the wells are used for domestic supply, although the groundwater quality would suggest that if this does occur, pre-treatment would be required. Groundwater salinities from these wells range from less than 5,000 mg/L to more than 50,000 mg/L, and the depths to groundwater in sampled wells range from 0.5 m below ground level, near Port Augusta, to about 50 m below ground level near Roxby Downs (see Appendices K2 and K3 for details).

12.3.6 GROUNDWATER DEPENDENT ECOSYSTEMS

A number of hypersaline springs and seeps are located around Lake Torrens. Only one of these, the Yarra Wurta spring group, is known to have an ecosystem with an obligate dependence on groundwater. Yarra Wurta spring is located on the northern limit of the Torrens Hinge Zone and is underlaid by the Adelaide Geosyncline rocks and the Andamooka Limestone. The ecological significance of Yarra Wurta spring has been assessed and findings are presented in Chapter 15, Terrestrial Ecology.

A number of freshwater swamps and terminal drainage features occur on the Stuart Shelf. The closest, Coorlay Lagoon, located approximately 25 km south of Olympic Dam, is a final drainage point for a number of watercourses that drain the Arcoona Plateau. The water table at this location occurs within the Arcoona aquitard and is very close to the surface. Given that the salinity of groundwater in this area is typically greater than 50,000 mg/L, it is unlikely that any vegetation is reliant upon groundwater.

A stygofauna assessment was carried out for the Draft EIS and results are presented in Chapter 15, Terrestrial Ecology.

12.4 GROUNDWATER-AFFECTING ACTIVITIES

Groundwater-affecting activities are those components of the mining and processing operation that have the potential to alter groundwater systems on a local or regional scale. These usually include extracting groundwater for mine dewatering or water supply, and seepage from above-ground sources such as tailings and water storages.

This section describes the groundwater-affecting activities of the existing operation and the proposed expansion. It also summarises the current response to groundwater beneath the SML from the existing operation, which is monitored by a dedicated network of more than 80 wells and reported annually to DWLBC, Environment Protection Authority (SA EPA), and the Department of Primary Industries and Resources (PIRSA). The predicted response to groundwater from the proposed expansion is presented in Section 12.6.

12.4.1 EXISTING OPERATION

Dewatering

Groundwater from the underground workings drains into, and is collected from, 28 raise bores (ventilation shafts) that have been developed from the surface to the ore body, and penetrate both the Andamooka Limestone aquifer and the Tent Hill aquifer. Water collected from the raise bores is pumped to the surface and used in the mine process. Historically, groundwater has been extracted from the raise bores (referred to as 'mine dewatering') at rates between 1.3–2.1 ML/d.

Drawdown of groundwater (i.e. a 'cone of depression') has occurred in the Tent Hill aquifer as a consequence of the mine dewatering (see Figure 12.8), and extends up to 10 km to the north and east of the mine and around 5 km to the south-west. The decline in groundwater levels has been variable (up to 100 m), depending on proximity to the underground mine decline, ventilation shafts and raise bores, but has approached a steady state condition.

Water supply

A saline wellfield comprising four production wells established in the Tent Hill aquifer in the late 1990s (see Figure 12.9) to provide the existing operation with water for dust suppression and other low-end uses. Extraction of groundwater has historically ranged from almost zero to 1.1 ML/d with an average of around 0.2 ML/d. Drawdown of up to 40 m has been observed in the Tent Hill aquifer in the vicinity of the wellfield.

Tailings and water storages

Seepage from the TSF and mine water evaporation ponds (MWEP) have formed a mound within the Andamooka Limestone aquifer. The mound had risen about 20 m above the historic water table to approximately 30 m beneath the ground surface (about 70 m AHD) by 1998 and is mostly attributed to early tailings deposition and leakage from the old MWEP. Subsequently, a dedicated production well (LP02) was installed to recover water from the mound beneath the TSF for reuse within the metallurgical plant. The MWEP was decommissioned in 2001 and a new MWEP was established to the north-east of the mine. The seepage rate from the TSF is currently estimated at between 0.5 and 1.5 ML/y and the mound is currently around 35 m beneath the ground surface.

Seepage from the base of the TSF moves downward through the underlying sediments and the unsaturated zone of the Andamooka Limestone, where it undergoes a natural process of *in situ* neutralisation during which the pH increases to near neutral values. As a result of the reactions that occur, the concentration of heavy metals in the TSF liquor is greatly reduced by the time it reaches the groundwater. For example, the concentration of uranium in tailings water is up to 180 mg/L, but groundwater monitoring shows that the concentration of uranium in seepage reaching the groundwater is less than 1 mg/L.

Groundwater monitoring data show that local groundwater chemistry in the Andamooka Limestone aquifer around the TSF is similar to the regional groundwater chemistry, with the exception of slightly elevated uranium concentrations and slightly decreased pH. The average concentration of uranium in the groundwater beneath the TSF is around 0.09 mg/L, compared to an average background concentration of around 0.03 mg/L.

The downward movement of water from the Andamooka Limestone aquifer to the deeper Tent Hill aquifer is restricted by the Arcoona aquitard. However, water level monitoring results across the SML indicate that some 'leakage' through the overlying aquitard occurs in areas of increased drawdown and mounding.

12.4.2 PROPOSED EXPANSION

Changes associated with the proposed expansion, particularly those relating to the mining method and scale, would alter the groundwater-affecting activities in the following ways:

- A new open pit would operate and would require dewatering and depressurisation to control potential inflows of groundwater to the pit and to reduce residual pore pressures behind the pit walls. Dewatering and depressurisation of the open pit would result in more groundwater being removed from the local aquifers than currently occurs from groundwater discharge into the underground workings.
- New saline water supply wellfields would be constructed to extract water from the local saline aquifers.
- Unlike the underground mine post closure, the completed open pit would become a long-term, regional groundwater sink affecting the direction of groundwater flow and regional groundwater levels.
- The design, construction and size of the tailings storage facility would be different from the existing TSF and would result in a change in the rate and area of seepage.
- A rock storage facility (RSF) would be constructed. This could facilitate higher local recharge beneath the RSF by increasing the amount of rainfall that reaches the underlying aquifers.

To provide context and describe their relevance to the impact assessment, the groundwater-affecting activities are described in more detail below.

Dewatering and depressurisation

Prior to commencing mining it would be necessary to remove groundwater from the overburden (including the Andamooka Limestone and Tent Hill aquifers) and the ore body to ensure dry and safe mining conditions. Removal of water from the rock material surrounding the pit increases pit slope stability and is referred to as depressurisation. Up to 30 production wells would be installed into the Tent Hill aquifer (see Chapter 5, Description of the Proposed Expansion, Figure 5.12 for the proposed layout). Initially, groundwater extraction is expected to be around 15 ML/d but would reduce rapidly to around 8 ML/d within one year, and 5 ML/d within five years.

The Andamooka Limestone aquifer is mainly dewatered in the vicinity of the open pit due to current operation. The Tent Hill production wells would also be screened across this aquifer and capture residual groundwater. The low permeability rocks underlying the Tent Hill aquifer would be depressurised through the use of sumps in the base of the pit and horizontal drain holes in the pit walls.

Water supply

The proposed coastal desalination plant would supply primary potable and process water. Additional sources of water would be needed during the construction phase for activities such as dust suppression. This demand would be met by using the groundwater from the depressurisation activities and extracting groundwater from local saline aquifers.

The primary supply of saline water would be sourced from the 'Motherwell' saline wellfield in the Andamooka Limestone aquifer, approximately 30 km north of Olympic Dam (see Chapter 5, Description of the Proposed Expansion, Figure 5.25). Extraction rates are estimated to range between 15 and 28 ML/d.

Smaller 'satellite' wellfields would be located in the vicinity of the TSF, mine maintenance industrial area, Roxby Downs and the proposed airport, and would extract water from the Tent Hill aquifer (see Chapter 5, Figure 5.26). It is expected that these wellfields would provide a total of around 7–10 ML/d of saline water.

Open pit

After mining finished and dewatering operations stopped, groundwater would begin to seep into the pit. Due to the high evaporation rates, much of the groundwater would evaporate from the pit walls. However, some may reach and accumulate at the base (see Chapter 11, Surface Water, for detail of pit lake formation). Given the relatively low groundwater inflow rates (around 3.5 ML/d) compared to the evaporation, the height of the pit lake would not reach the level of the Tent Hill or Andamooka Limestone aquifers and water would continue to flow into the pit. As a result, the pit would become a permanent groundwater sink.

Tailings storage facility

Process tailings from the existing and expanded metallurgical plants would be disposed of in a new tailings storage facility (TSF). Although improvements to the design and construction of the TSF would reduce the rate of seepage per unit area, seepage would occur over a greater area due to the increased scale of the facility, and the total seepage rate will be higher than for the existing TSF. Seepage from the new TSF would probably contribute to the lateral and vertical extent of the existing groundwater mound and would affect the local groundwater chemistry.

Rock storage facility

For the natural undisturbed regional area it is estimated that less than 0.2% of the average annual rainfall, or around 0.1 to 0.2 mm/y, actually travels down through the soil profile and enters the groundwater. This is due to surface ponding and evaporation, and storage in the few metres of the soil profile, where it is available for plant uptake and evaporation before it moves downward.

Mine rock stored in the RSF is essentially dry and therefore has no inherent ability to release water. However, due to blasting and fracturing of the mine rock, its porosity and permeability increase and water may flow more rapidly through it than through the natural soils. As a result it is possible that more rainfall may reach the base of the RSF. When the water is in the soil profile beneath the RSF it would not evaporate, but instead would continue to move down the profile, eventually reaching the groundwater and increasing the natural recharge. Water leaving the base of the RSF could also affect local groundwater chemistry through contact with mine rock.

12.5 DESIGN MODIFICATIONS TO PROTECT ENVIRONMENTAL VALUES

12.5.1 ENVIRONMENTAL VALUES

The main environmental values of the project area in relation to groundwater are (see Section 12.3):

- groundwater systems of the Stuart Shelf
- neighbouring groundwater systems of the GAB and Arckaringa Basin
- users of the identified groundwater resources
- ecosystems in the Stuart Shelf that are dependent on groundwater for their survival.

12.5.2 MAJOR ELEMENTS OF THE PROJECT DESIGN

The main components of the project design that influence the assessment and management of groundwater resources (see Chapter 5, Description of the Proposed Expansion, for the full description of the project components) are discussed below.

The risk-based design of the TSF considers a range of issues, including safety, effective use of mine rock, effective containment and stability of tailings, and control and minimisation of seepage. The main controls that have been incorporated into the design of the TSF to address seepage are (see also Chapter 5, Section 5.5.6):

- Thickening the tailings from their current solids concentration of about 47% to 52–55%. This would reduce the amount of free liquor and the driving head to downward movement of liquor. Thickened tailings also increase the consolidation of tailings and make them less permeable.
- Constructing a liner (1.5 mm high density polyethylene (HDPE)) and underdrainage beneath and around the central decant pond area to collect seepage that can then be reused and recycled.
- Constructing internal curtain drains and toe drains around the perimeter of the TSF to prevent lateral escape of seepage and surface expression.
- Capping the TSF at closure to reduce the infiltration of surface water. Eventually the TSF would drain completely and seepage would decrease to very low levels controlled by natural infiltration of rainwater through the TSF capping material.

The greatest effect of the RSF on groundwater is the infiltration of incident rainfall through the RSF to the base of the facility, resulting in a localised increase in groundwater recharge. Water stored or moving through the RSF would contact mine rock and its metals concentrations would increase. The main design controls in place to address this are:

- minimise rainfall infiltration by traffic compaction on all surfaces except the ultimate inner and outer RSF slopes
- surround all reactive rock in the RSF with benign and/or neutralising material
- place a layer of benign and/or neutralising materials (overburden) at the base of the RSF to increase the potential for neutralisation and natural attenuation of seepage fluid.

Additional mitigation measures and standard controls to avoid or reduce impacts on groundwater are presented in Section 12.6.

12.6 IMPACT ASSESSMENT AND MANAGEMENT

12.6.1 CHANGES TO GROUNDWATER LEVELS

A regional numerical groundwater model was constructed to predict the changes in groundwater levels across the Stuart Shelf during construction, operation and post closure. The model predicts the area over which groundwater levels are changed from their natural state. This is referred to as the extent of groundwater drawdown or the zone of influence. For the purpose of this assessment, the extent of groundwater drawdown is defined by the 1 m vertical drawdown contour, which is considered the limit of accuracy given the regional scale of the model and the timeframe of model predictions.

The groundwater model shows that dewatering and depressurisation of the open pit and extraction of groundwater for construction water supply would result in an overall loss of groundwater from the system and drawdown in the Andamooka Limestone and Tent Hill aquifers. Changes to groundwater levels on a regional basis would mostly occur post closure due to flow of groundwater into the pit and subsequent evaporative losses. Results of the groundwater modelling are summarised below and further detailed in Appendix K6.

Tent Hill aquifer

The average extraction of groundwater from the Tent Hill aquifer is expected to range from around 12 ML/d, including depressurisation and water supply, during early mining to around 3.5 ML/d post closure. At the end of the construction period (scheduled for 2017), localised vertical drawdown is expected around the satellite wellfields and the open pit (see Figure 12.14).

Groundwater drawdown is initially driven from the dewatering and satellite wellfields during the construction phase but is gradually overridden by the effects of groundwater flow to the open pit. At the modelled 40-year mine life, the zone of influence is expected to have stabilised north of Olympic Dam but would continue to develop to the south over the very long term. The final zone of influence (500 years post closure) is expected to be around 20 km north and up to 45 km south of Olympic Dam (see Figure 12.14). The residual impact is categorised as moderate as it represents a long-term impact to a common receiver.

Andamooka Limestone aquifer

The groundwater levels in the Andamooka Limestone aquifer would change because of removal of groundwater from the Motherwell wellfield, addition of seepage from above ground sources and groundwater flow towards the pit.

Saline water supply

Groundwater extraction from the Motherwell saline wellfield during the construction period is expected to peak at around 28 ML/d and would result in groundwater drawdown. The predicted zone of influence (as defined by the 1 m drawdown contour) is shown on Figure 12.15. By the end of the assessed mining operation (i.e. Year 40), groundwater levels in this area would have recovered to pre-mine conditions (see Figure 12.15). The residual impact of operating the saline wellfields is categorised as low as it represents a short-term impact to a common receiver.

Seepage

Seepage from the TSF would cause a groundwater mound to form beneath the facility. The mound is expected to rise to a maximum of 14 m above existing water levels (around 35 m below ground) during the first 10 years of mining and then gradually subside as seepage rates decrease. Post closure, the influence of the open pit as a regional drawdown sink would start to dominate and the mound under the TSF would be underdrawn and disappear.

It is important to note that although formation of a groundwater mound beneath the TSF would affect groundwater levels for up to 6 km, transport of solutes in the seepage from the TSF would not extend that far. It is unlikely that solutes would travel more than a few hundred metres from the edge of the TSF due to the very low rates of groundwater flow. No groundwater mound is expected to form beneath the RSF due to the very low rates of seepage (see Section 12.6.2 for further discussion about seepage from the TSF and RSF).

Although the groundwater mound would recede and then disappear post closure, the residual impact is categorised as moderate as it represents a long-term impact to a common receiver.

Groundwater flow to the open pit

As mentioned above, groundwater flow into the open pit would be very low during mine operations because of the effects of mine dewatering and depressurisation. Inflow into the pit is expected to reach a maximum of 1 ML/d after around 15 years of mining due to the influence of the groundwater mound that would have formed beneath the TSF.

Post closure, groundwater from the Andamooka Limestone aquifer would not flow directly to the pit; instead, it would preferentially flow downwards through the Arcoona aquitard to the Tent Hill aquifer, from where it would then flow to the pit.

Groundwater drawdown of up to 10 m below pre-mining levels is expected in the Andamooka Limestone beneath the SML, post closure. The zone of influence in this aquifer is expected to extend up to 5 km north of the expanded SML and up to 20 km to the south-west (see Figure 12.15 and Table 12.1).

Regional groundwater interactions

Changes in groundwater levels across the regional groundwater flow system are most obvious south of Olympic Dam. This is because groundwater flowing from the Arckaringa Basin to the Andamooka Limestone aquifer (across the northern part of the Stuart Shelf) dominates the Stuart Shelf groundwater system and limits the impacts between Olympic Dam and groundwater systems to the north. The residual impact as a result of regional groundwater drawdown is categorised as moderate as it represents a long-term impact on a common receiver and not a direct impact to a receptor.

Table 12.1 Predicted effects in the Andamooka Limestone aquifer

Groundwater-affecting activity	Groundwater extraction (or addition[1])	Zone of influence	Comment
Saline water supply	Up to 28 ML/d	<2 km from wellfield	Wellfield operational during construction period only
Seepage from TSF	3.2 ML/d (see Section 12.6.2)	Up to 6 km from TSF	Height of mound continues to decrease after 2020
Flow toward pit	Up to 1 ML/d	5 km north 20 km south-west	Post closure effect overprints (dominates) all influence from the TSF and wellfield

[1] Seepage from the TSF results in addition of water to the system.

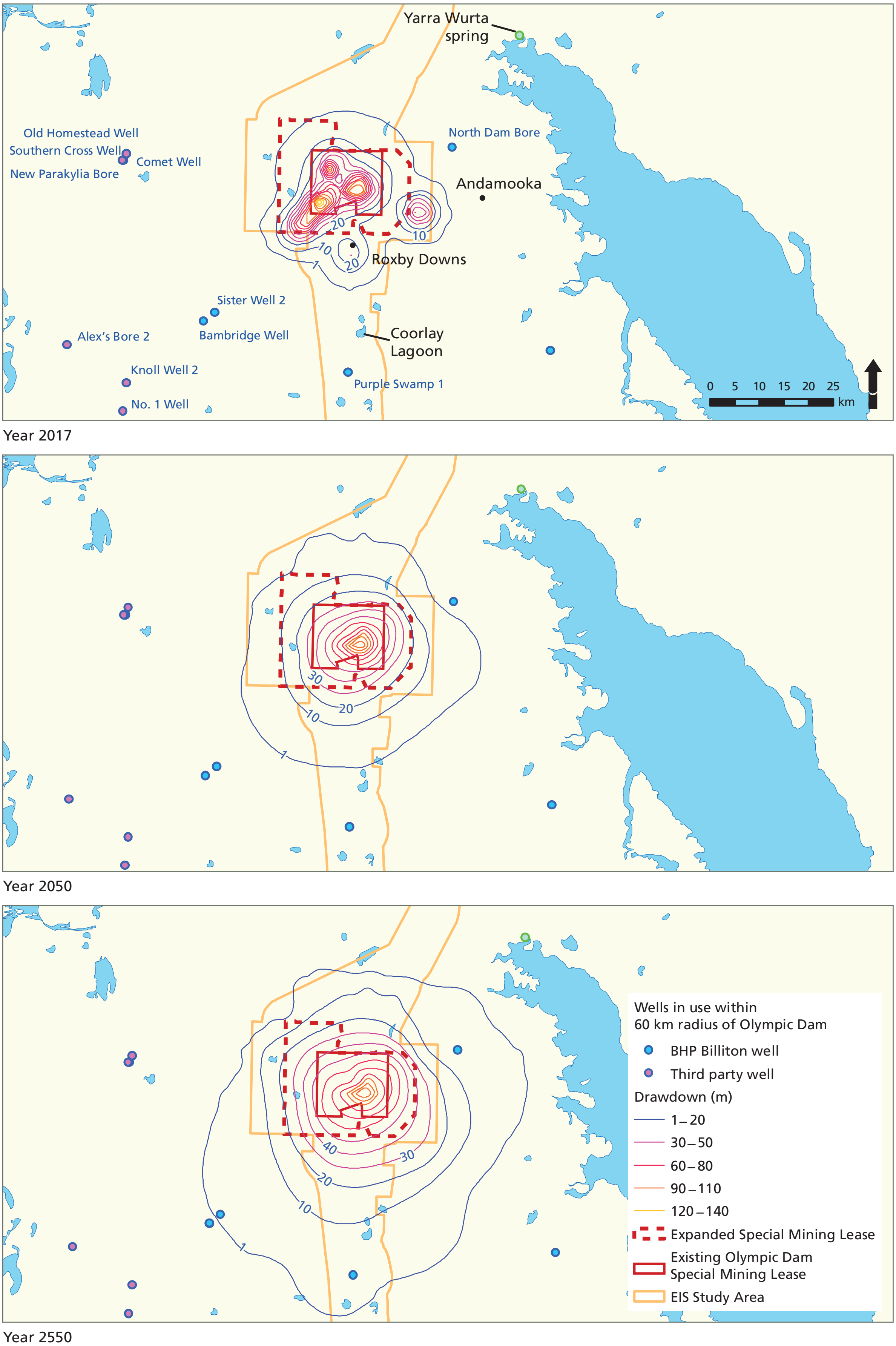


Figure 12.14 Predicted drawdown in the Tent Hill aquifer

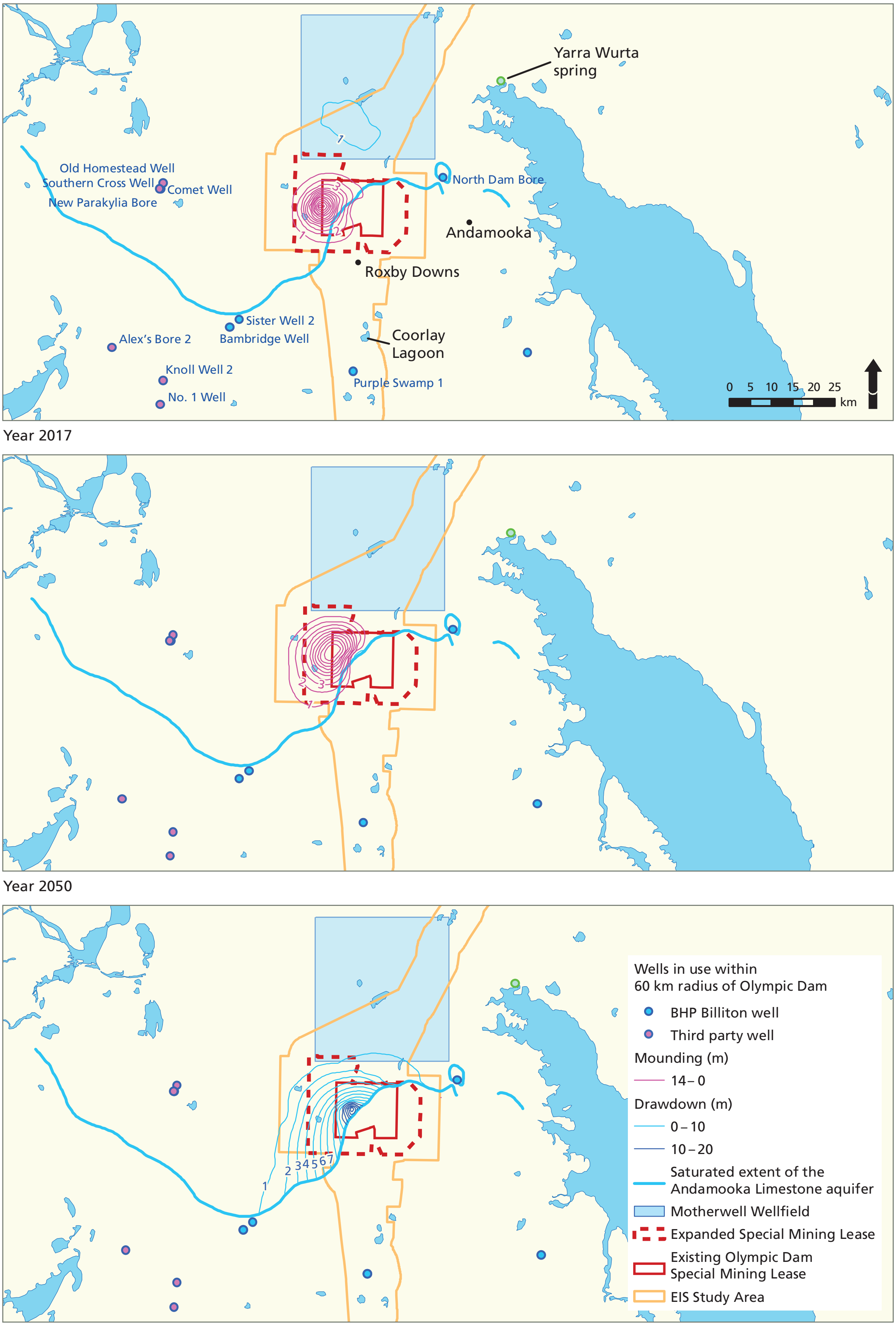


Figure 12.15 Predicted drawdown and mounding in the Andamooka Limestone aquifer

12

The groundwater model predicts no change in flow (and no residual impact) to the northern boundary between the Stuart Shelf and the GAB, even under the upper limits of sensitivity analysis (see Appendix K6 for sensitivity analysis).

The model also shows that groundwater response to activities at Olympic Dam is due to removing groundwater already stored within the aquifers of the Stuart Shelf rather than drawing more water from other groundwater systems (i.e. Arckaringa Basin). This results in very little effect (<2%) on the amount of water flowing into the Stuart Shelf from the Arckaringa Basin. Table 12.2 summarises the predicted changes in inflow and outflow at the boundaries of the Stuart Shelf groundwater system.

12.6.2 GROUNDWATER QUALITY

As well as changing groundwater levels (as discussed in Section 12.6.1), seepage from above ground sources such as the TSF and RSF may contain elevated concentrations of metals and increased acidity and therefore could change the chemical properties (or water quality) of the groundwater beneath them.

The rate of seepage, extent of change and the final groundwater quality would depend on the design and operation of the facility, the properties of the tailings and mine rock, the interaction of seepage with the sediments beneath the respective facilities, and closure management.

When seepage has reached the groundwater table, the potential for environmental impact would depend on continued chemical reactions within the aquifer, the direction of groundwater flow, the location of potential receptors in relation to groundwater movement, and the sensitivity of receptors to changes in water quality.

The detailed design of the RSF and TSF, including the methods proposed to minimise seepage and the characterisation of mine rock and tailings (i.e. operational inputs), are provided in Chapter 5, Description of the Proposed Expansion, Sections 5.4.6 and 5.5.6, and are detailed in Appendices F1 and K5.

Seepage rates

Tailings storage facility

Flow modelling was carried out to predict seepage rates from the proposed TSF (see Table 12.3). The assumptions for the model were based on measured and interpreted rates from the current facility and a comparison of the surface water balance for the existing and new facilities. The modelling indicated that (see Appendix F1 for detail):

- The water balance for the new cells is similar to that of the existing TSF Cell 4. Because of the higher solids content (thickening) of the future tailings, less free liquor would occur on the surface of the tailings, resulting in less seepage per unit area.
- Initially, the seepage rate from each cell would be around 4 m^3/ha/d. This would decrease over the first two years as the tailings consolidated and formed a layer with very low permeability. Steady state seepage from each cell during operations would be around 0.88 m^3/ha/d.

Table 12.2 Maximum predicted change in groundwater inflow and outflow across the Stuart Shelf

	Pre-mining (kL/d)	Post closure (kL/d)	Change (kL/d)
Inflow to the Stuart Shelf from the Arckaringa Basin	3,060	3,000	60[1]
Outflow from the northern boundary of the Stuart Shelf (adjacent GAB) due to evaporative loss	43	43	0
Outflow from the Stuart Shelf to the northern end of Lake Torrens due to evaporative loss	5,250	5,050	200[2]

[1] Predicted at 500 years post closure.
[2] Predicted at mine closure and 100 years post closure.

Table 12.3 Predicted rates of seepage from the TSF

Indicative time frame	Activity	Total seepage area (ha)	Seepage per hectare (m^3/ha/d)	Total seepage (ML/d)
Years 1–5	Commissioning and operation of cell 1	400	4.0	1.6
Years 5–10	Seepage rate increases as more cells are commissioned	1,200–3,200	1.9–3.2	3.6–7.8
	Maximum seepage rate reached as last cell is commissioned	3,600	2.3	8.2
Years 12–40	Seepage reaches operational steady state	3,600	0.88	3.2
Year 40 (closure)	TSF is decommissioned and capped Seepage begins to decrease as no more tailings are added to the facility	3,600	<0.88	<3.2
Post closure	Tailings drain down over time and eventually reach steady state	3,600	Trending to background	Trending to background

- Post closure, seepage from the TSF would be significantly reduced as the tailings pond was removed, the facility covered, and the tailings drained. In the long term, recharge rates would approach the natural regional rate that occurs due to rainfall infiltration.

Rock storage facility

Blasting would cause the porosity and permeability of the mine rock placed in the RSF to be greater than that of the natural undisturbed terrain. Because of this, the rainfall recharge across the RSF footprint would increase due to preferential flow paths in the rock. Seepage from the RSF would be expected to be around 1% of annual rainfall, or around 0.3 ML/d (<0.05 m^3/ha/d).

The proposed construction of the RSF would result in the surface of each bench being continually compacted by the earth moving equipment. This would help to minimise rainfall infiltration and promote surface water run-off, ponding and evaporation (see Chapter 5, Description of the Proposed Expansion, Figure 5.16).

Seepage quality

Materials such as mine rock and tailings have unique geochemical properties that affect their behaviour when they are exposed to the atmosphere and are subjected to weathering. As a result, these materials could release metals, acid, soluble salts or radioactive compounds to water that percolates through them. However, the characteristics of seepage that reaches the groundwater are not necessarily the same as that which leaves the base of the storage facility. The seepage travels through various sediments and rock layers, which may be acid neutralising, cause metals to precipitate as secondary minerals, or to sorb to reactive surfaces. These processes are referred to as natural attenuation. The geochemical properties of the soil and rock materials will determine how they react with the seepage, and ultimately the quality of flows entering the groundwater.

Geochemical investigations were undertaken for the materials to be placed in the TSF and the RSF. Details are presented in Appendix K4 and K5 and are summarised below.

Tailings storage facility

As the geochemical properties of the future tailings are not expected to differ significantly from those of the current tailings, geochemical processes within and beneath the proposed TSF are expected to be similar to those within and beneath the existing facility (as established through data from geological logs). As such, the geochemical observations for the existing TSF have been used to predict future conditions. Results of the geochemical assessment are summarised below and detailed in Appendix K4:

- Some secondary minerals may form within the tailings and may keep some of the acidity within the tailings. However, seepage from the base of the TSF would remain acidic and be characterised by elevated solute concentrations similar to that of the decant liquor.
- Results from geotechnical testing within the footprint of the proposed TSF indicate that layers of sands, clays and calcareous soils of varying thickness would underlie the proposed TSF. Geochemical testing indicated that of these, the calcareous clays would have the highest acid neutralising capacity (ANC) and would neutralise acidic seepage from the tailings most effectively.
- Geochemical testing showed that the Andamooka Limestone Formation is dolomitic in this location and has a high ANC. Within the unsaturated zone it may be possible that secondary minerals could form that may 'blind' the rock, making it unavailable for further reaction with the seepage fluid.
- The seepage beneath the TSF is being naturally 'treated' through neutralisation by the carbonate materials as well as sorption and precipitation of secondary minerals. This leads to improved water quality through natural attenuation of contaminants before they reach the groundwater system. Although most contaminants are removed by these processes, selenium and uranium (albeit much reduced from the concentrations in the tailings percolate) remain elevated above background levels. *In situ* reactions of the seepage with the carbonate minerals in the soils, clays and the Andamooka Limestone also lead to bicarbonate concentrations exceeding background levels.
- There is a possibility that the clays could become less permeable over time due to the accumulation of secondary minerals, decreasing the overall ability of the calcareous clays to neutralise the acidity immediately below the TSF. The reduced permeability could also lead to changes in flow path directions. However, changes to flow direction would bring the percolate into contact with 'fresh' clays and would promote further neutralisation.
- In the longer term, existing dissolution features in the Andamooka Limestone are likely to be locally enhanced by the neutralising reactions and may lead to marginal increases in horizontal and vertical permeability. Like the calcareous clays, these effects would expose fresh reaction surfaces within the limestone and neutralisation would continue.
- The water quality monitoring results for the existing groundwater mound have been used to infer the water quality of seepage reaching the groundwater beneath the existing TSF (see Table 12.4).

Rock storage facility

Geochemical test work was undertaken on various Olympic Dam rock types to characterise them into classes based on their potential for acid and/or metal generation. This was used in the design of the RSF, particularly the selective placement of different rock types within the facility (see Chapter 5, Description of the Proposed Expansion, Table 5.12). The description of mine rock types and volumes generated over time are shown in Table 12.5 and Figure 12.16.

Table 12.4 Inferred changes to water quality parameters in the seepage mound based on comparison of current groundwater monitoring results with background concentrations

Parameter	Background concentration (mg/L)	TSF mound concentration (mg/L)
pH (no units)	7.1	6.8
HCO_3	188	553
Total dissolved solids	22,000	27,950
Calcium	893	954
Chloride	11,202	12,155
Potassium	44	55
Magnesium	614	1,010
Sodium	5,790	7,660
Sulphate	3,575	5,100
Uranium	0.027	0.088
Silver	0.0008	0.0008
Aluminium	0.05	0.03
Arsenic	0.003	0.005
Boron	3.8	6.8
Barium	0.029	0.013
Cadmium	1	1
Cobalt	0.004	0.007
Chromium	0.003	0.003
Copper	0.019	0.034
Iron	0.43	0.19
Mercury	0.2	0.1
Manganese	0.74	0.52
Nickel	0.015	0.014
Lead	0.003	0.004
Selenium	0.01	0.05
Zinc	0.033	0.042

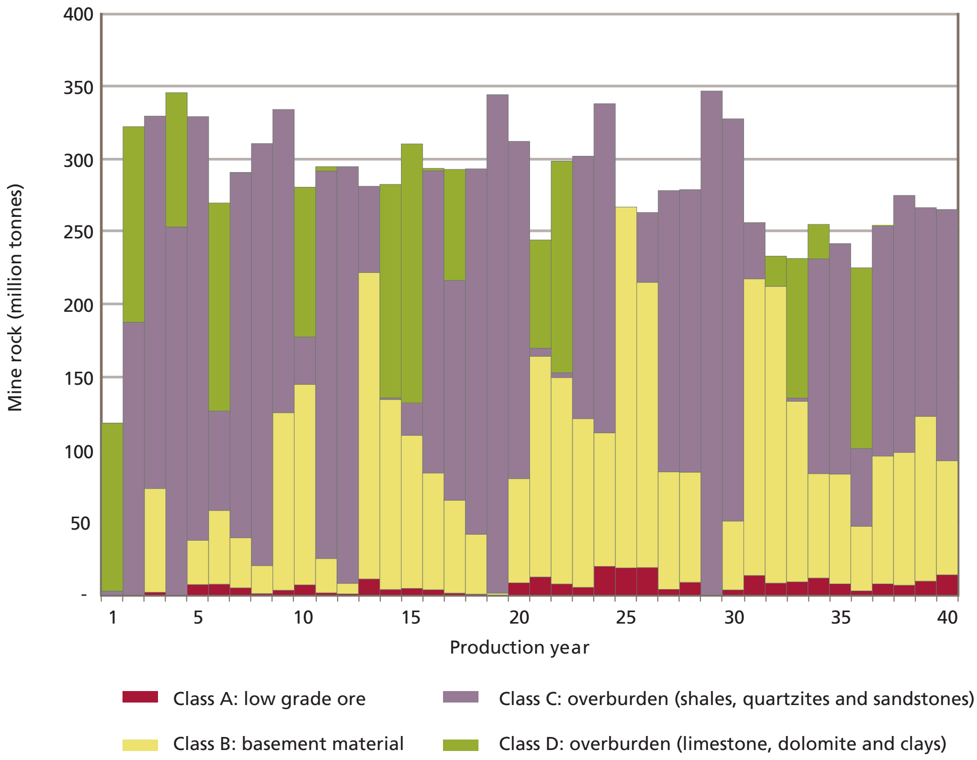
Table 12.5 Geochemical classifications of Olympic Dam mine rock types

Class	Geological unit	Geochemistry
A	Low-grade ore (ODBC)	Material with moderate metals mobilisation potential and negligible acid neutralising capacity
B	Basement (ODBC)	Material with low to moderate metals mobilisation potential and negligible acid neutralising capacity
C	Overburden (Tregolana Shale, Arcoona Quartzite Red, Arcoona Quartzite White, Arcoona Quartzite Transition, Corraberra Sandstone)	Material with low metals mobilisation potential
D	Overburden (Andamooka limestones, dolomite, calcareous clays)	Material for which the neutralising potential greatly exceeds metals mobilisation potential

Geochemical test work was undertaken to characterise potential seepage quality from the RSF (see Appendix K5 for further detail). The assessment of seepage quality considers the geochemical processes within the RSF and the interactions with the underlying soils.

Almost all of the overburden material was found to be non-reactive, net acid consuming and is considered to have a low potential for solute release. However, the basement rocks contain elevated concentrations of a range of metals which have the potential to be released into water that infiltrates the RSF.

Overall, the mine rock in the RSF would be net acid consuming; therefore seepage is expected to be neutral, not acidic. Zones of acidity could form, however, particularly when water infiltrating the RSF comes into contact with reactive rock (i.e. class A and B). To address this, mine rock would be placed selectively (i.e. in particular locations) within the RSF so that it was completely surrounded by overburden material. In addition, a layer of benign material would be placed at the base of the RSF, so that water coming into contact with reactive rock would have to travel through overburden material, which has a high acid neutralising capacity and an ability to attenuate the



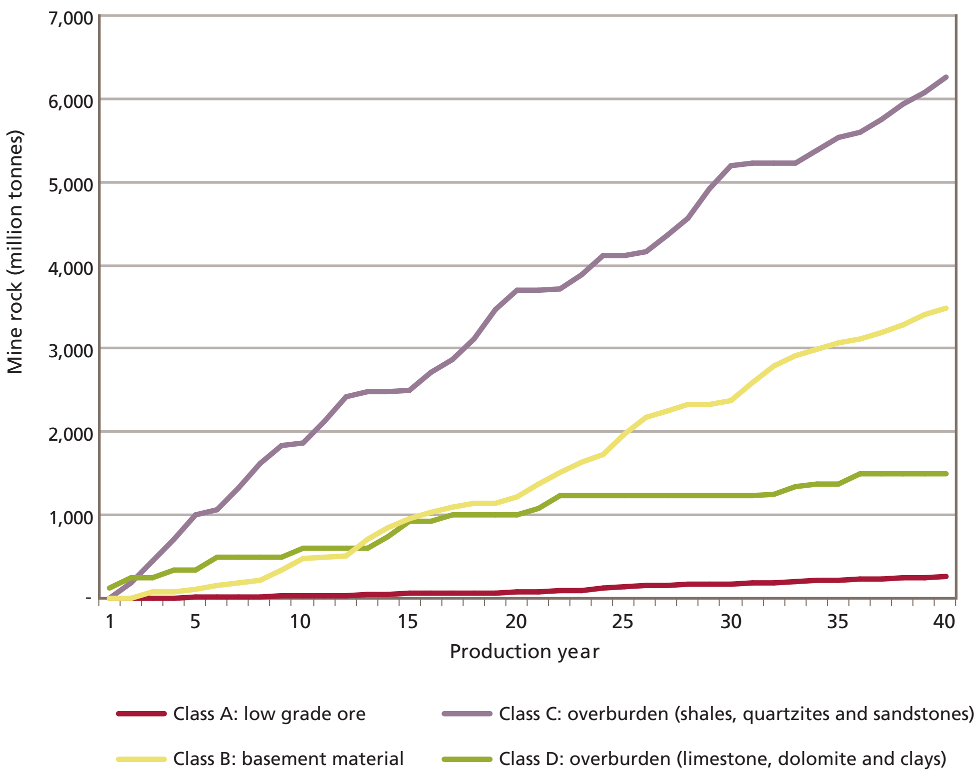


Figure 12.16 Mine rock extraction by type over time

dissolved metals naturally, before it leaves through the base of the facility. Therefore, interaction with the overburden materials would ensure that the percolate from the base would be neutral in pH and would cause the removal of dissolved metals before it exits the facility.

Sediments beneath the RSF are similar to those beneath the TSF. Similarly, the calcareous clays have a high capacity to attenuate metals that may remain in the seepage even after it has passed through the overburden materials. The rate of seepage from the RSF would be much less than that of the TSF, is likely to be non-acidic and is likely to have lower concentrations of metals. Consequently, the affects on groundwater would be considerably less than observed for the TSF.

Fate of contaminants

Particle tracking of solutes has been carried out as part of the numerical groundwater modelling to predict the movement of seepage from the TSF and the RSF when it reaches the groundwater. The model predicts that flows entering the Andamooka Limestone beneath the TSF or RSF would first mound and then move away laterally from these facilities.

Movement through the aquifer is likely to be very low due to the low hydraulic gradient and is expected to be much less than 1 m/y. By the end of mining, seepage would not be likely to have travelled more than 100 m from the TSF or the RSF.

The maximum distance that solutes could move away from the facilities would occur between 100 and 500 years post closure, before the effect of the drawdown from the open pit dominated and regional groundwater flowed towards the pit. Simulation of seepage movement in groundwater shows that, in the longer term, drawdown caused by the open pit would effectively capture contaminants that entered the groundwater system from the TSF and RSF.

Attenuation zone and water quality criteria

As discussed earlier, the groundwater beneath Olympic Dam is highly saline and has naturally high concentrations of metals, which make it unsuitable for domestic or stock use. The South Australian Environment Protection (Water Quality) Policy 2003, however, specifies that groundwater-affecting activities should not alter groundwater chemistry even when natural groundwater quality exceeds criteria prescribed by the policy. Furthermore, if changes to groundwater chemistry are likely, the person undertaking those activities is to either obtain an exemption from the obligation to comply with the water quality criteria (which also requires the establishment of an attenuation zone), or seek to have the water quality criteria amended to reflect the naturally occurring groundwater quality.

As seepage from the TSF and RSF would change the concentrations of most elements in the vicinity of these facilities, BHP Billiton proposes to either apply for an exemption or seek a variation to the groundwater quality criteria of the local groundwater system. BHP Billiton could readily comply with the requirements of the EPP under each scenario.

In particular, if an exemption were sought and BHP Billiton established an attenuation zone, it is anticipated that the boundary of the zone would coincide with the expanded SML boundary in most areas. The exception is the area immediately south and west of Arid Recovery, where there is less than a 1 km buffer between the TSF and the edge of the SML. If an attenuation zone extended further than this boundary it would not affect any third party users. Elevated concentrations of metals in groundwater would not adversely affect native flora and fauna because the groundwater would be well below the ground surface and well below the depths of tree roots (Jackson et al. 1999).

Summary of seepage to the groundwater

Table 12.6 presents a summary of factors that influence seepage from the TSF and RSF.

Based on current modelling, seepage from on-site facilities such as the TSF and RSF is not expected to pose an environmental risk. Nevertheless, BHP Billiton Group standards require that the designs of water containment and tailings storage facilities aim to minimise seepage. Control measures have been considered in the design of the TSF. The RSF would be operated and closed to minimise infiltration of rainwater into zones containing potentially reactive material, minimising seepage from these areas.

The existing groundwater monitoring program would be extended to monitor effects on groundwater quality from seepage and would be compared against predicted solute movement. The data would be assessed regularly and incorporated into the BHP Billiton Environmental Management Program (EM Program). If rates of seepage transport away from the TSF or RSF were higher than predicted, risks would be reviewed and remedial actions would be investigated.

The current licence to operate at Olympic Dam requires groundwater levels to not rise above 80 m AHD (approximately 20 m below ground level). Modelling predicts that the maximum height of the mound would be around 65 m AHD (35 m below ground level) and would therefore comply with current requirements. The current program of harvesting and recycling of water from the mound beneath the TSF would continue and would further limit the height of the mound.

The residual impact from seepage to the groundwater is categorised as moderate as it represents a long-term impact to a common (local) receiver. However, if the application for an attenuation zone is approved, or if the groundwater quality criteria are amended, the residual impact from seepage to groundwater would be categorised as low as concentrations would be within legislated compliance limits (see Chapter 1, Introduction, Section 1.6.2, for details of management categories).

Table 12.6 Factors that influence seepage from the TSF and RSF

	TSF	RSF
Facility design	Central rock lined decant pond and liquor recycling would significantly reduce the amount of free water available to infiltrate into the tailings	Classification of mine rock based on potential reactivity would facilitate appropriate placement of potentially reactive rock within the facility
Amount and characteristics of facility inputs, including the influence of rainfall and evaporation	Thickening the tailings to around 52–55% solids would reduce free water and subsequently reduce infiltration and seepage	Appropriate placement of mine rock would minimise exposure to weathering and reduce leaching of metals and acidity
Quantity of seepage from the base of the facility	Expected to be higher in the first two years following cell commissioning, after which tailings would consolidate and form a low permeability base Post closure, TSF would be covered, infiltration would decrease and the TSF would gradually drain, reaching steady-state, low-flow conditions	Seepage from the base is expected to be around 1% of rainfall (5–10 times greater than the natural recharge rate) due to preferential flow paths
Geochemical processes in soil and groundwater beneath the facility	Calcareous clays and Andamooka Limestone beneath the TSF have been demonstrated to, and are expected to continue to, attenuate most metals Groundwater chemistry under the existing TSF is stable and is characterised by a slight local increase in uranium and salinity	Calcareous clays and Andamooka Limestone beneath the RSF are expected to attenuate most metals
Transport of seepage water within groundwater	Seepage movement would be very low A groundwater mound would form beneath the TSF and would influence groundwater levels for up to 6 km Groundwater modelling shows that solute transport would be constrained to within a few hundred metres of the TSF All seepage would be captured by drawdown from the open pit	The expectation is that no groundwater mound would form beneath the RSF due to the very low infiltration rates and the unsaturated extent of the Andamooka Limestone Groundwater modelling demonstrates that seepage would travel no more than a few hundred metres from the RSF and would ultimately be captured by drawdown from the open pit
Receptors	Nearest sensitive receptor (pastoral well) is around 55 km up hydraulic gradient and would not be adversely affected by either the groundwater mound or seepage from the TSF	Nearest sensitive receptor is Lake Torrens, around 40 km east of the RSF, and would not be adversely affected by seepage from the RSF

Other potential contaminant sources

During construction, operation and maintenance of other proposed expansion infrastructure, other potential contaminant sources could be:

- the expansion of the metallurgical plant
- worksite compounds used as a base for vehicles and other equipment
- fuel stores, including tank farms and mobile tankers
- hazardous goods compounds, including chemicals and explosives
- machinery and equipment workshops (e.g. for the manufacture and maintenance of machinery).

The chemical and hazardous goods storages and fuel storage would be bunded in accordance with the South Australian EPA requirements of bund sizes and volumes to be 120% of the net capacity of the largest tank and 133% for flammable material, resulting in a low potential for groundwater contamination. Workshops and vehicle compounds would be equipped with hydrocarbon and chemical interception facilities to minimise the discharge to groundwater of hazardous materials including hydrocarbons. In addition, construction works would comply with environmental management specifications designed to address contamination risks associated with the activities (see Chapter 24, Environmental Management Framework). For further detail about the storage of potentially hazardous or contaminating sources see Chapter 5, Description of the Proposed Expansion, Section 5.5.5 and Chapter 22, Hazard and Risk, Section 22.6.8.

12.6.3 THIRD-PARTY GROUNDWATER USERS

Stuart Shelf

There are four pastoralist stockwater supply wells located in, or close to, the predicted zone of drawdown from the open pit (see Figures 12.14 and 12.15). These wells are located on pastoral leases held by BHP Billiton.

The closest third-party supply wells are located more than 15 km outside the 1 m drawdown contour predicted by the model (see Figure 12.14). Any change to the water levels in third-party wells, should it occur, would be in the range of centimetres rather than metres. This is considered insignificant in terms of the total water column usually intersected by pastoral wells (5–10 m; see Appendix K2 for detail). It is therefore concluded that groundwater drawdown would not have an adverse impact on the pumping capacities of these stockwater wells and there would be no residual impact.

The groundwater levels in wells in the Olympic Dam region would be monitored throughout the operation phase. Information would be incorporated into the groundwater model to confirm its accuracy and the model would be refined if required. If monitoring showed that drawdown was affecting current third-party users, alternative water supply options would be investigated. These may include relocating or deepening existing groundwater wells, or providing an alternative water supply. Options would be considered in consultation with the third-party user.

Infrastructure corridors

In addition to near-mine water supplies, it would be necessary to develop groundwater supplies along the infrastructure corridors to provide the volumes of water required during construction. Although the exact location of groundwater supply wells is not known, it is anticipated that supply centres would be 10–20 km apart along the linear infrastructure corridors.

The residual impact of construction water supply wellfields on third-party water users is categorised as low as it would be short-term and would be managed by targeting deeper saline aquifers, and ensuring wells are located to minimise potential interference between those used for construction and those for pastoral uses.

12.6.4 GROUNDWATER-DEPENDENT ECOSYSTEMS

The closest known obligate groundwater-dependent ecosystem is the Yarra Wurta spring group located at the northern end of Lake Torrens, around 45 km from Olympic Dam (see Figures 12.14 and 12.15).

Although there is some evidence that groundwater feeding the Yarra Wurta springs may originate from the Adelaide Geosyncline rocks east of Lake Torrens rather than from the aquifers of the Stuart Shelf, this is not definite (see Appendix K1). It is possible that groundwater from the Andamooka Limestone aquifer may also contribute to spring flows.

For the purpose of the groundwater model, and to be conservative, it was assumed that Yarra Wurta springs depend entirely on groundwater flow from the Stuart Shelf. Modelling predicts that the post closure 1 m drawdown contour is more than 15 km from the springs. Any drawdown at Yarra Wurta is likely to take more than 100 years to develop and be in the order of centimetres rather than metres. Ongoing monitoring of groundwater levels and spring flow at Yarra Wurta springs would occur and would be used to validate and update the groundwater model as required.

Although it is unlikely that the ecological values of Yarra Wurta would be negatively affected, surveys were undertaken as part of the Draft EIS to determine their ecological significance (see Chapter 15, Terrestrial Ecology).

12.7 FINDINGS AND CONCLUSIONS

Groundwater drawdown

Drawdown of up to 10 m below pre-mining levels is expected in the Andamooka Limestone beneath the SML. The zone of influence in this upper aquifer is expected to extend up to 5 km north of the SML and up to 20 km to the south-west.

Groundwater drawdown in the lower Tent Hill aquifer would be driven at first by the satellite water supply wellfields and would be gradually overridden by the effects of groundwater flow to the open pit. The final zone of influence (500 years post closure) is expected to be around 20 km north and up to 45 km south of Olympic Dam. Regional groundwater drawdown would not affect flora and fauna, however, as it represents a long-term impact to a common receiver, the residual impact is categorised as moderate.

The effects of changes in groundwater levels are most prominent south of Olympic Dam because groundwater flowing from the Arckaringa Basin (across the northern part of the Stuart Shelf) acts as a buffer between Olympic Dam and groundwater systems to the north. Groundwater drawdown, due to the open pit and saline water supply, would not affect the northern boundary of Stuart Shelf and there would be no impact on the artesian aquifers of the GAB and the corresponding springs.

Three BHP Billiton-owned groundwater wells occur within the predicted zone of groundwater drawdown. No third-party groundwater wells occur within this zone; the nearest is around 55 km from the mine site. No residual impact to third-party groundwater users is expected.

Water supply development

Saline water for dust suppression and other low-quality uses would be sourced from a primary saline wellfield (Motherwell) in the Andamooka Limestone around 30 km north of Olympic Dam, and from various satellite wellfields within and close to the SML. Water recovered from depressurisation activities would also be recycled and reused. Total groundwater extraction would be around 12 ML/d from the Tent Hill aquifer and around 28 ML/d from the Andamooka Limestone aquifer. Groundwater drawdown is initially driven from the dewatering and satellite wellfields during the construction phase but is gradually overridden by the effects of groundwater flow to the open pit.

Temporary water supply wells may be required about every 10–20 km along the linear infrastructure corridors, but these would only be required for a short term and would be located so that they have minimal impact on third-party users. Consequently, the residual impact is categorised as low.

No groundwater would be extracted from the GAB outside of approval from the South Australian Government, resulting in no residual impact.

Seepage and water quality

Seepage from the TSF during the first 10 years of the expanded operation at Olympic Dam would range up to a maximum of 8.2 ML/d. This would then decrease to an operational steady state of around 3.2 ML/d. Post closure, seepage would decrease to very low levels after the facility drains down. The time to steady state conditions would be accelerated by the installation of a cap over the tailings to reduce rainfall infiltration.

The RSF would be a source of enhanced local rainfall recharge due to infiltration of water into the facility and movement through preferential flow paths. Seepage from the RSF would be expected to be around 1% of the rainfall recharge (5–10 times greater than natural recharge), or around 0.3 ML/d.

A groundwater mound to around 35 m below the surface would form beneath the tailings and would affect water levels for up to 6 km. Due to the very low permeability of the Andamooka Limestone, however, lateral movement of potential contaminants would be constrained to within a few hundred metres of the TSF. No groundwater mound is expected to form beneath the RSF.

The potential for acid generation from the RSF is low. The neutralising base layer of the RSF and the naturally occurring calcareous clays and Andamooka Limestone beneath the TSF and RSF are expected to attenuate most metals.

Eventually, the open pit would act as a regional groundwater sink, capturing all seepage from the TSF and RSF. The residual impact on the groundwater is considered moderate as it represents a long-term impact to a common receiver.