OLYMPIC DAM EXPANSION

DRAFT ENVIRONMENTAL IMPACT STATEMENT 2009

APPENDIX K
GROUNDWATER AND GEOCHEMISTRY

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APPENDIX K

GROUNDWATER AND GEOCHEMISTRY

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APPENDIX K1

Baseline hydrogeological assessment

OLYMPIC DAM Expansion Project

BASELINE HYDROGEOLOGICAL ASSESSMENT

FINAL

Prepared for

ARUP/HLA
(OLYMPIC DAM EIS Project)

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1 INTRODUCTION

BHP Billiton Olympic Dam Corporation P/L (BHP Billiton) owns and operates the Olympic Dam (OD) CU-Au-U mine, which is located in South Australia's Far North (Figure 1-1). In 2004 BHP Billiton commenced detailed studies to assess the potential for expanding the existing OD mining operation from about 10 Mt/yr to more than 70 Mt/yr ore processing. There are two aspects to the OD Expansion (ODX) plans (see):

(i) Mining related infrastructure located in the vicinity of the Special Mining Lease (SML) - including development of an open pit, construction of rock storage facilities (RSF) expansion of existing tailings storage facilities (TSF), and groundwater supply wellfields; and

(ii) Infrastructure corridors , including
– road, rail, power alignments and port facilities between Port Augusta-Port Bonython and OD; and
– gas pipeline linking the Cooper Basin gas fields with OD.

Arup-HLA, on behalf of the ODX Environmental Impact Statement (EIS) Project Team, and BHP Billiton have engaged Sinclair Knight Merz Pty Limited (SKM), formerly Resource & Environmental Management Pty Ltd, to undertake a comprehensive review of baseline hydrogeological conditions in the vicinity of the proposed ODX and associated infrastructure corridors. It is intended that the findings will support the Environmental Impact Statement process. The report collates data available at project initiation (in early 2005) and the results of additional investigations carried out to address gaps in the initial dataset. It forms the scientific basis for the development of computer models that can simulate the long-term impacts of mining activities on groundwater conditions and allow assessment of how future groundwater conditions might impact upon other users of the resource (e.g. the environment and pastoral industries).

Until planning commenced for the proposed mine expansion there was limited information available to characterise regional groundwater conditions and dynamics. Apart from detailed groundwater and environmental studies associated with mine water supply development from Great Artesian Basin (GAB) aquifers, more than 100 km to the north of OD, there had been limited investigations of the groundwater systems of the Stuart Shelf geological province, within which OD occurs, leading up to the preparation of this report. Some South Australian Government publications have provided broad details of the geological (but not hydrogeological) setting of OD and the Infrastructure Corridors, and groundwater investigations (including monitoring) undertaken by BHP Billiton since mining operations commenced in the late 1980s have focused on the immediate mine area. The most comprehensive studies that assess the hydrogeology of the Stuart Shelf prior to 2004 include Golder (1995 and 1998) and Kellet et al. (1999). A desk-top study completed in 2005 (REM-Golder, 2005) collated the information available at that time.

Since mid-2006, however, BHP Billiton has undertaken a number of investigations associated with assessing mine pit-groundwater interactions (WMC, 2007; REM 2007a), saline water supply development (REM, 2007b, 2007c, 2008a, 2008b) and regional groundwater conditions (levels and quality) (REM, 2007c, 2007d). These studies have greatly contributed to the understanding of Stuart Shelf groundwater processes.

The Study Area covered by the Hydrogeological Baseline Assessment (this report) is focussed on the Stuart Shelf groundwater flow system (GFS), the regional system in which OD is located. In order to address potential impacts on identified groundwater receptors, including ones located outside the Sturt Shelf GFS, the Study Area reaches beyond the Stuart Shelf to bounding regional groundwater systems. As shown in Figure 1-2, the Study Area extends to the eastern side of Lake Torrens (east of OD), Lake Eyre to the north, the Arckaringa Basin to the northwest (where the Prominent Hill Cu-AU Mine is under development), the Stuart Highway to the southwest and Woomera in the south.

The Study Area also encompasses the two infrastructure corridors: (i) the northern gas pipeline corridor between OD and Moomba, which traverses part of the GAB GFS; and (ii) the southern infrastructure corridor between OD and Whyalla, which includes areas of the Stuart Shelf and Gawler Craton where groundwater drains into the Spencer Gulf.

The following presents details of the structure of this groundwater baseline groundwater report:

Section 1 *Introduction*
Introductory information for the report.

Section 2 *Regional geological and hydrological setting*
A description of the geological and hydrological setting of the Study Area and Infrastructure Corridors.

Section 3 *Baseline hydrogeology*
A description of the hydrogeological setting of the Study Area including the Special Mine Lease (SML) and Infrastructure Corridors. Includes a summation of baseline groundwater quality and level data.

Section 4 *Conceptual hydrogeological model of the Stuart Shelf region*
A summary of the interactions between the Stuart Shelf GFS and bounding systems, and recharge-discharge mechanisms.

Section 5 *Groundwater users*
A description of third party and environmental groundwater users in the Study Area and along the Infrastructure Corridors.

Section 6 *Assessment of groundwater system response to existing mining operations*
An assessment of the influence existing mining operations have had on Study Area groundwater resources, based on monitoring data collected by BHP Billiton in compliance with regulatory approvals.

Section 7 *References*
A listing of reports, publications and mapping products referenced for the report.

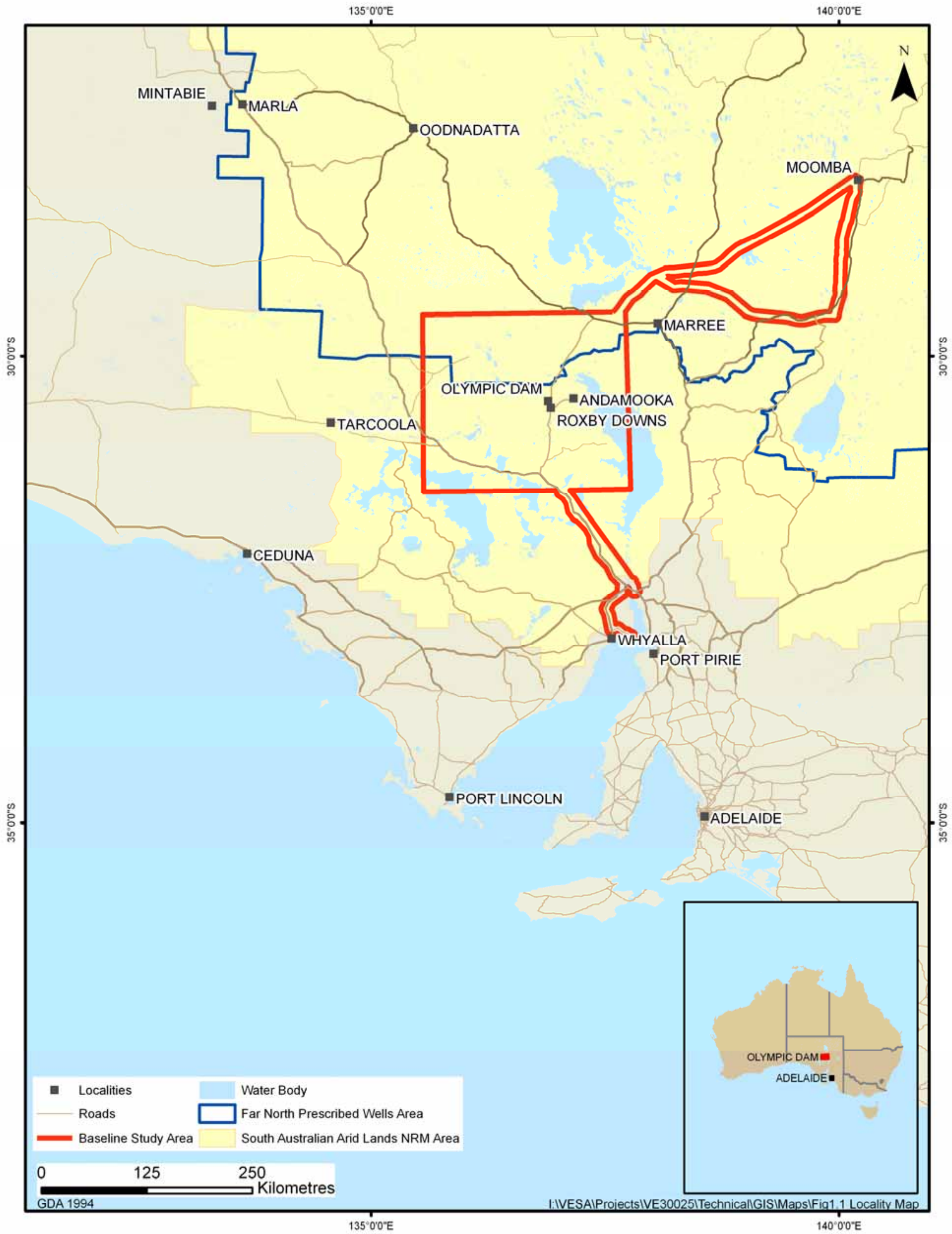


Figure 1-1 Locality plan for the OD mine site and infrastructure corridors

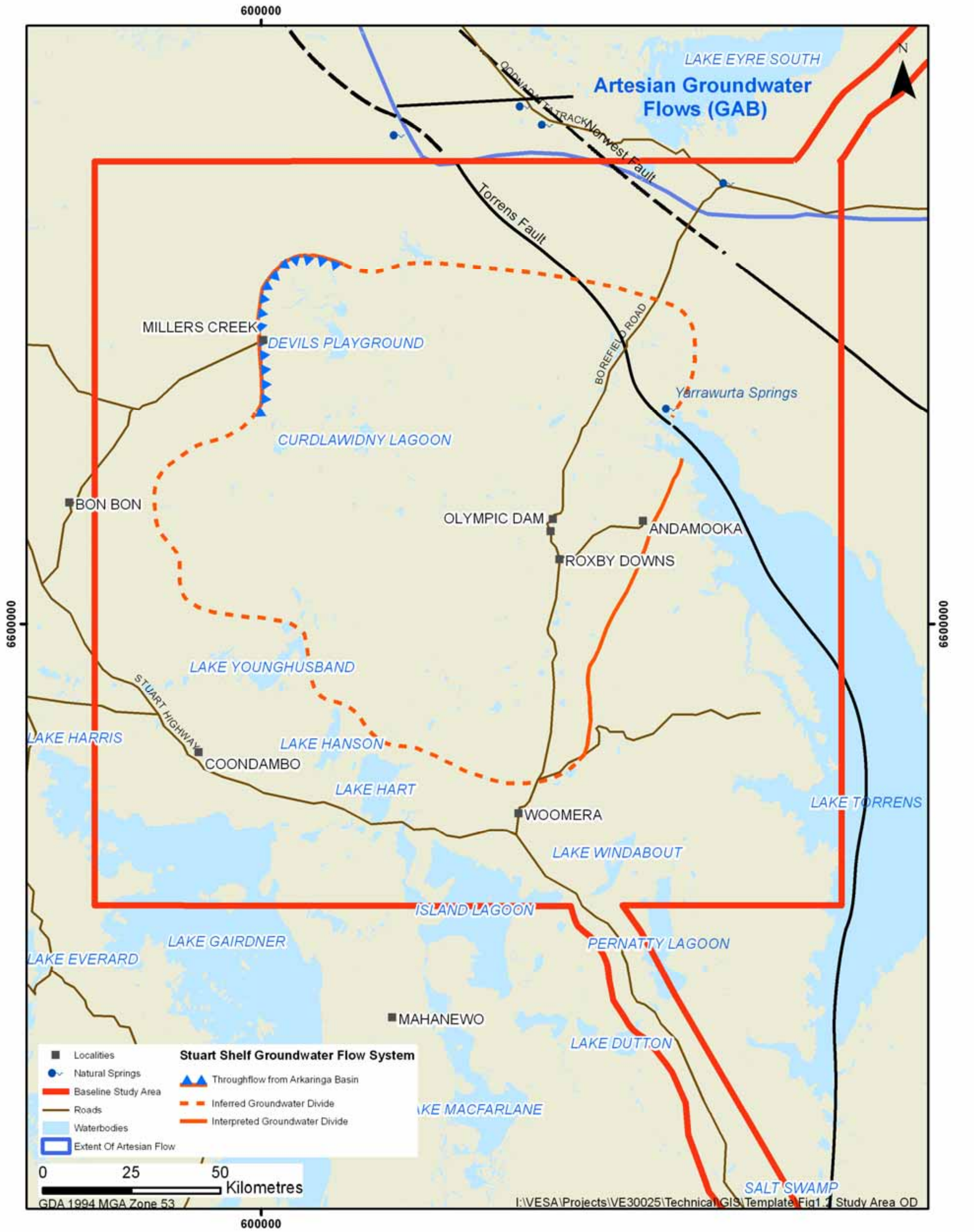


Figure 1-2 Study Area in the vicinity of OD

2 REGIONAL GEOLOGICAL AND HYDROLOGICAL SETTING

2.1 Overview

The main geological provinces in the Study Area and superficial geology are shown in Figure 2-1.

The Neoproterozoic sedimentary rock sequence of the Stuart Shelf and Adelaide Geosyncline geological provinces are separated by the Torrens Fault and the Torrens Hinge Zone (a zone of approximately parallel synclinal and anticlinal structures). These regional structures are aligned along the north–south axis of Lake Torrens and strike to the northwest, running between OD and Lake Eyre through to and beyond the Peake-Denison Inliers (Figure 2-2).

Stuart Shelf rock formations, comprising the Tent Hill Formation (a sequence of shales, sandstones and quartzites) and the Andamooka Limestone (dolomitic limestones), are much thinner and less deformed than their Adelaide Geosyncline equivalents. The Stuart Shelf rock sequence is underlain by Proterozoic crystalline and sedimentary basement rocks of the Gawler Craton, such as the Pandurra Formation and the OD Breccia Complex.

Three important sedimentary basins occur adjacent to and, in some cases, overlie Stuart Shelf and Adelaide Geosyncline rocks. These basins are also shown in Figure 2-2 and include the:

- Permian Arckaringa Basin, located to the northwest of OD, which is a suite of sandstones, siltstones, diamictite and, north of the Boorthanna Fault, carbonaceous formations.
- Mesozoic Eromanga Basin, which is the largest of three sedimentary basins that comprise the GAB. It is comprised of the Algebuckina Formation, Cadna-owie Formation and Bulldog Shale. In the immediate vicinity of OD only the Bulldog Shale occurs as remnants.
- Tertiary Torrens Basin, which lies predominantly to the east of the Torrens Fault and is a large synclinal structure of folded Adelaide Geosyncline rocks infilled with Tertiary sediments to depths of about 300 m.

Figure 2-3 presents block diagrams showing the stratigraphic relationship between the various geological units described above and presented in Figure 2-2, as well as important geological structures. Figure 2-4 also shows the geological structures around OD in more detail.

The most significant structural features of the broader Study Area are the: (i) Torrens and Norwest Faults, which bound the Adelaide Geosyncline; (ii) the Boorthanna Fault, which marks the northern limit of relatively shallow occurrences of the Boorthanna Formation (a sandstone and diamictite sequence of the Arckaringa Basin); and (iii) the Billa Kalina Fault, which is the bounding fault system to the eastern part of the Arckaringa Basin. The ecologically important Yarra Wurta Spring Complex (Yarra Wurta Springs; provides a refuge for the Lake Eyre Hardyhead fish species) is located on the eastern side of the Torrens Fault and is underlain by Adelaide Geosyncline rocks (REM 2007d).

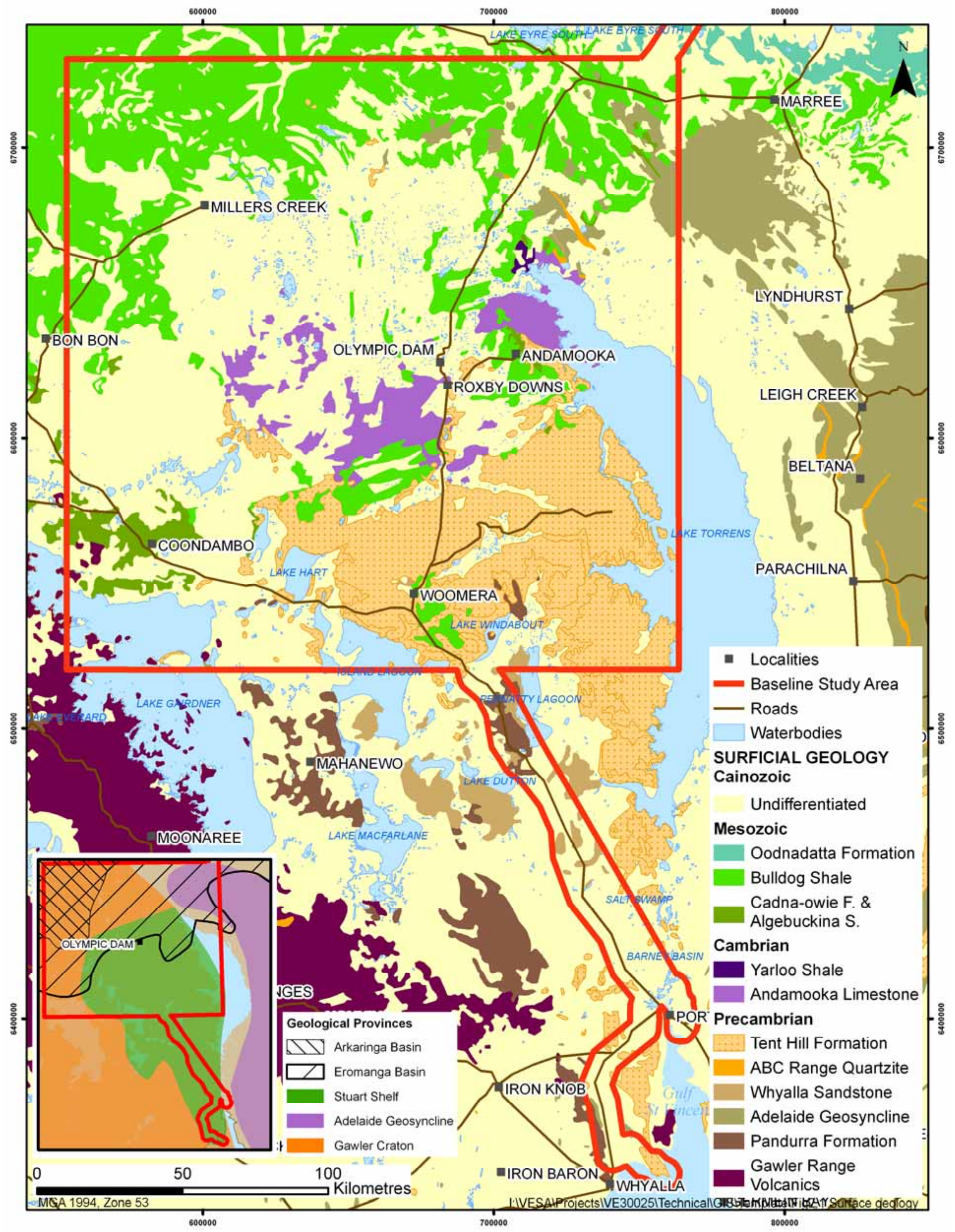


Figure 2-1 Geological provinces and surficial geology of the Study Area

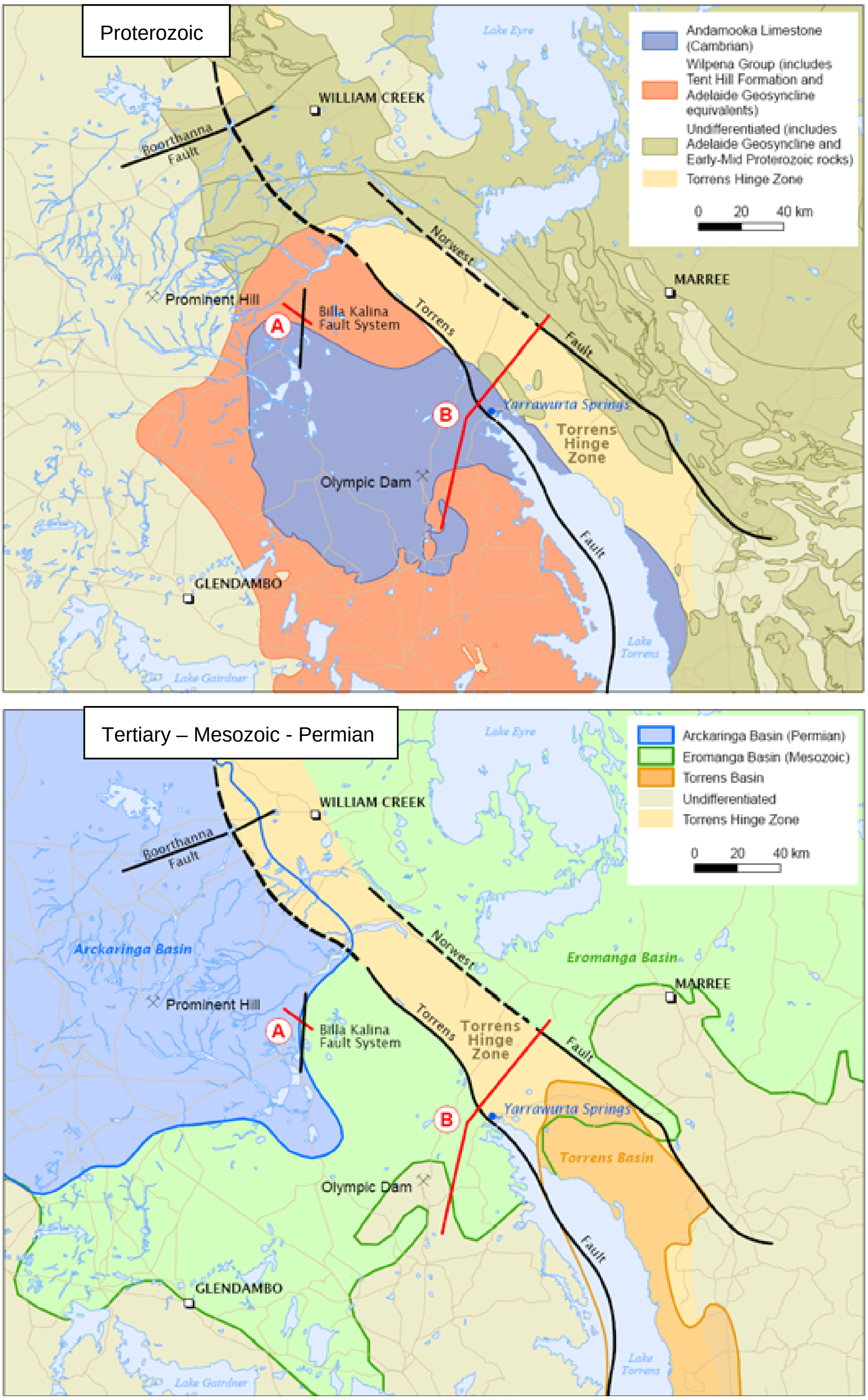


Figure 2-2 Key geological formations in the central Study Area (Sturt Shelf)

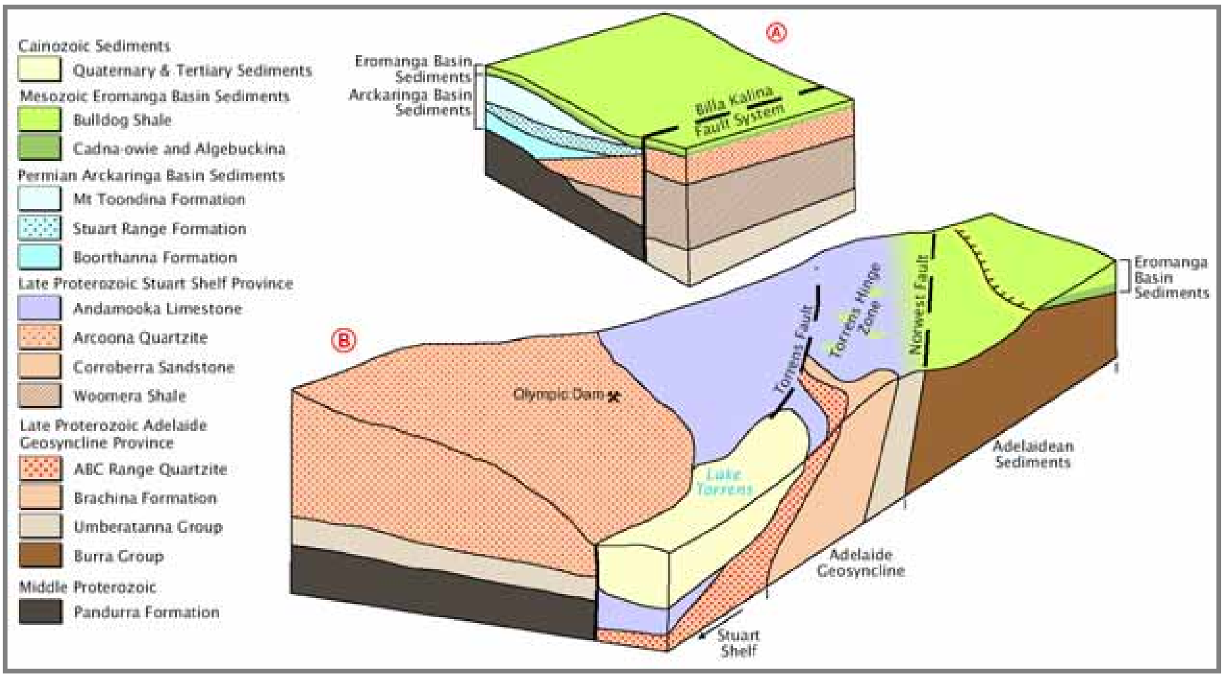


Figure 2-3 Major structural features and geology of the Stuart Shelf and environs

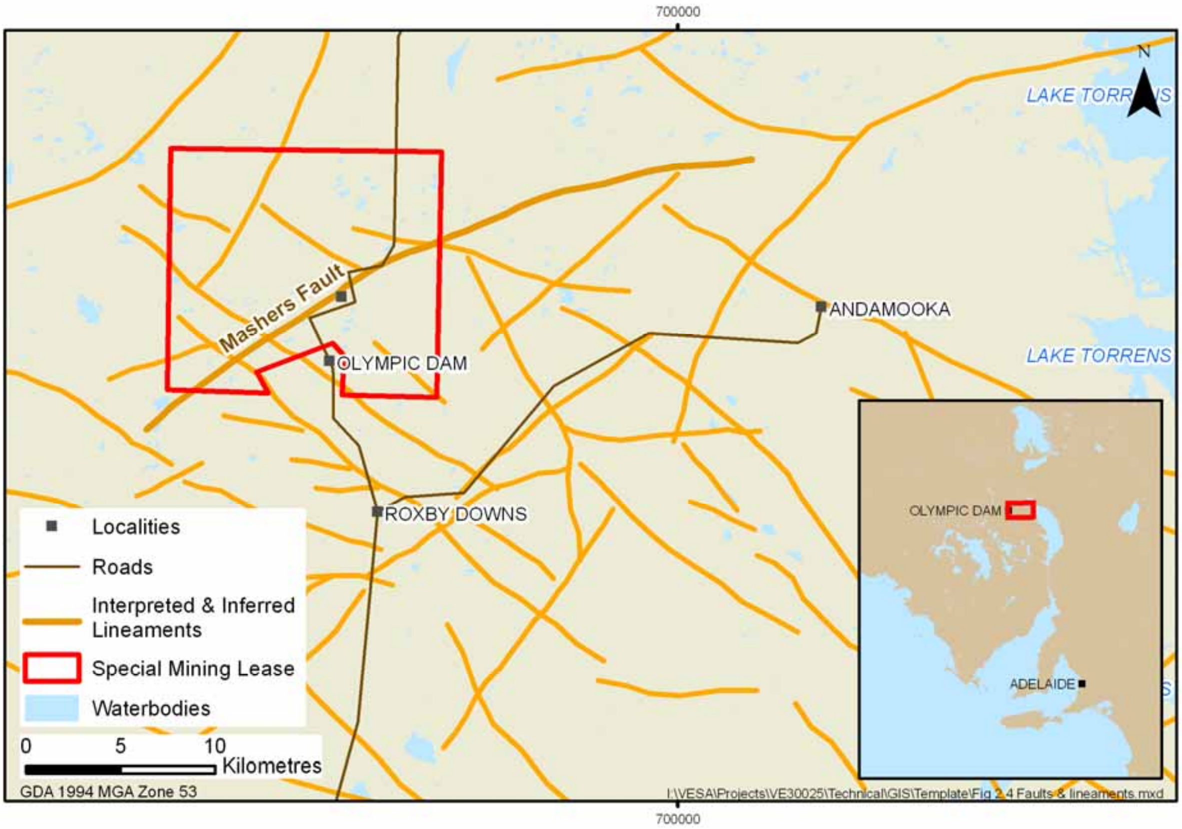


Figure 2-4 Geological lineaments in the vicinity of OD

2.2 Stuart Shelf

2.2.1 Geology

Table 2.1 presents a summary of important Stuart Shelf stratigraphy and lithology.

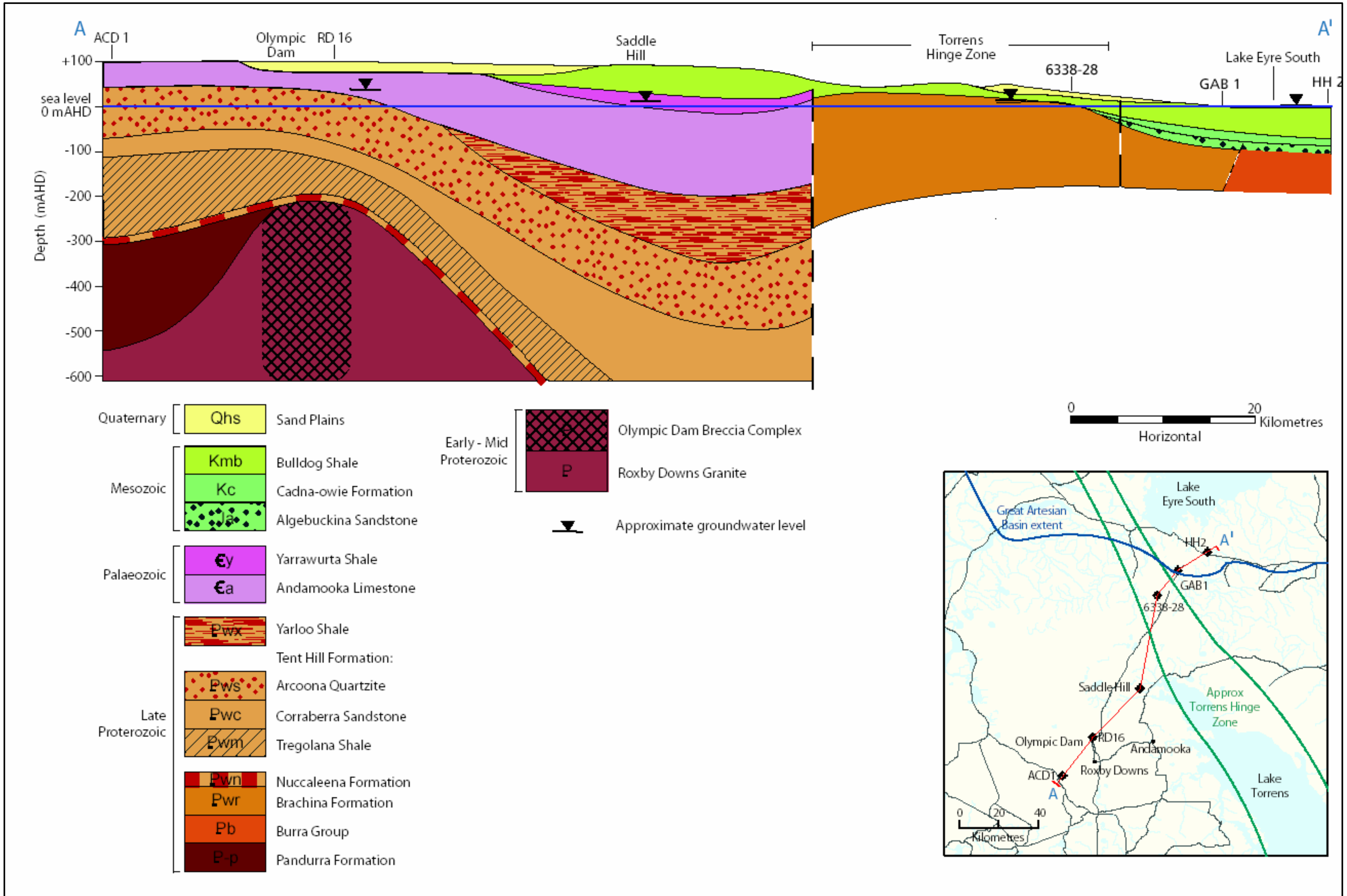
The OD mine is located within the Stuart Shelf geological province, which comprises of thin platform sediments of Neoproterozoic and Palaeozoic age mantling the crystalline Archaean-Mesoproterozoic rocks of the Gawler Craton (Parker, 1993). The Gawler Craton is geologically stable, having not been substantially deformed or remobilised since Proterozoic times (Parker, 1993). The Gawler Range Volcanics geological province is of Meso-Proterozoic age and extends across the Central Gawler Craton (Flint, 1993). Stuart Shelf sedimentary rocks mantle the northern part of this province.

The OD ore body is formed within the OD Breccia Complex, which is hosted by the Roxby Downs Granite (Flint, 1993). The Roxby Downs Granite forms the basement of the immediate area of OD, whilst further afield basement rocks comprise of metasediments, metavolcanics and plutonic complexes (Preiss, 1987). These basement rocks are unconformably overlain by sedimentary sequences deposited in the Adelaide Geosyncline and on the Stuart Shelf.

The Torrens Hinge Zone forms the eastern boundary of the Gawler Craton, and is marked by the Torrens Fault along its western margin (Figure 2-2). The Torrens Hinge Zone represents an extensive zone of faulting and deformation that separates undeformed sedimentary rocks of the Stuart Shelf and the folded sedimentary rocks of the Adelaide Geosyncline (Preiss 1987). Figure 2-5 and Figure 2-6 present simplified stratigraphic cross-sections of the Stuart Shelf, the south-westerly extent of the GAB and the westerly extent of the Adelaide Geosyncline for reference. The mostly undeformed sedimentary sequences of the Stuart Shelf are counterparts of the units within the Adelaide Geosyncline.

The shallowest sedimentary rocks of most significance on the Stuart Shelf belong to the Marinoan unit (including the Tent Hill Formation, which includes both the Corraberra Sandstone and Arcoona Quartzite members) of the Adelaidean Period, and Palaeozoic platform carbonates of the Arrowie Basin (the Andamooka Limestone) that lap onto the Stuart Shelf from across the Torrens Hinge Zone.

The dome structure of the basement rocks beneath the SML, along with steeply plunging surfaces to the west, north and south, is shown in Figure 2-7. Figure 2-8 through Figure 2-9 present a regional view of structural contours for the other important geological units on the Sturt Shelf, showing the base of the Corraberra Sandstone, and the base and thickness of the Andamooka Limestone, respectively.



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

Figure 2-5 Schematic cross-section of northern Stuart Shelf and southern GAB

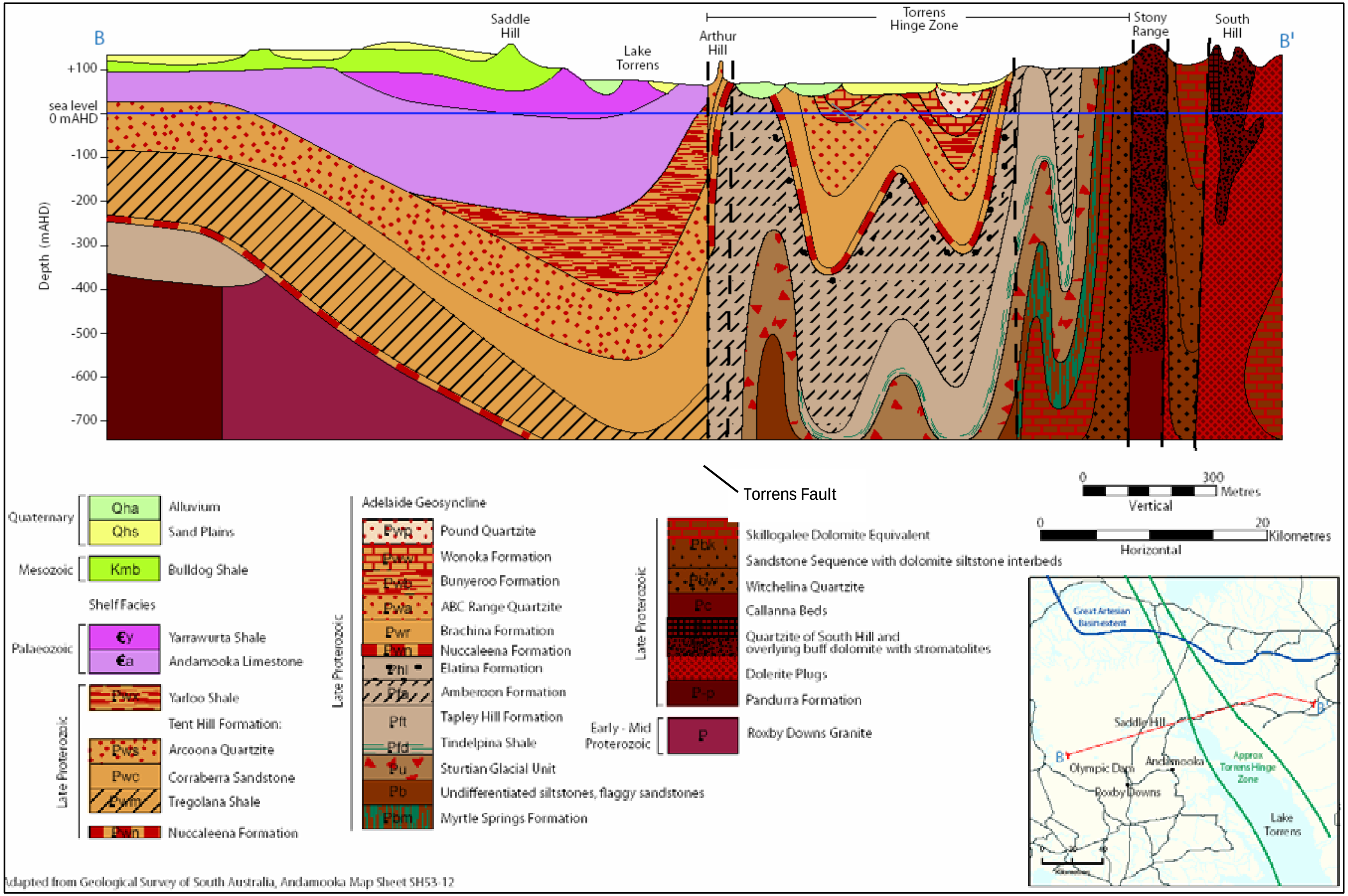


Figure 2-6 Schematic cross-section of northern Stuart Shelf and westerly extent of Adelaide Geosyncline

Table 2-1 Summary of Important Stuart Shelf Stratigraphy and Lithology [1]

Age	Unit	Description	Approximate Thickness (m)	Notes
Quaternary	Undifferentiated	Clayey sands, sand plains and dunefields, playa and drainage lakes	0-10	Extensive occurrence, but variable
Cretaceous & Jurassic	Bulldog Shale	Siltstones, conglomerates, shales and carbonaceous clays	0-50	Remnants scattered across Study Area, part of Eromanga Basin
Cambrian	Andamooka Limestone [2]	Indurated limestones (various facies), variably dolomitic and shaley	Up to 200	Variable sedimentary sequence, dips and becomes thicker to the northeast
Neoproterozoic	Yarloo Shale	Laminated shale, discontinuous, absent beneath and south of OD	0-50	Separates the Andamooka Limestone and Arcoona Quartzite northeast of OD, thickest near Hinge Zone, possible remnants in area of OD
	Tent Hill Formation [3]			Upper section interbedded with shales and lower section more massive, dips to the northeast
	Arcoona Quartzite	Quartzite with shale interbeds in its upper part	150-200	Indurated (where observed in OD decline) dips and becomes thicker to the northeast
	Corraberra Sandstone	Silty sandstone and micaceous siltstone, with shaley interbeds	30	Dark strong rock (where observed in OD decline), thins over the basement high interpreted in the area of OD
	Tregolana Shale	Laminated shale; partly micaceous	150-300	
	Whyalla Sandstone / Elatina Formation (Willochra Sub-group)	Cross-bedded sandstone, with coarse granule lenses and pebbles / fine and gritty sandstones and siltstones	20 [4] 120-200 [5]	Underlies southern portion of Study Area, but extent expected to be limited to around Woomera and Lake Torrens.
Neo-Mesoproterozoic	Pandurra Formation	Medium to coarse grained sandstones	300^+	Underlies southern portion of Study Area, shallows in the very southeast corner, part of the Cariewerloo Basin. The (upper) Member 4 can range from 0 to more than 200 m in thickness [2].
Mesoproterozoic	Basement	Diverse igneous and metamorphic rocks	-	

Notes:
1. Adapted from Golder (1995), and Dalgarno (1982)
2. REM (2007b, 2007d, 2008b)
3. REM (2007b)
4. Preiss (1993)
5. Source: SA Geodata base

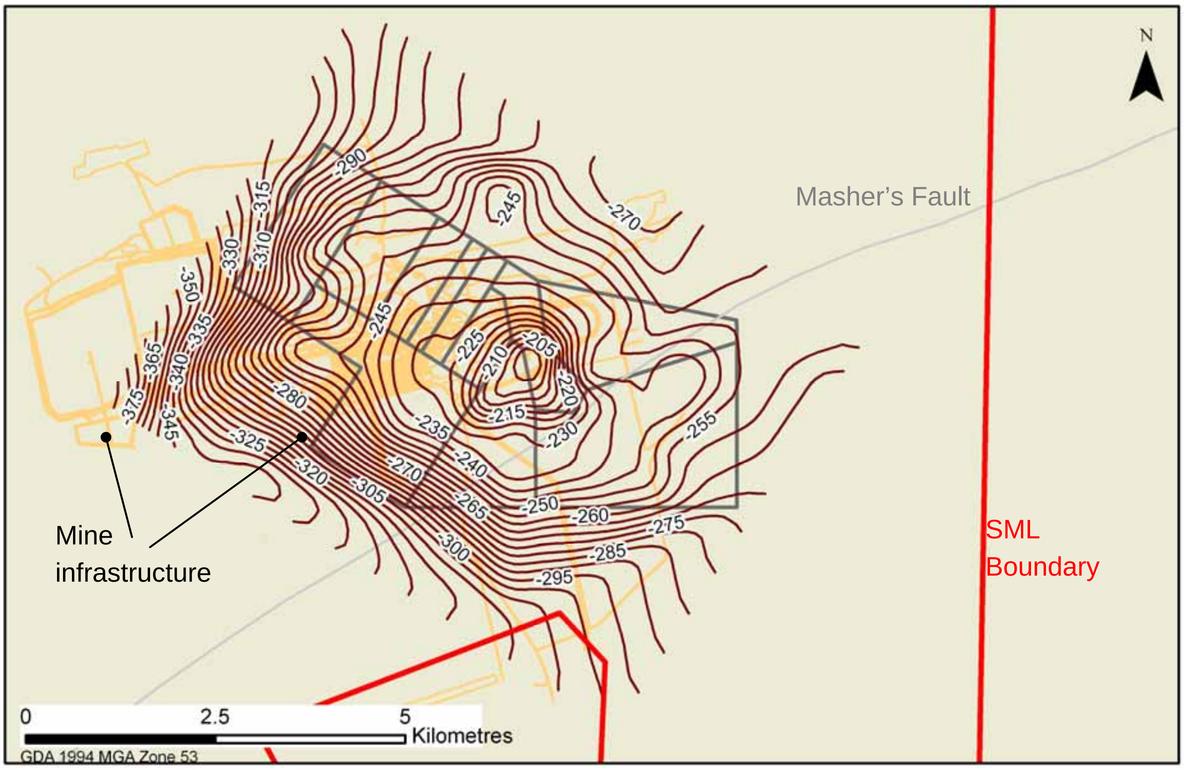


Figure 2-7 Structure contours – top of basement beneath SML

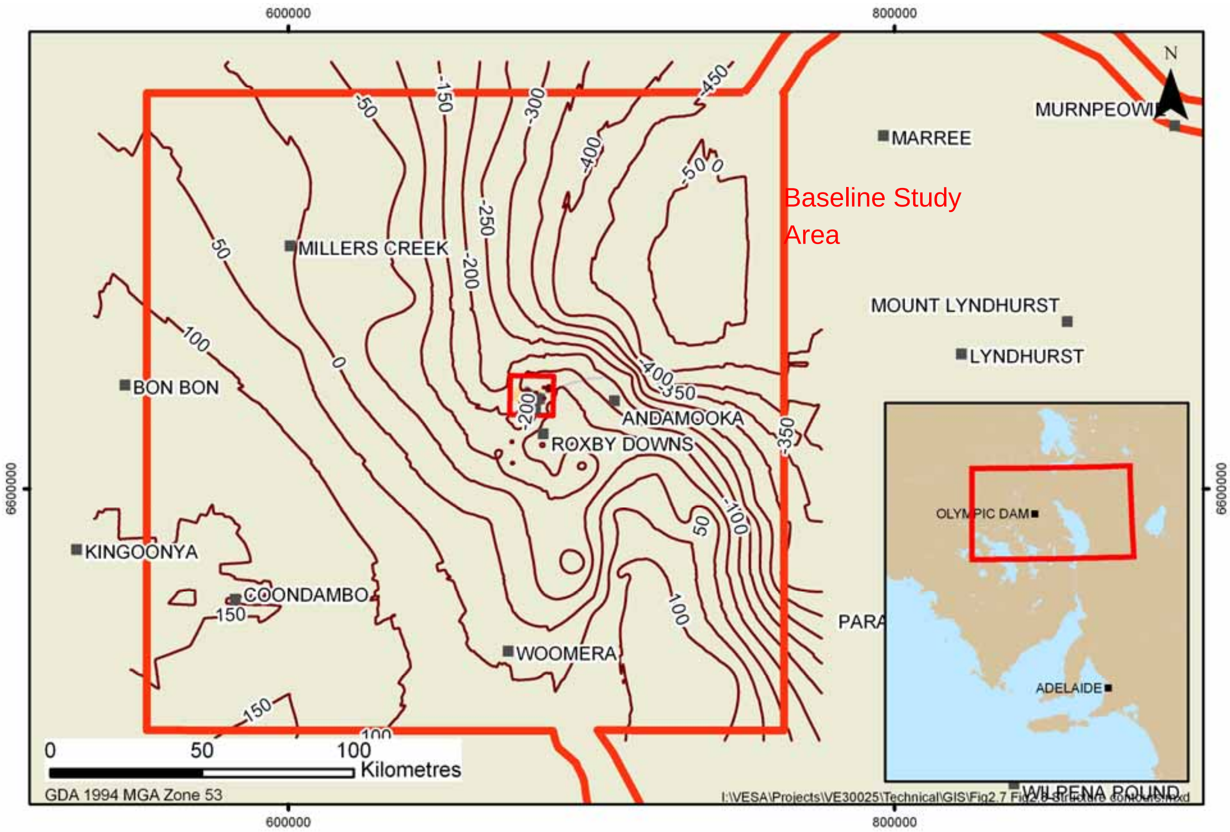


Figure 2-8 Structure contours – base of Corraberra Sandstone (Sturt Shelf)

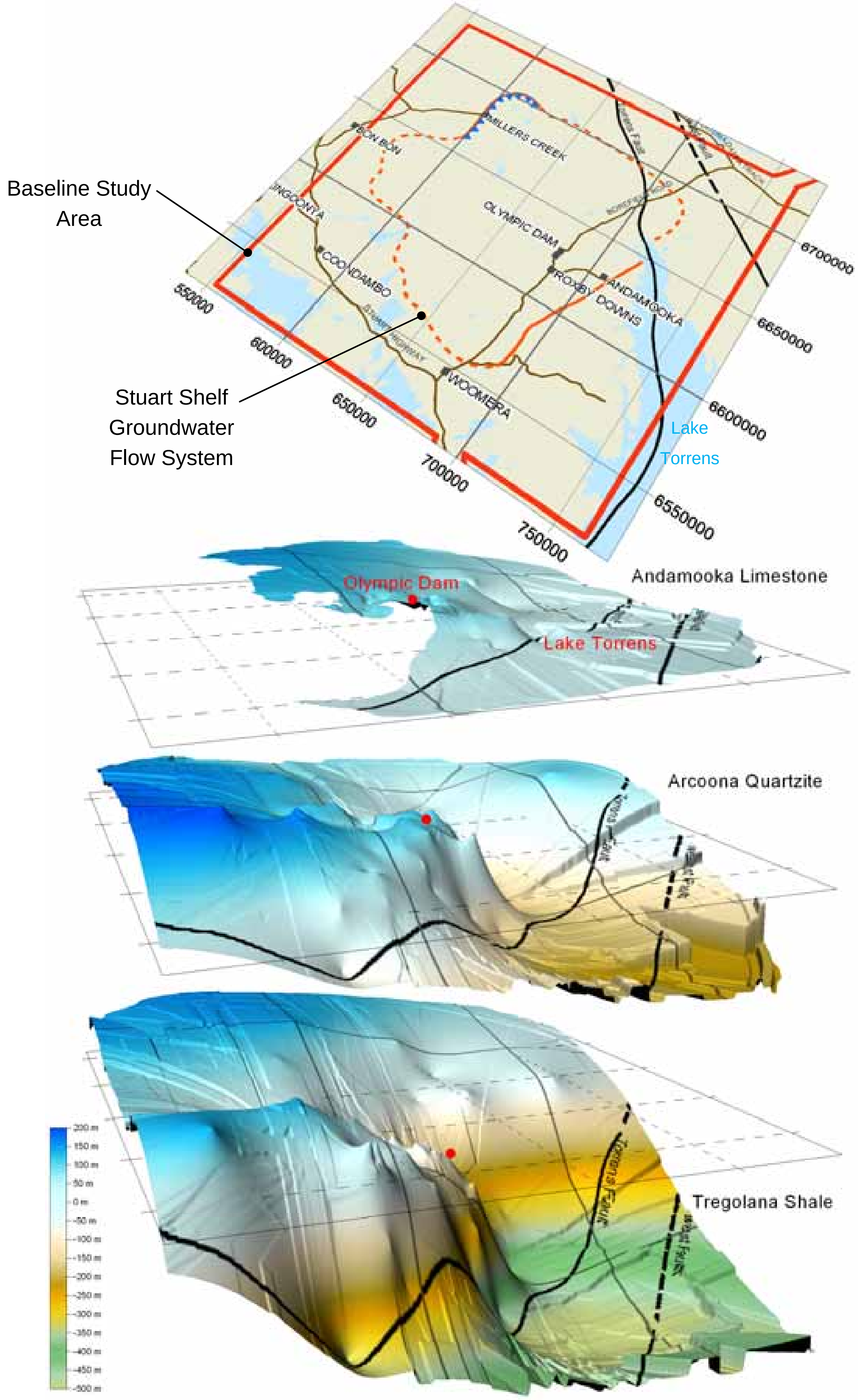


Figure 2-9 Elevations of top of key geological formations

Complex geological structure within the Tent Hill Formation and basement is interpreted from the large number of lineaments that have been mapped on the Stuart Shelf (Figure 2-4). A major east-west trending shear zone that is co-incident with the OD ore body, known as Mashers Fault (Figure 2-4 and Figure 2-7) is observed in all lithological units below the Andamooka Limestone. This fault, and others, has been active since mineralisation of the OD ore body occurred. In general they strike northwest-northeast, are discontinuous and sometimes have dislocated the cover sequence.

Golder (1995) noted that, in the immediate area of OD, near-surface karst is commonly observed within the Andamooka Limestone, and described these karst features as being inconspicuous, vegetated dolines and sometimes vertical pipe solution features. The modern day dune and swale landscape north of OD may mask the location of these features. Recent drilling undertaken in the Study Area has identified that extensive karst and sometimes fracturing is also common toward the base of the limestone unit (REM, 2007d and 2008b). Televiewer results consistently indicate two main fracture sets : a steep dipping set and a near horizontal bedding set (REM 2008b).

2.2.2 Hydrological setting

The Study Area experiences an arid climate. Figure 2-10 presents climate data for Andamooka (temperature and rainfall) and Woomera (evaporation). Maximum summer temperatures can range above 35°C, whilst in winter maximum temperatures typically range below 20°C. Annual rainfall averages around 200 mm/yr and annual evaporation averages around 3,050 mm, with evaporation exceeding rainfall for every month of the year.

As shown in Figure 2-10, average monthly rainfall does not show any distinct seasonality, and is relatively consistent throughout the year (typically less than 20 mm/month). However, the data do not adequately describe the true pattern of rainfall, which tends to be sporadic.

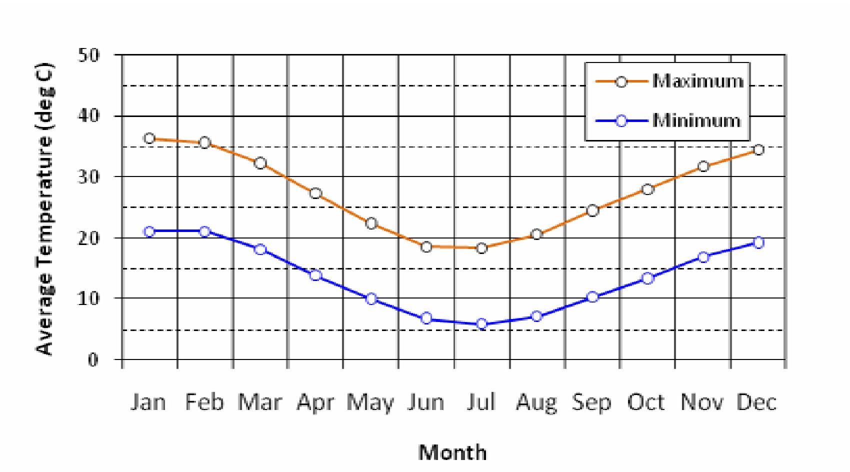
Rainfall runoff is erratic, occurring only after significant and intense rainfall events. There are no permanent surface water bodies in the Study Area, and the normal condition for lakes, surface depressions and watercourses is dry.

The Stuart Shelf is typified by many small, internally draining sub-catchments (Kinhill, 1997), the termini of which in many cases are claypans. OD lies within the Lake Torrens surface water catchment (Figure 2-11), which is a large playa lake, but the dominant Stuart Shelf surface water catchment is the Lake Gairdner catchment.

Evaporation and, possibly, transpiration are expected to form the primary water discharge processes from these sub-catchments. Seepage (recharge) losses from water bodies formed after significant rainfall events are expected to be small because of the typical presence of a shallow clayey profile.

South of OD, and north of Woomera, playa lakes are common. Many of these lakes are the termini for local drainages, and some are inferred to intersect the regional water table (Waterhouse et al., 2002) and so may form active areas of evaporative groundwater loss.

In the north, where the Andamooka Limestone occurs, a number of vegetated swamps occur in association with internally draining sub-catchments (Golder, 1995). It is possible these ‘swamps’ overlie infilled dolines and may act as localised areas of more concentrated (but low) recharge.



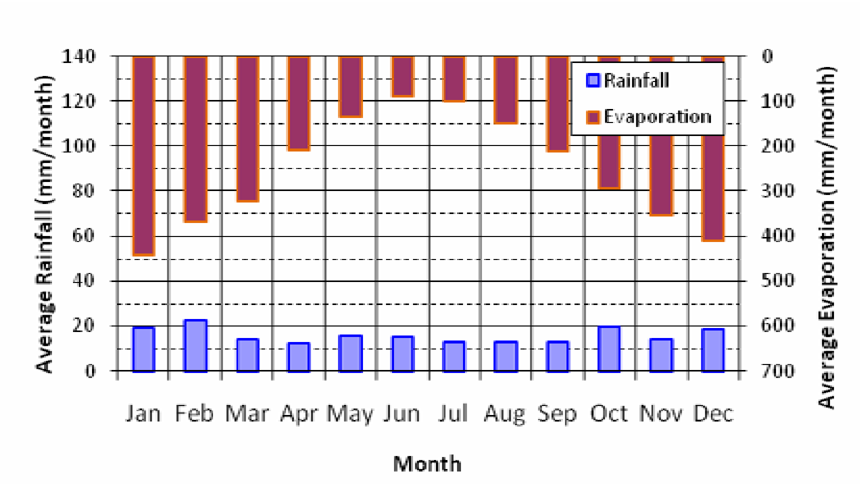


Figure 2-10 Climate data for Andamooka (Station 016065) and Woomera (Station 016001)

(source: Bureau of Meteorology)

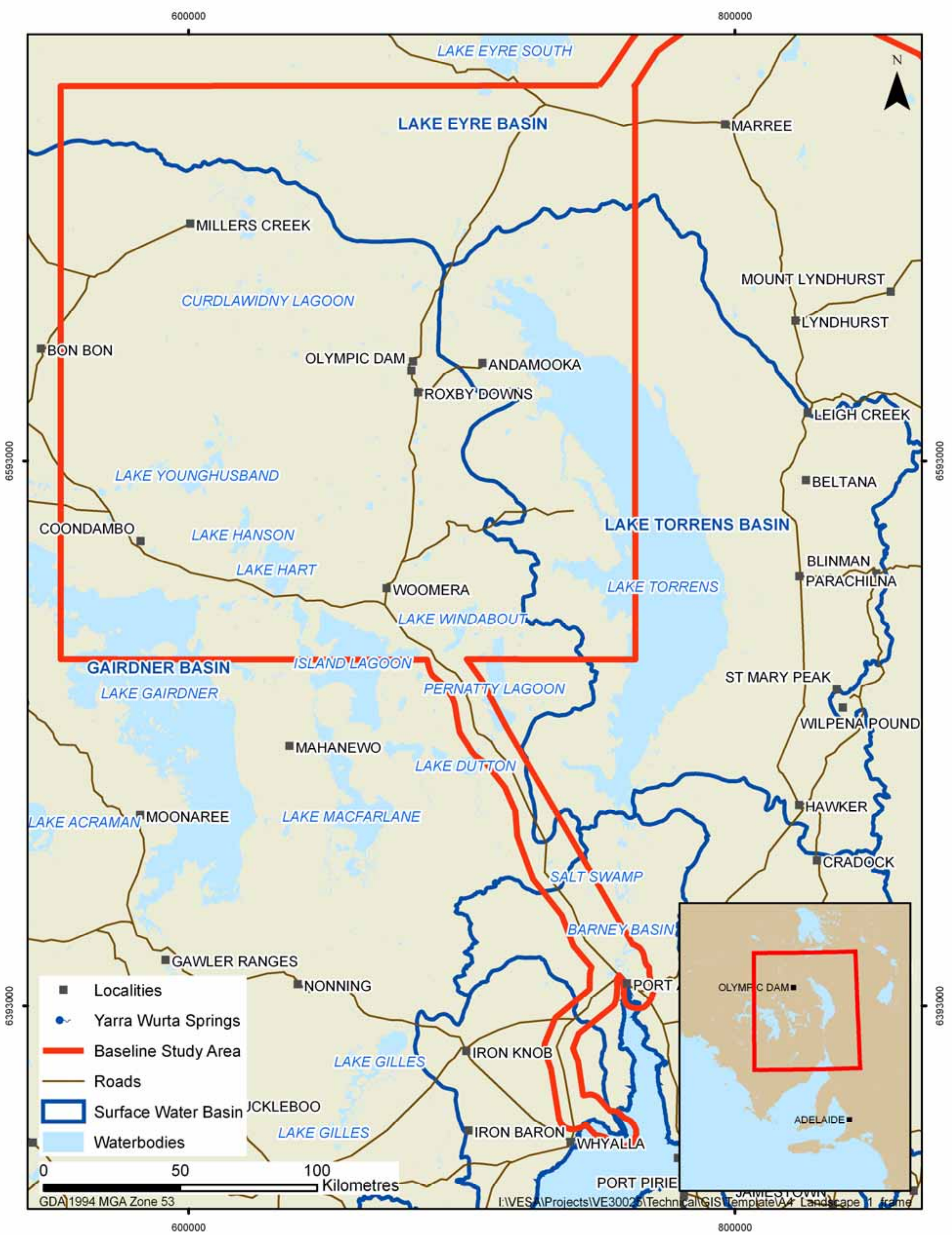


Figure 2-11 Surface water catchments of the Baseline Study Area (central & southern extent)

2.3 Infrastructure corridors

2.3.1 Geology

Southern Corridor

The proposed Southern Infrastructure Corridor for the OD expansion is shown on Figure 2-1 as an overlay to the surficial geology of South Australia's mid-north. As shown, the corridor extends south of Roxby Downs toward Port Augusta and Whyalla, generally following existing road, rail and power alignments.

Geological cross-sections consistent with the alignment are presented as Figure 2-5 (Woomera to Roxby Downs), Figure 2-12 (Port Augusta to Woomera) and Figure 2-13 (Whyalla to Port Augusta). The sections have been developed from the Andamooka (Dalgarno 1982), Torrens (Johns et al, 1971) and Port Augusta (Dalgarno et al, 1968) 1:250 000 map sheets and borehole stratigraphy records (source: SAGeodatabase). A detailed description of the stratigraphy of the Study Area, including names of key formations and hydrogeological information is presented in Table 2.2.

Basement rocks of the Southern Infrastructure Corridor consist of Archean to Mesoproterozoic crystalline rocks of the Gawler Craton. The eastern and southern boundaries of the Gawler Craton are marked by the Torrens Hinge Zone and the southern edge of the continental shelf, with most of the rock units of interest being deposited on the Stuart Shelf (Figure 2-2) where they remain relatively un-deformed and flat-lying.

The Gawler Range Volcanics erupted over the basement from numerous centres, and comprise of basic and felsic volcanics and intrusives, pyroclastic rocks and basaltic lavas. They extend beneath the cover of the younger sediments of the Stuart Shelf (Flint, 1993), and are exposed to the west of Port Augusta (Figure 2-1).

The Whyalla Sandstone, a coarse-grained sandstone of the Marinoan unit that is contiguous with the Elatina Formation (Preiss, 1987) of the Adelaide Geosyncline, underlies the Tent Hill Formation but is limited in its extent to the very southern portion of the Stuart Shelf.

The Pandurra Formation, an unmetamorphosed sequence of fluvial sediments deposited in the Cariewerloo Basin of the north-eastern Gawler Craton (Flint, 1991), occurs on the Stuart Shelf south of OD and overlies the Gawler Range Volcanics. The thickness of the Pandurra Formation varies considerably due to faulting and erosion (Figure 2-12 and Figure 2-13), and it is exposed across a broad area between Whyalla and Lake Hart to the west of Woomera. The Pandurra Formation is typically overlain by the Umberatana Group of sediments, which are found across the entire Study Area.

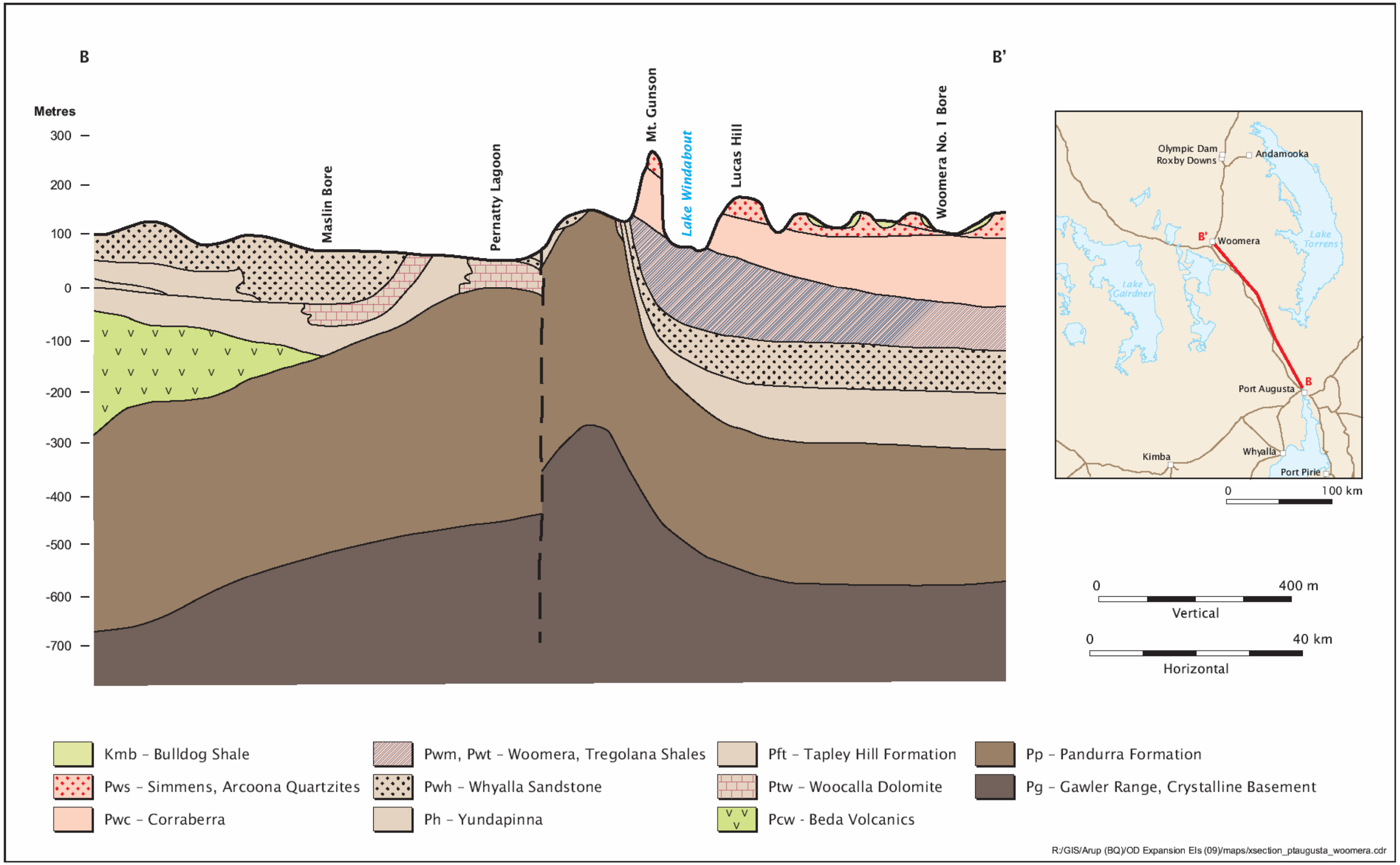


Figure 2-12 Geological section along the Southern Corridor - Port Augusta to Woomera

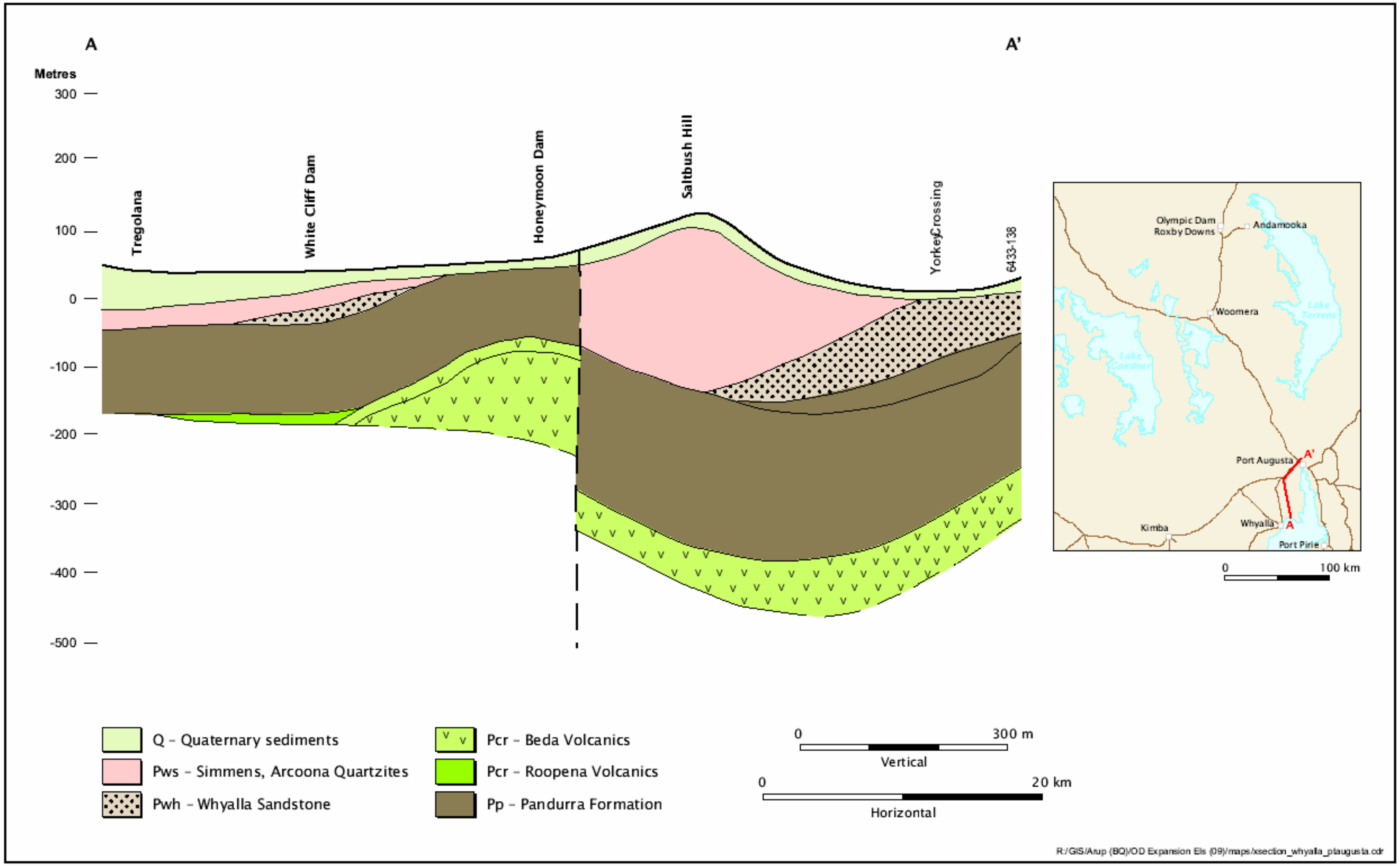


Figure 2-13 Geological section along the Southern Corridor - Whyalla to Port Augusta

Table 2-2 Summary of Important Southern Infrastructure Corridor stratigraphy and lithology [1]

Age	Unit	Description	Approximate Thickness (m)	Notes
Quaternary	Undifferentiated	Clayey sands, sand plains and dunefields, playa and drainage lakes	0-10	Extensive occurrence, but variable
Tertiary	Undifferentiated	Channel fill and fluviolacustrine sediments; isolated cappings of silcrete and laterite	Up to 25	
Jurassic-Cretaceous	Bulldog Shale	Grey marine fossiliferous shaley mudstone, minor sandy interbeds	0-50	Scattered remnants of Eromanga Basin occur in Study Area
Cambrian	Andamooka Limestone	Yellow-brown to brown-grey dolomitic limestone; unfossiliferous in west, stromatolitic in east. Well jointed karstic features	Up to 200	Highly heterogenous karstic features
Neoproterozoic	Tent Hill Formation			Stuart Shelf rocks
	Arcoona Quartzite	Fine to coarse grained, well sorted quartzite with shale interbeds in its upper part	20-150	Also referred to as Simmens Quartzite. Thickens to NE
	Corraberra Sandstone	Fine to medium grained micaceous sandstone with interbedded shale and siltstone	20-150	Variable thickness
	Tregolana Shale	Laminated shale; dominantly fine detrital quartz	150-300	Also referred to as Woomera Shale
	Whyalla Sandstone	Cross bedded coarse grained well rounded quartz sandstone	20-100	Possible Aeolian origins

Table 2.2 Summary of Important Southern Infrastructure Corridor stratigraphy and lithology [1] (cont.)

Age	Unit	Description	Approximate Thickness (m)	Notes
Neoproterozoic	Umberatana Group			Adelaide Geosyncline rocks
	"Yudnapinni Beds"	Sandstones, red and green siltstones	70-150	
	Tapley Hill Formation	Dark grey laminated shale and siltstone, thin dolomite bands and sandstones	10-100	
	Woocalla Dolomite Member	Thin bedded, oolitic and stromatolitic dolomite	20-50	
Mesoproterozoic	Gairdner Dyke Swarm	Basalt and dolerite dykes		Unconformably overlain by Umberatana Group
	Beda Volcanics	Basalts interlayered with Backy Point Formation	0-220	Occurs in Pt Augusta region
	Backy Point Formation	Red to purple, medium to v coarse grained feldspathic fluvial quartzite.	~180	
	Pandurra Formation	Medium to coarse grained poorly sorted sandstone, occasional conglomerate and shale	200-1000	Variable thickness, thins out in southern area. Extensive across eastern Gawler Craton; absent from OD
	Roopena Volcanics	Andesitic and basaltic flows		
	Gawler Range Volcanics	Basic and felsic volcanics and intrusives, pyroclastic rocks, basaltic lavas		Mantle upwelling volcanics
	Basement	Diverse igneous and high grade metamorphic rocks	-	

Notes: 1. Source : 1:250 000 Torrens (Johns et al, 1971) , Pt Augusta (Dalgarno et al, 1968) and Andamooka (Dalgarno, 1982) map sheets

Along the eastern margin of the Gawler Craton, south of Woomera, between Dutton Lake and Port Augusta, the Beda Volcanics is interlayered with coarse grained feldspathic quartzites of the Backy Point Formation.

The Tapley Hill Formation comprises dark grey, laminated shale and siltstones deposited during a marine transgression. In some areas toward the centre of the Southern Infrastructure Corridor this unit may include the Woocalla Dolomite Member, a sequence of sandstones, and red and green siltstones (Johns et al, 1981). On the Torrens 1 : 250 000 map sheet, the Tapley Hill Formation is overlain by the Whyalla Sandstone, a coarse grained sandstone probably of Aeolian origins.

The Tent Hill Formation, the dominant shallow formation in the southern part of the Stuart Shelf (south of OD), also occurs along much of the Southern Infrastructure Corridor. The Tregolana Shale Member (the Woomera Shale equivalent) comprises laminated shale and siltstone deposited in a low-energy environment (Flint, 1993). These pass into the Corraberra Sandstone Member, a fine to medium grained micacous sandstone with interbedded shale and siltstone (Kellett et al, 1999). Lying conformably on this is the Arcoona Quartzite Member (Simmens Quartzite equivalent), a fine to coarse grained, well-sorted sandstone.

The Andamooka Limestone thins south of OD to become absent at Woomera.

Tertiary palaeochannels and fluviolacustrine deposits, as well as isolated silcrete and laterite cappings occur along the Southern Infrastructure Corridor, overlying or incised into older rocks. Quaternary sands comprising of lithosols, playa deposits and dune fields, also occur across the landscape, particularly in the northern parts of the Andamooka 1:250 000 map sheet.

The Cultana Inlier is located just north of Whyalla. It appears to have been displaced by faulting associated with the Torrens Hinge Zone, and older sediments and volcanics are exposed at the surface. The inferred alignment of the Torrens Fault continues across the Stony Point area, crossing the OD Southern Infrastructure Corridor at its' southern-most point.

Northern Corridor

The proposed gas pipeline corridor alignment options for the OD Expansion Project are shown on Figure 2-14 as an overlay to the surficial geology of South Australia's northeast. The corridor begins in Moomba and passes to the east of Lake Eyre South before extending along Borefield Road to OD. One corridor option extends south from Moomba along the Strzelecki Track to Lake Callabonna before passing west towards Lake Eyre. The other crosses directly towards Lake Eyre via Lake Gregory.

Geological cross-sections consistent with the alignment are presented as Figure 2-15 through Figure 2-18. The sections have been developed from the Andamooka (Dalgarno, 1982), Curdimurka (Callan et al, 1992), Marree (Forbes, 1965), Kopperamanna (Forbes, 1974), Callabonna (Callan and Sheard, 1970) and Strzelecki (Gravestock and Hill, 1970) 1:250 000 geological map sheets, as well as borehole stratigraphy records (source: SAGeodatabase).

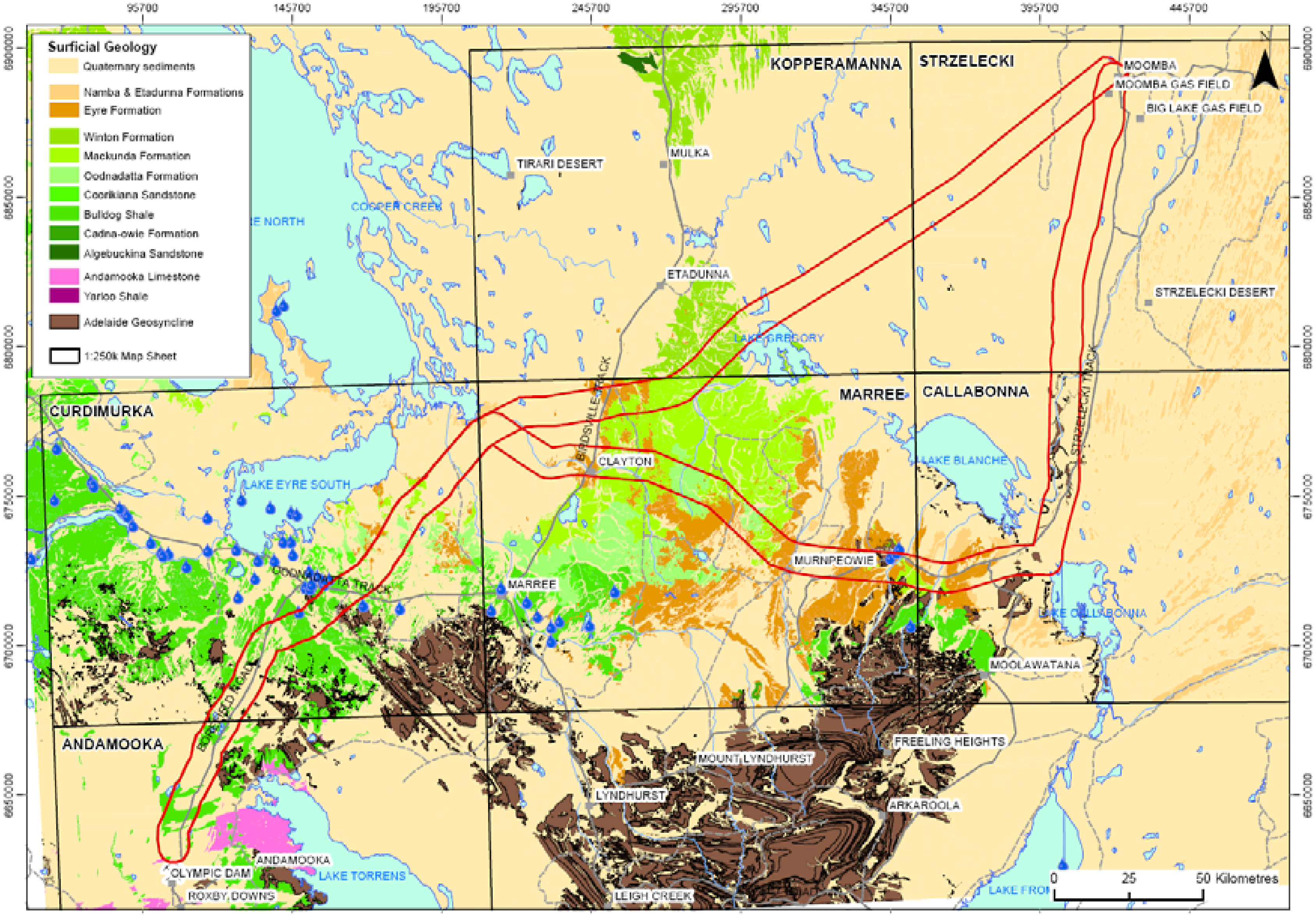


Figure 2-14 Regional surficial geological setting for Northern (gas pipeline) Corridor

The geology of the northern infrastructure corridor consists of three main geological provinces: (i) Stuart Shelf; (ii) Lake Eyre Basin (Callabonna sub-basin); and (iii) Great Artesian Basin (Eromanga Basin). Additionally, the Adelaide Geosyncline and Torrens Hinge Zone geological provinces are imposed beneath the southwestern portion of the gas pipeline corridor (Figure 2-1).

A detailed description of the stratigraphy of the Study Area, including names of key geological regions, formations and hydrogeological information is presented in Table 2-3.

The geology of the southwestern part of the northern infrastructure corridor is consistent with the OD Study Area.

Across the northern part of the Stuart Shelf, scattered remnants of the Jurassic-Cretaceous Eromanga Basin can be found. These sediments include the fine to coarse-grained Algebuckina Sandstone, a pale grey to white sandstone which underlies the pale grey siltstones and sandstones of the Cadna-owie Formation (Habermehl, 1980). The grey marine fossiliferous Bulldog Shale overlies these units. Outcrops of the Cadna-owie Formation and Algebuckina Sandstone occur adjacent to, and immediately north of, the Proterozoic basement rocks of the uplifted Adelaide Geosyncline/Torrens Hinge Zone in the area covered by the Curdimurka and Marree geological map sheets (Figure 2-14 and Figure 2-16).

Further to the northeast, in the area covered by the Marree, Kopperamanna, Callabonna and Strzelecki geological map sheets, the claystones, siltstones and sandstones of the Winton, Mackunda, and Oodnadatta Formation units of the Eromanga Basin overly the Bulldog Shale. In this area, the basin plunges steeply in a series of anticlinal and synclinal structures to depths of approximately 2 km below ground level (Habermehl, 1980).

The Tertiary Lake Eyre Basin unconformably overlies the Eromanga Basin sediments in the north-eastern portion of the gas pipeline corridor(s) (Strzelecki and Callabonna 1:250 000 geological map sheets), and consists of the carbonaceous and pyritic fine to very coarse sandstones and coals of the Eyre Formation, which have been deposited in a variably fluvial and swamp environment. The Eyre Formation on-laps the upper Eromanga Basin sequence to the immediate north of the outcropping Adelaide Geosyncline (Figure 2-16). The laucustrine, fluvial and deltaic clays, silts and fine sands of the Namba Formation (and its dolomitic Etadunna Formation equivalent) form the upper most unit of the Lake Eyre Basin in the Study Area, and overlies the Eyre Formation towards the northern and eastern most parts of the gas pipeline corridor(s), but is absent over the Eyre Formation further to the south and west.

The surface geology that occurs across the Study Area comprises of Tertiary palaeochannels and fluviolacustrine deposits, as well as isolated silcrete and laterite cappings. Quaternary sands comprising of lithosols, playa deposits and dune fields, occur across the landscape.

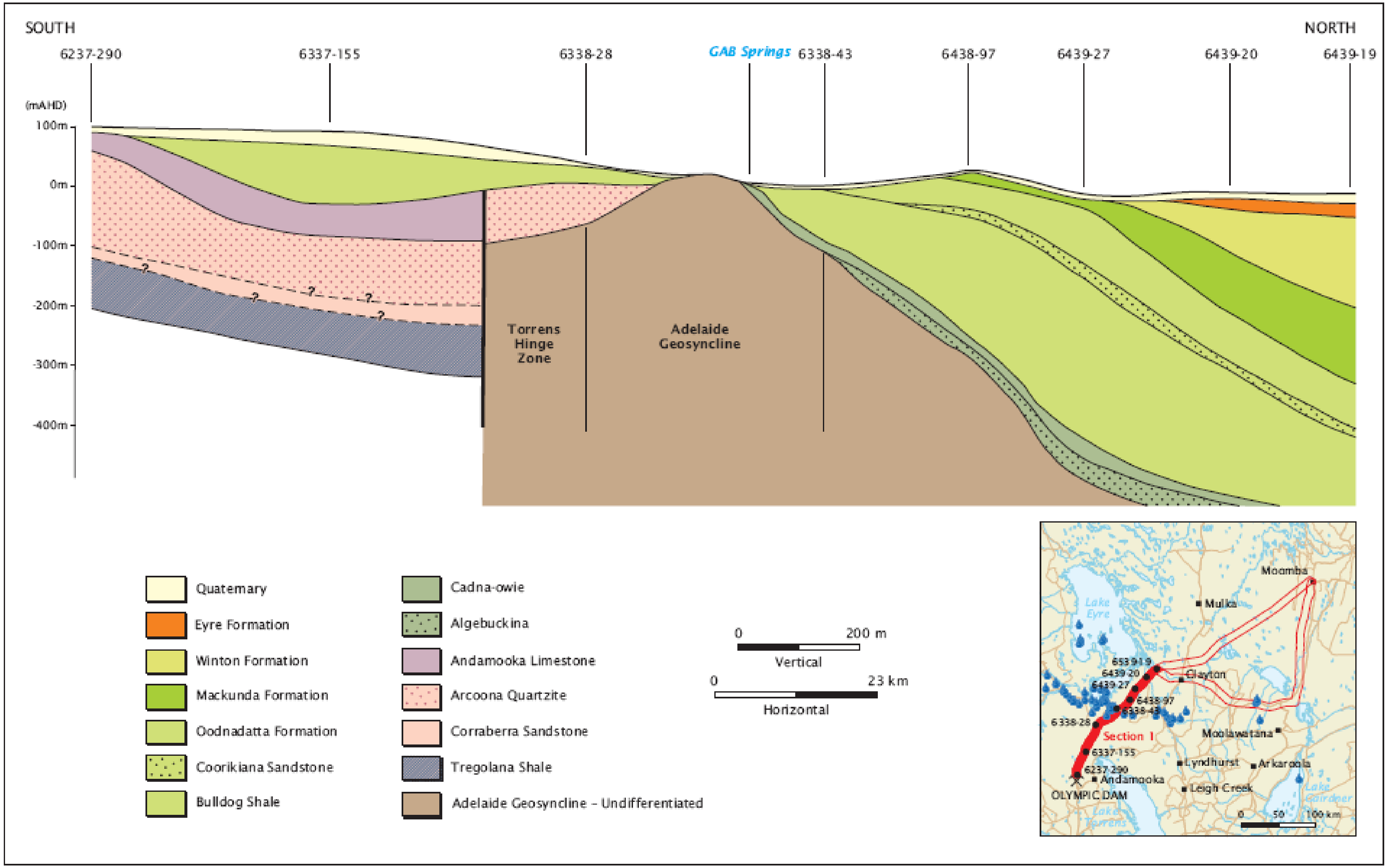


Figure 2-15
Geological section along the Northern Corridor – OD to Lake Eyre South

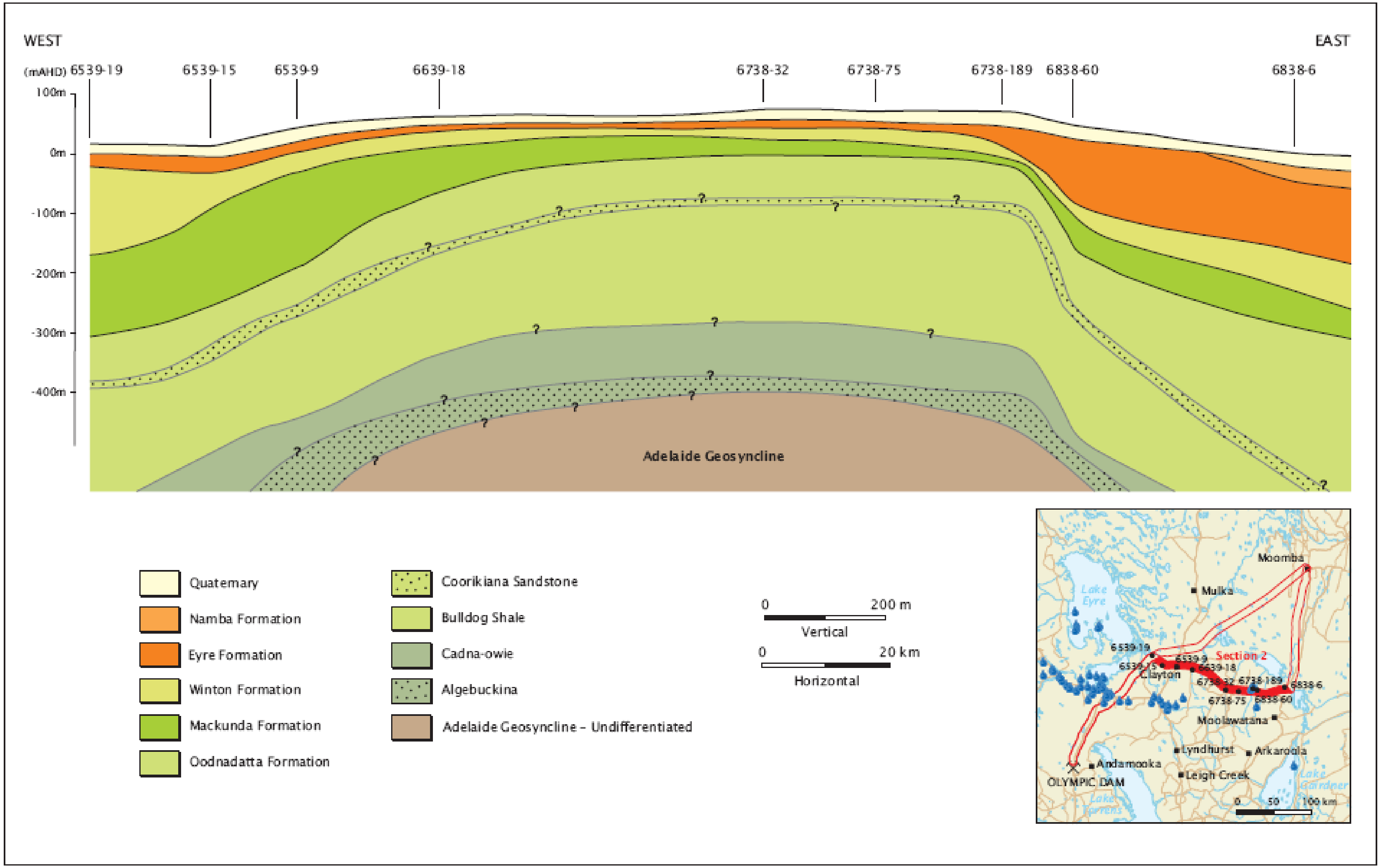


Figure 2-16
Geological section along the Northern Corridor – Lake Eyre South to Lake Blanche

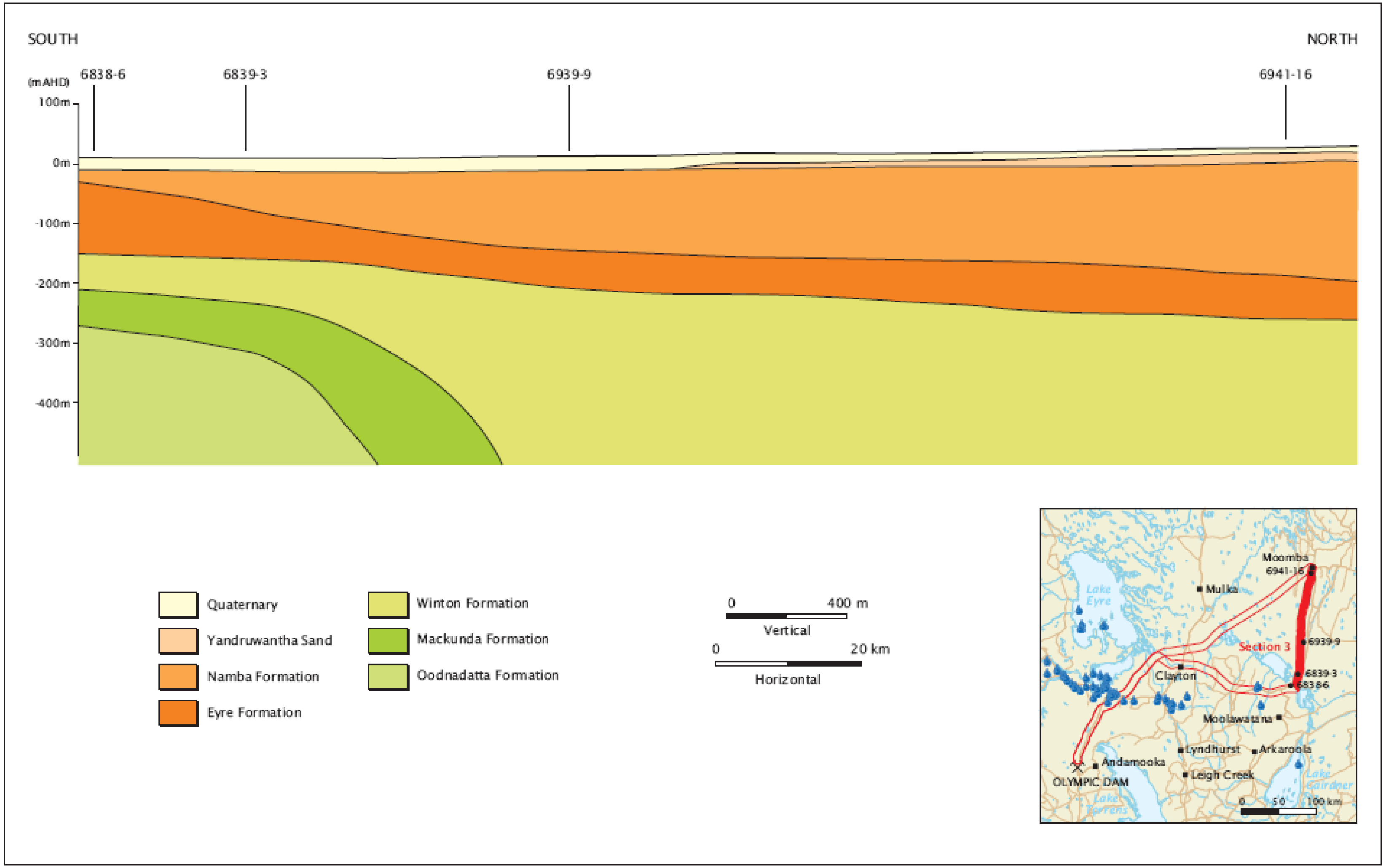


Figure 2-17
Geological section along the Northern Corridor – Lake Blanche to Moomba

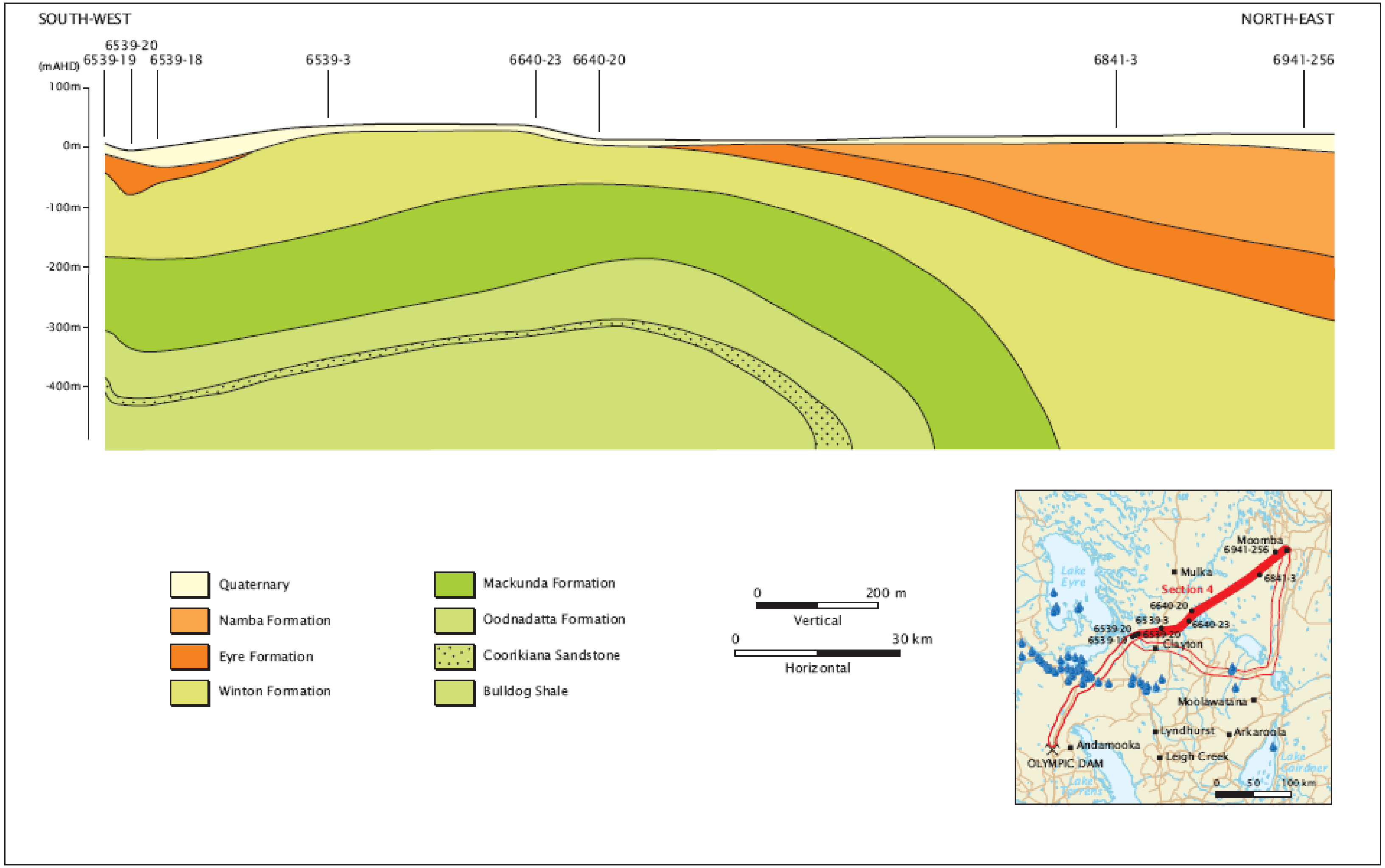


Figure 2-18 Geological section along the Northern Corridor – Lake Eyre South to Moomba

Table 2-3 Summary of stratigraphy and lithology along the Northern (gas pipeline) Infrastructure Corridor [1]

Age	Unit	Description	Approximate Thickness (m)	Notes
Quaternary	Undifferentiated	Clayey sands, sand plains and dunefields, playa and drainage lakes	0-20	Extensive occurrence, but variable
Tertiary	Namba Formation	Fine grey to olive clay and yellow well sorted silt to fine sand, with interbeds of medium to coarse sand. Dolomitic clay and carbonate at base.	0-190	Also referred to as Etadunna Formation in the western parts of the Study Area
	Eyre Formation	Carbonaceous fine to coarse quartz sand, pebbly sands and lignite	0-110	
Jurassic-Cretaceous	Winton Formation	Laminated dark grey claystone and pale grey siltstone, minor carbonaceous and coal material	0-615	Scattered remnants of Eromanga Basin occur in southern most Study Area and become dominant sedimentary feature to the north and east.
	Mackunda Formation	Medium to dark grey fine sandstone, interlayered with very fine sandstone and claystone	0-120	
	Oodnadatta Formation	Pale to medium grey claystone	0-280	
	Coorikana Sandstone	Grey fine to coarse sandstone and pebble conglomerate	0-8	
	Bulldog Shale	Grey marine fossiliferous shaley mudstone, minor sandy interbeds	0-300	
	Cadna-owie Formation	Pale grey siltstone, fine grained sandstone with coarse sandstone interbeds and minor carbonaceous claystone intervals	0-70	
	Algebuckina Sandstone	Fine to coarse grained quartz sandstone, minor shale and siltstone lenses	0-200+	

Notes: 1. Source : 1:250 000 geological map sheets - Andamooka (Dalgarno, 1982), Curdimurka (Callan et al, 1992), Marree (Forbes, 1965), Kopperamanna (Forbes, 1974), Callabonna (Callan and Sheard, 1970) and Strzelecki (Gravestock and Hill, 1970)

2.3.2 Hydrological setting

Southern Corridor

Climatic patterns along the Southern Infrastructure Corridor are consistent with those observed around OD, as indicated by climate data presented on Figure 2-10 (Andamooka; temperature and rainfall, and Woomera; evaporation), and Figure 2-19 (Port Augusta). Average annual rainfall ranges between 200 and 210 mm/yr and maximum summer temperatures range above 30˚C.

As for the OD Project Area, there is no distinct seasonality to rainfall along the Southern Infrastructure Corridor and rainfall runoff is erratic. Annual evaporation (for Woomera) averages above 3,000 mm, and average monthly evaporation exceeds average monthly rainfall for every month of the year.

The Southern Infrastructure Corridor traverses the internally draining Gairdner catchment, and the Mambray Coast and Spencer Gulf catchments that drain to Spencer Gulf (Figure 2-11). There are no permanent surface water bodies along the corridor, and the normal condition for lakes, surface depressions and watercourses is dry. The dominant surface water features in the vicinity of the Southern Infrastructure Corridor are the salt lakes Lake Torrens, Island Lagoon and Pernatty Lagoon, but many other smaller lakes occur.

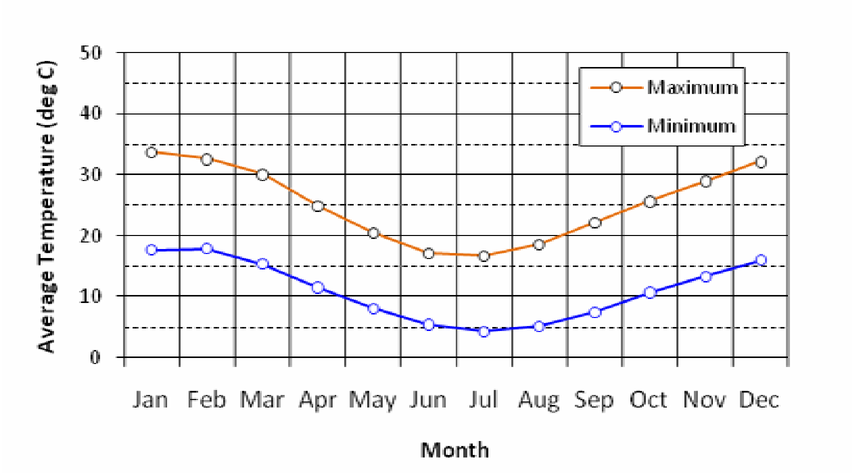
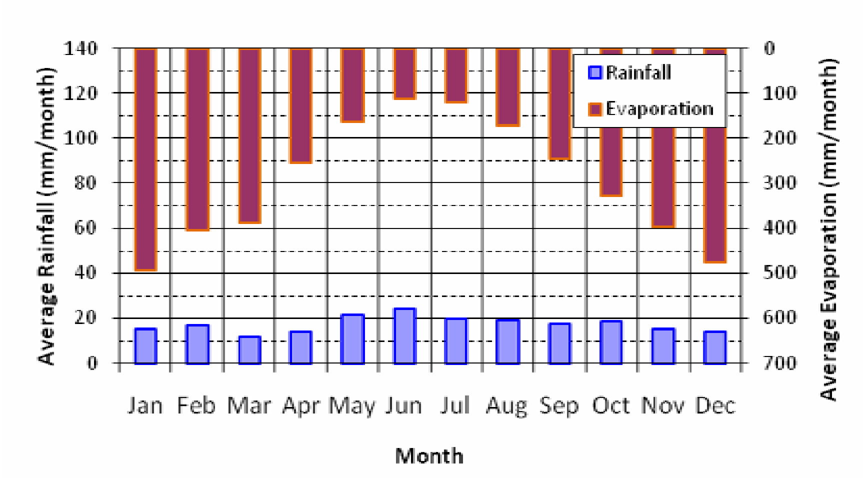


Figure 2-19
Climate data for Port Augusta (Station 016056)

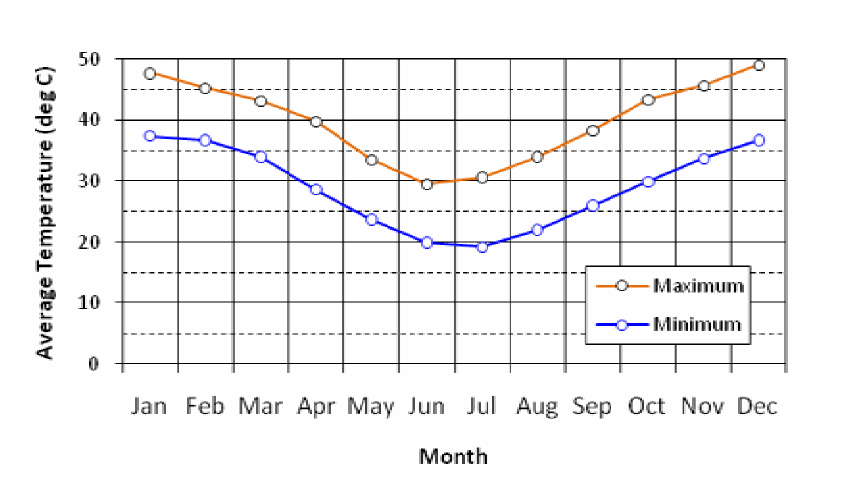
(source: Bureau of Meteorology; note Evaporation data from Woomera station)



Northern Corridor

Average climate data for the southern part of the northern corridor is expected to be similar to that presented in Figure 2-10 (i.e. around OD).

The more arid northern regions are represented by data for Moomba presented in Figure 2-20. Average temperature data for the more northern alignments are consistently between around 10 and 15°C higher than those observed around OD. Similarly, average evaporation rates are also consistently higher than those observed around OD. Average monthly rainfall data displays slight seasonality, with January and February noticeably reporting higher rainfall than for other months.



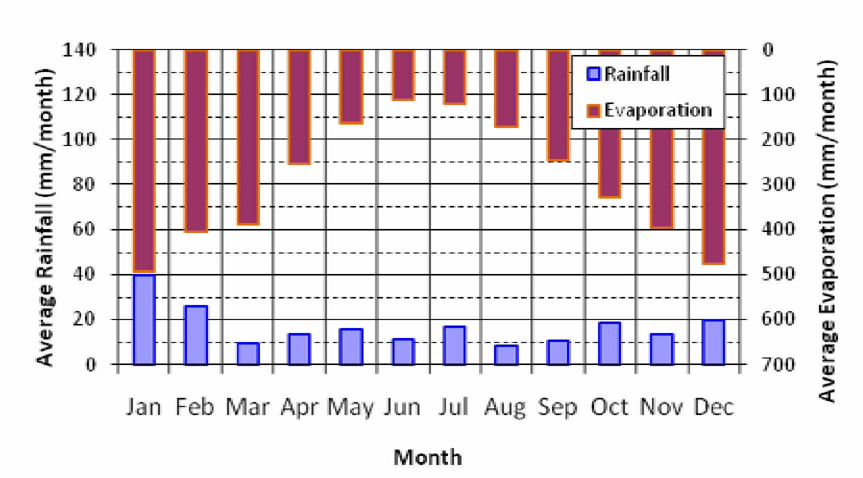


Figure 2-20
Climate data for Moomba (Station 017096)

(source: Bureau of Meteorology)

The Northern Infrastructure Corridor traverses the northern part of the Torrens catchment (see Figure 2-11) but predominantly lies within the Lake Eyre catchment. Figure 2-21 presents the hydrological features along the corridor, notably the Lake Eyre complex and salt lakes such as Lake Gregory, Lake Blanche and Lake Callabonna (which drain an area south of the corridor).

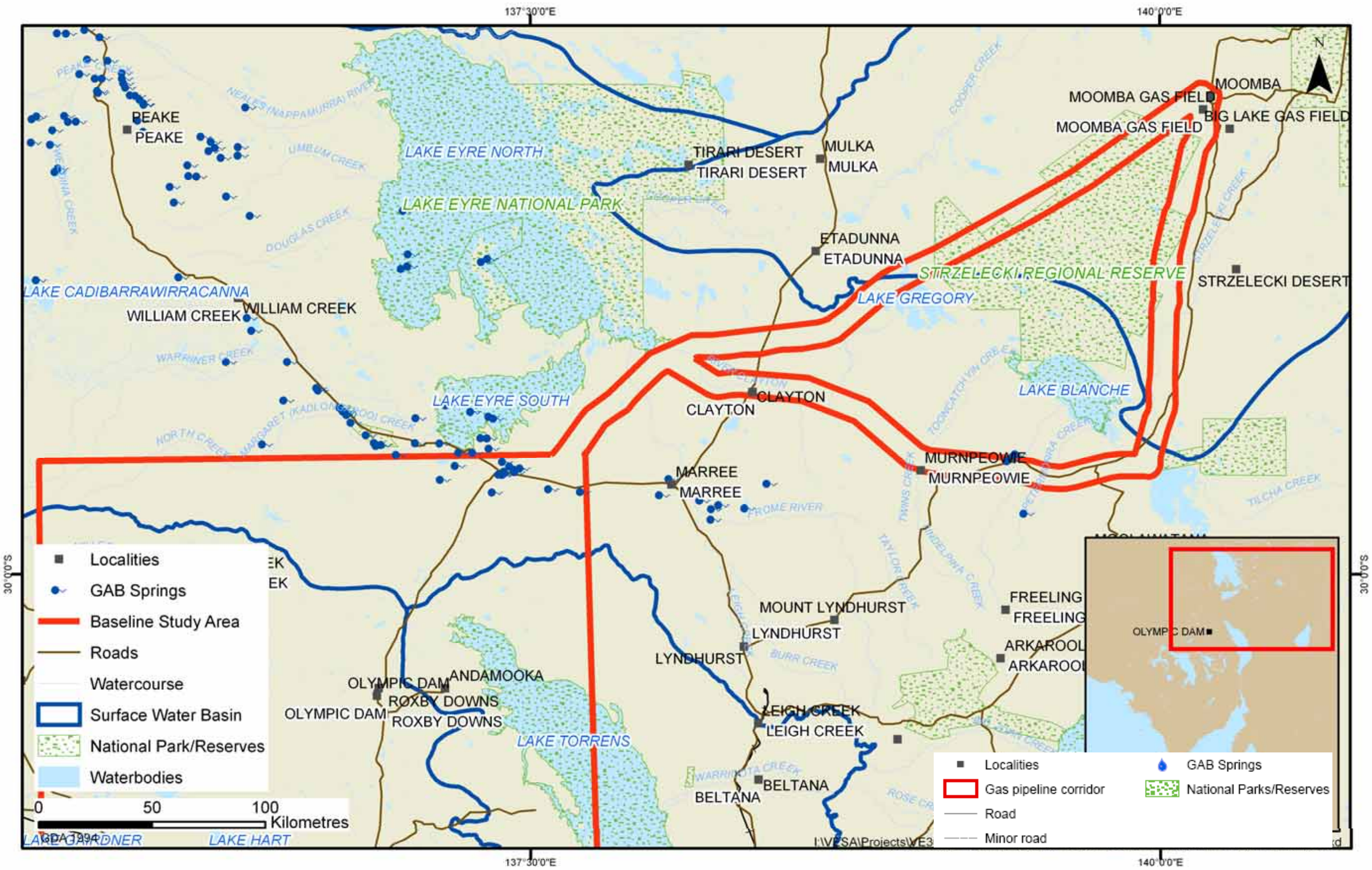


Figure 2-21 Hydrology of the Northern Infrastructure Corridor

2.4 Sedimentary basins and palaeochannels

2.4.1 Arckaringa Basin

The Permian Arckaringa Basin sediments unconformably overlie Cambrian-aged sedimentary rocks of the Stuart Shelf to the west of OD (see Figure 2-2), and comprise (from oldest to youngest):

- Boorthanna Formation
  glacigene sediments with a basal diamictite sequence and an upper unit of coarse and fine sandstones;
- Stuart Range Formation
  a marine shale, with minor siltstone and sandstone, overlying the Boorthanna Formation in most parts of the Arckaringa Basin; and
- Mount Toondina Formation
  siltstone, sandstone and carbonate rocks (absent from the southeastern part of the Basin).

The southern margin of the Boorthanna Formation to the south of the Boorthana Fault unconformably overlies the Andamooka Limestone and Tent Hill Formation on the Stuart Shelf. In this area the Arckaringa Basin extends to within about 50 km of OD.

2.4.2 Eromanga Basin

The Mesozoic Great Artesian Basin (GAB) underlies almost 1.7 million km^2 of central and northeastern Australia (Kinhill, 1997), which is almost 20% of the continental land mass. The GAB is one of the largest groundwater reservoirs in the world and comprises of three sedimentary sub-basins, the: (i) Carpentaria Basin of Northern Queensland; (ii) Surat Basin of northeastern NSW and southeastern Queensland; and (iii) Eromanga Basin, the largest of the three sub-basins and extends across Queensland, NSW, Northern Territory and South Australia (Figure 2-22).

The Eromanga Basin is more extensive than the Arckaringa Basin and extends into the northwestern and central part of South Australia as shown in Figure 2-22. The important sedimentary sequences of the Eromanga Basin in South Australia comprise of (oldest to youngest):

- silt, sand and gravel sequences of the Cadna-owie Formation and Algebuckina Sandstone, which lie unconformably on Arckaringa Basin sediments to the west of OD and Adelaide Geosyncline rocks north of the Torrens Hinge Zone (Figure 2-2); and
- grey marine mudstones of the Bulldog Shale, which overlies the Cadna-owie Formation and Algebuckina Sandstone north of the Torrens Hinge Zone and the western parts of the Stuart Shelf but occurs as remnants directly overlying Stuart Shelf rocks south of the Torrens Hinge Zone.

OD is located on the southern margins of the Eromanga Basin, approximately 80 km from where artesian conditions exist (see Figure 2-22).

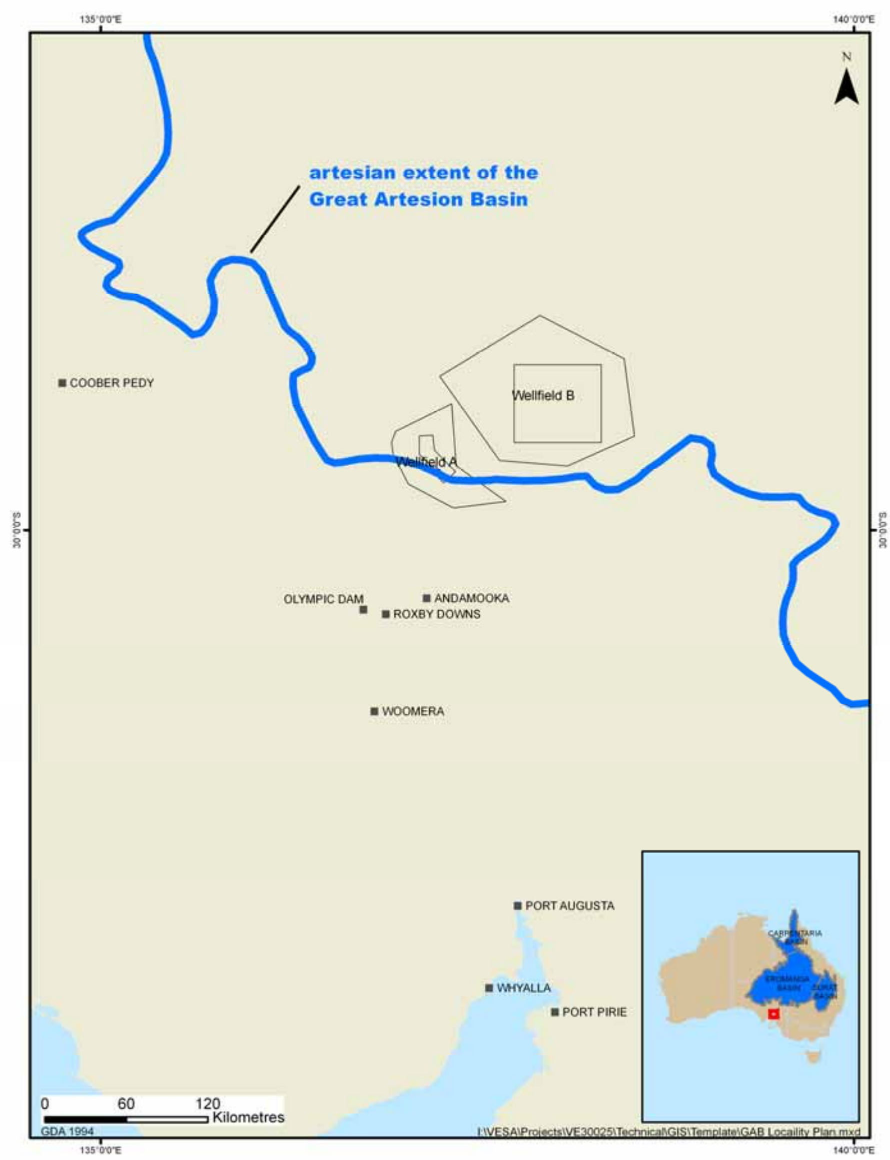


Figure 2-22 GAB locality plan

2.4.3 Torrens Basin

The Tertiary Torrens Basin occurs within 50 km east of OD. It is a north-south trending structural depression that is coincident with the Torrens Hinge Zone, and its western margin is marked by the Torrens Fault (Figure 2-2). Accumulated sediments are roughly 100 m thick at the northern end of Lake Torrens and deepen towards the east and south of the basin to almost 300 m (Alley and Benbow, 1995), and these sediments overlie the Andamooka Limestone and Adeliade Geosyncline rocks (Figure 2-2 and Figure 2-3).

2.4.4 Tertiary Palaeochannels

Tertiary palaeochannels are a common feature of inland Australia, and they are often synonymous with lower parts of the landscape (Hou *et al*, 2000). The Kingoonya Palaeochannel is a major palaeodrainage of South Australia's Gawler Craton, extending to within around 50 km west of OD (Golder, 1995).

3 BASELINE HYDROGEOLOGY

3.1 Overview

A summary of the hydrostratigraphy for the Stuart Shelf and broader Study Area is presented in Table 3-1. In general, the hydrostratigraphy of the Stuart Shelf west of the Torrens Fault is quite uniform and, in most cases, is consistent with the regional stratigraphy described in Section 2.

Over much of the Stuart Shelf, and broader Gawler Craton, groundwater does not typically occur within the thin Quaternary aeolian and eolian sediments, as they typically occur above the regional water table. However, there may be some situations, e.g. in topographic lows or where dune fields are underlain by clayey profiles, that Quaternary sediments form local (possibly perched) groundwater flow systems.

In terms of the OD mining operation, there are two important groundwater systems on the Stuart Shelf, the Andamooka Limestone and the Tent Hill Formation, which comprises the fractured Corraberra Sandstone and the lower (10 to 20 m) section of the Arcoona Quartzite (Figure 3-1).

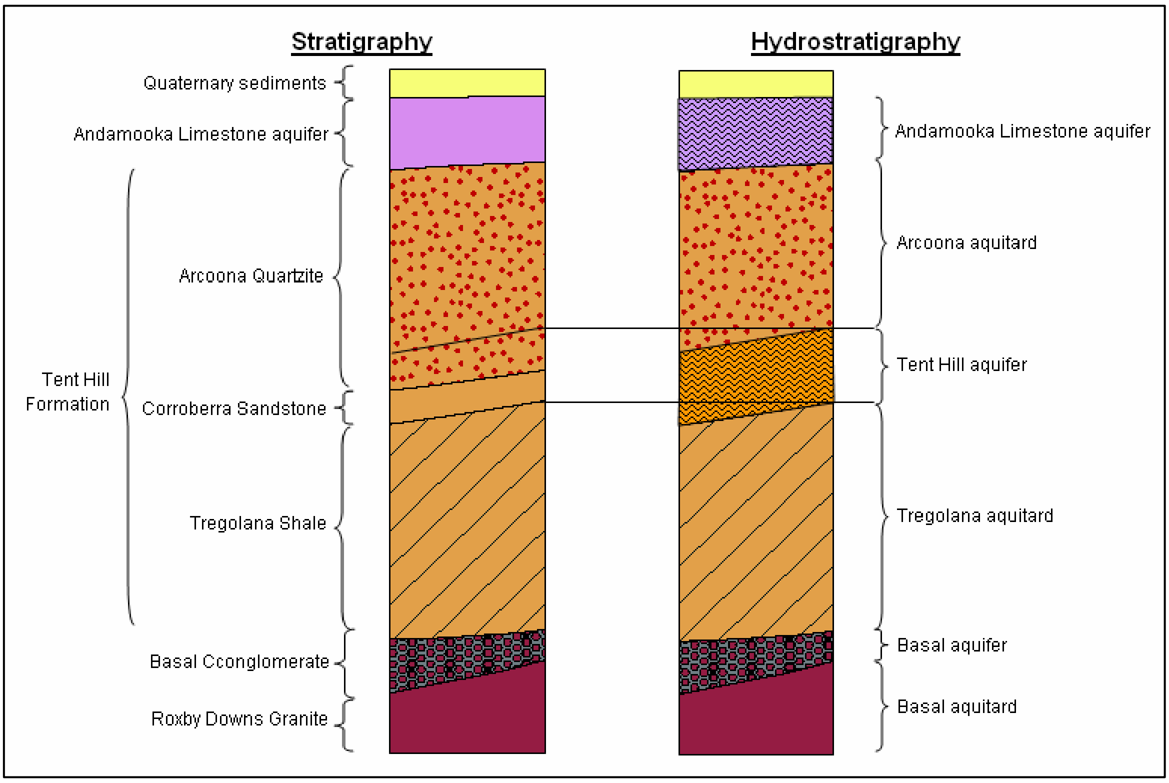


Figure 3-1 Sturt Shelf hydrostratigraphy at OD.

The Pandurra Formation likely forms an aquifer in the southern and western portion of the Stuart Shelf, although large water supplies have not been developed from this unit. Precambrian sedimentary rocks are generally considered to form poor aquifers in the Study Area and along the Southern Infrastructure Corridor, apart from where they are fractured and significant secondary porosity is developed.

Table 3-1 Hydrostratigraphic units of the Stuart Shelf (oldest to youngest)

Unit	Description
Basement rocks	
Various	Typically the crystalline basement rocks of the region form saline / hypersaline aquifers only where fractured. This is also the case for sedimentary basement rocks, although primary porosity-associated permeability exists (e.g. Pandurra Formation).
Stuart Shelf (& Adelaide Geosyncline equivalents)	
Tent Hill aquifer	Corraberra Sandstone and lower Arcoona Quartzite units. Moderate permeability aquifer with variable degree of secondary porosity. Can be high yielding in association with major structures. Typically hypersaline, with brines beneath and adjacent to Lake Torrens. There is no real equivalent Adelaide Geosyncline aquifer.
Tent Hill aquitard	Upper Arcoona Quartzite unit. Low permeability but leaky aquitard confining the underlying Tent Hill aquifer. Can yield water where significant secondary porosity is induced by fracturing. Equivalent to the ABC Range Quartzite.
Yarloo Shale	Low permeability unit overlying Tent Hill aquitard north of OD.
Andamooka aquifer	Regional water table aquifer with significant transmissivity at the regional scale, associated with karst and (possibly fracture) related secondary porosity. Becomes confined by Yarra Wurta and Bulldog Shale to the north. Typically hypersaline, with brines sitting at the base beneath and adjacent to Lake Torrens.
Arckaringa Basin	
Boorthanna aquifer	Extensive regional-scale aquifer, typically occurring as several zones within the Boorthana Formation, separated by significant thicknesses of low permeability sediments, especially in the eastern parts of the Basin where thicker and deeper intersections occur. Moderate permeability. Likely to form a water table aquifer west of OD, but is confined by the Stuart Range aquitard to the northwest.
Stuart Range aquitard	Significant low permeability aquitard, where present northwest of OD, that separates the Boorthanna aquifer from overlying aquifers of either the Arckaringa or Eromanga Basins. Where present, the lower silty sediments of the Mount Toondina Formation are also contained within this hydrostratigraphic unit.
Mount Toondina aquifer	Shallow sandstones and carbonate sequences form an aquifer. Variable degree of hydraulic connection with shallower Eromanga aquifers exists. [5]
Eromanga Basin	
Eromanga aquifer	Sandy aquifers occurring extensively throughout northern South Australia. About 100 km north of OD, these aquifers are commonly artesian. West and northwest of OD, water table aquifers and non-artesian aquifers overlie Arckaringa Basin sediments. Commonly referred to as the Eromanga aquifers but this term is considered misleading because they are not always artesian. Groundwater salinity ranges from <2000 mg/L (artesian Eromanga aquifer) to brackish / saline (non-artesian Eromanga aquifer).
Bulldog Shale aquitard	Mudstone unit with some silty and sandy intervals. Can be a confining unit to the Eromanga aquifer, and may contain laterally discontinuous perched aquifers.
Tertiary & Quaternary	
Various	Tertiary palaeochannel aquifers are common in the Gawler Craton, although none has been mapped in the immediate area of OD. The Torrens Basin holds the most important Tertiary and Quaternary aquifers in the immediate Study Area, but these are poorly studied. Tertiary aquifer groundwater salinity is typically hypersaline. Quaternary aquifer groundwater salinity is expected to be variable, being brackish near recharge and hypersaline within Lake Torrens.

Other important regional hydrogeological units, listed from oldest to youngest, include:

- non-artesian aquifers associated with the Permian Arckaringa Basin to the west of OD;
- Mesozoic Eromanga aquifers, which are artesian further to the north of OD (Figure 2-22) and non-artesian immediately to the north and west of OD, where present; and
- non-artesian aquifers associated with Tertiary palaeochannels, southwest and west of OD.

The following provides more detailed discussion concerning each of the important aquifers comprising the regional groundwater system.

3.2 Stuart Shelf groundwater system

3.2.1 General

The shallowest sedimentary rocks of the Stuart Shelf are the most important aquifers in the vicinity of the OD mining operation:

- To the north of OD, the Andamooka Limestone aquifer (ALA) forms the regional water table aquifer and comprises a dolomitic limestone having significantly developed karst (airlift yields of up to 60 L/s have been reported). In the vicinity of the proposed pit the ALA is unsaturated, as it also tends to be further to the south.
- The Tent Hill aquifer (THA, typically comprising the Corraberra Sandstone and the lower part of the Arcoona Quartzite) is mainly a leaky confined fractured rock aquifer to the south of OD, with the low permeability Arcoona Quartzite forming the confining sequence (Figure 3-1). To the north of OD, the Tent Hill aquifer is further confined by the Yarloo Shale, which separates the Andamooka Limestone and Tent Hill Formation (Figure 2-6).

The THA will be targeted for dewatering operations as part of ODX, with subsequent depressurisation of the aquifer effectively underdraining the ALA, where it is saturated, via the leaky Arcoona aquitard (Figure 3-1).

The ALA covers an area of approximately 14,500 km^2, extending from about 50 and 80 km south and northwest of OD, respectively, to around 35 km north of the top of Lake Torrens (Figure 2-2). The aquifer gently dips and thickens north and northeast of OD (up to a maximum of 160 m at the northern end of Lake Torrens). The underlying THA also dips and thickens to the northeast of OD, although the lower permeable sections of the aquifer (the Corraberra Sandstone) reduce in thickness and degree of fracturing (REM, 2007d).

3.2.2 Hydrostratigraphy

Basement rocks

The Roxby Downs Granite and other basement rocks of the Stuart Shelf have very little primary porosity, and where secondary porosity is developed (due, for example, to fracturing) the rocks typically report a low permeability (WMC Resources, 1993). Where underground workings have encountered fractures, inflows are typically small and short-lived (Kinhill, 1997).

Aquifer testing, involving in-situ permeability and pumping tests, undertaken in the area of the SML has provided estimates of basement hydraulic conductivity ranging between $1x10^{-6}$ and $2x10^{-3}$ m/day (WMC 2007, GRM 2005, and AGC 1982).

Groundwater associated with the OD ore body reports salinities typically in excess of 70,000 mg/L, as well as heavy metals and detectable amounts of uranium and radium.

Pandurra Formation aquifer

There are limited data available concerning the hydrogeological characteristics of this unit near to OD, but investigations undertaken by Read and Beal (1988) show this unit can have transmissivities as high as 45 m^2/day. Groundwater salinities reportedly range above 17,000 mg/L (Kellet et al. 1999). The Pandurra Formation aquifer is likely recharged at the southern part of the Stuart Shelf, where the unit sub-crops or outcrops.

Nucaleena Formation (Basal Conglomerate) aquifer

The basal conglomerate (Figure 2-5 and Figure 3-1) occurs as a thin band of granite and massive haematite conglomerate with dolomitic cement immediately overlying basement rocks in the OD area. While high airlift yields have been encountered in this unit in isolated areas associated with deep valley fill deposits (WMC, 2007), the aquifer is not regionally extensive and is not considered to have significant groundwater resource potential.

Tregolana Shale aquitard

The Tregolana Shale, the equivalent of the Woomera Shale, acts as a low permeability confining layer that restricts groundwater movement between the THA and the deeper Pandurra Formation, where it occurs (Figure 2-5 and Figure 3-1), and Pre-Cambrian basement rocks.

The estimated horizontal hydraulic conductivity of this unit ranges between $1x10^{-4}$ and $2x10^{-2}$ m/day (WMC 2007, AGC 1982, and GRM 2005). The lower value is consistent with those found in the literature for fractured shales but up to four orders of magnitude higher than for unfractured shale (e.g. Weight and Sonderegger, 2000), and the higher value reported by GRM (2005) is probably unrepresentative of the unit. Vertical hydraulic conductivity is likely to be more than an order of magnitude lower than the value reported by AGC (1982; $8x10^{-4}$ m/day), especially where unfractured.

Tent Hill Aquifer (THA)

Extent and general characteristics

The fractured rock THA (Figure 3-1) is the most important aquifer over the southern portion of the Stuart Shelf, where it is the shallowest aquifer (albeit confined) or underlies a thin saturated sequence (less than 20 m) of ALA. Over much of the Andamooka 1:250 000 map sheet (Dalgarno, 1982) the THA occurs at depths of between 180 and 200 m below ground level. Beneath OD, the depth of this aquifer increases steeply to the north, west and south, with the base of the unit occurring at around -125 m AHD at the location of the existing underground workings (Figure 2-8).

The thickness of the THA is variable: although the Corraberra Sandstone is around 20 m thick, secondary porosity development in the lower Arcoona Quartzite can range from a few to tens of metres in thickness.

Groundwater flow in the THA is largely fracture-controlled, however primary porosity contributes useful degrees of permeability, possibly as a result of chemical weathering of the sandstone matrix. Around the SML, airlift yields during drilling typically range between 3 and 15 L/s and are consistently highest in the lower part of the aquifer (i.e. Corraberra Sandstone) where a higher density of fracturing and fissuring is apparent (see logs for PT-24 and PT5d in Figure 3-2). However, a high degree of anisotropy is evident in the collected hydraulic testing data where enhanced permeability (by at least an order of magnitude) is known to occur in fault zones. North of OD, however, where the THA occurs at depths of up to 400 m, the aquifer becomes noticeably less permeable with airlift yields of less than 1 L/s being typical (REM, 2007d, see RT-1 in Figure 3-2), possibly as a result of compressional effects on the aquifer skeleton.

The connectivity between the THA and the ALA is primarily constrained by the vertical permeability (Kv) of the Arcoona aquitard (Figure 3-1). Analysis of pumping test data shows that Kv can be an order of magnitude lower than the horizontal permeability (Kh), or less (REM, 2007b).

Well yields and aquifer hydraulic parameters

Highest airlift yields reported for THA wells in the SML and immediate environs are associated with geological structure (inferred faults, Figure 3-3). However, as there is no obvious dislocation of the surface cover or rock units in this area the high yields may be associated with brittle fracturing of the sandstone matrix of the THA. Whilst, aquifer potential appears enhanced in association with the Mashers Fault feature (with airlift yields ranging between 10 and 15 L/s), the aquifer is spatially extensive, albeit heterogeneous (REM, 2007b). Depending on location, production wells (200 mm DN cased) can sustain pumping rates of between 3 and 16 L/s.

The THA behaves as a well connected system with connectivity increased locally by structure through the Arcoona Quartzite. There are insufficient data, however, to ascertain whether secondary porosity associated with Mashers Fault is typical of structurally disrupted corridors within the region, although pumping tests conducted within the Mashers Fault zone shows the aquifer has a leaky bounded response to pumping that is consistent with a strip aquifer response, whereas elsewhere the unit responds in a more homogeneous manner (REM, 2007b). The vughy nature of the THA observed in some drill cores suggests chemical weathering may have occurred and contributes to the relative ‘homogeneity’ that exists away from structural controls such as Mashers Fault.

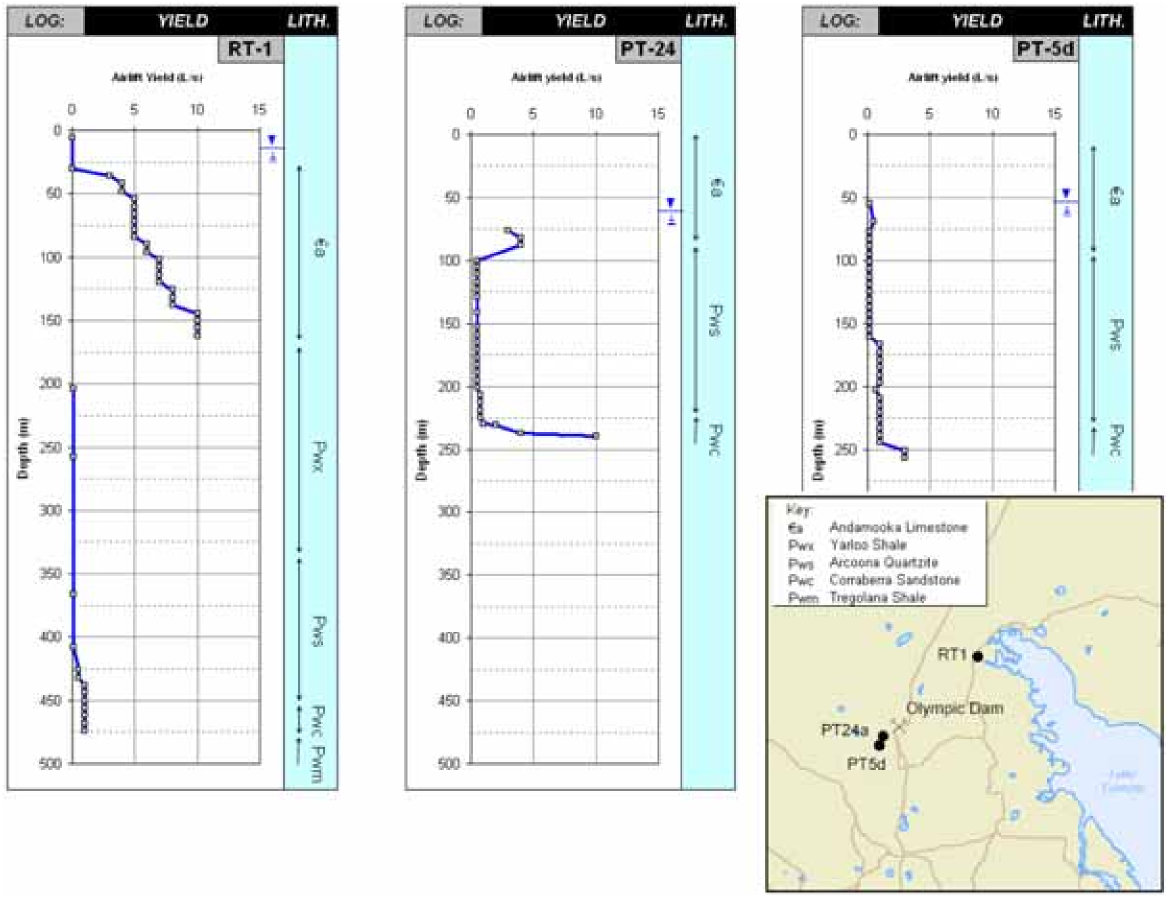


Figure 3-2 Airlift yield and lithological logs for selected drilling sites

Kellett et al (1999) reports that the hydraulic conductivity (K) of unfractured and fractured zones within the THA vary by as much as three orders of magnitude. For example, REM (2007b) and WMC (2007) present the results of aquifer testing conducted in 2007 where THA hydraulic conductivity values are estimated to range between 10^{-2} and 20 m/day (equating to tramsmissivities of between 1 and 640 m^2/day; with higher values associated with the Mashers Fault zone), Kinhill (1997) reports hydraulic conductivity values in the range 10^{-3} to 1 m/day, whilst earlier testing indicates hydraulic conductivities range between $1x10^{-3}$ and 2 m/day (AGC, 1982). Storativity estimates derived from field testing range between $4x10^{-5}$ and $6x10^{-3}$ (REM 2007b, and WMC 2007).

Analysis of pumping tests data using analytical solutions presented in Clark (1988) shows that:

- Where fracturing is well developed, THA response to pumping is consistent with what might be expected of a semi-bounded leaky strip aquifer having transmissivities of up to 900 m2/day (see results for well TPW-1; Figure 3-4).
- Away from structurally controlled fractured rock ‘strip’ aquifers, the THA responds to pumping in a manner more consistent with a leaky confined, semi-bounded uniform porous media (see results for wells TPW-2 and 3; Figure 3-4). TPW-2 test data show the presence of a significant recharge boundary (fracture) very close to the pumping well.

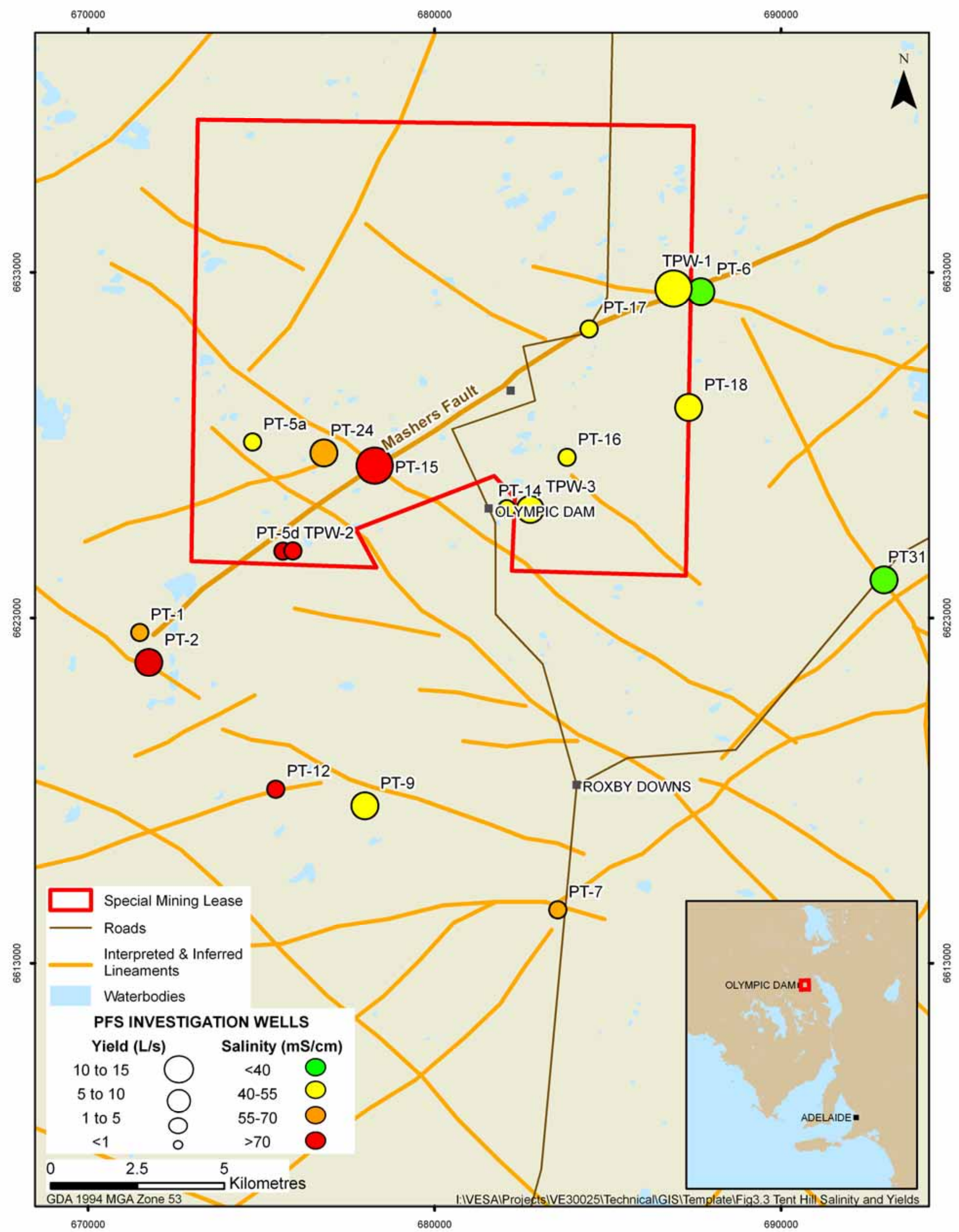


Figure 3-3 Tent Hill Aquifer Airlift yields and salinity

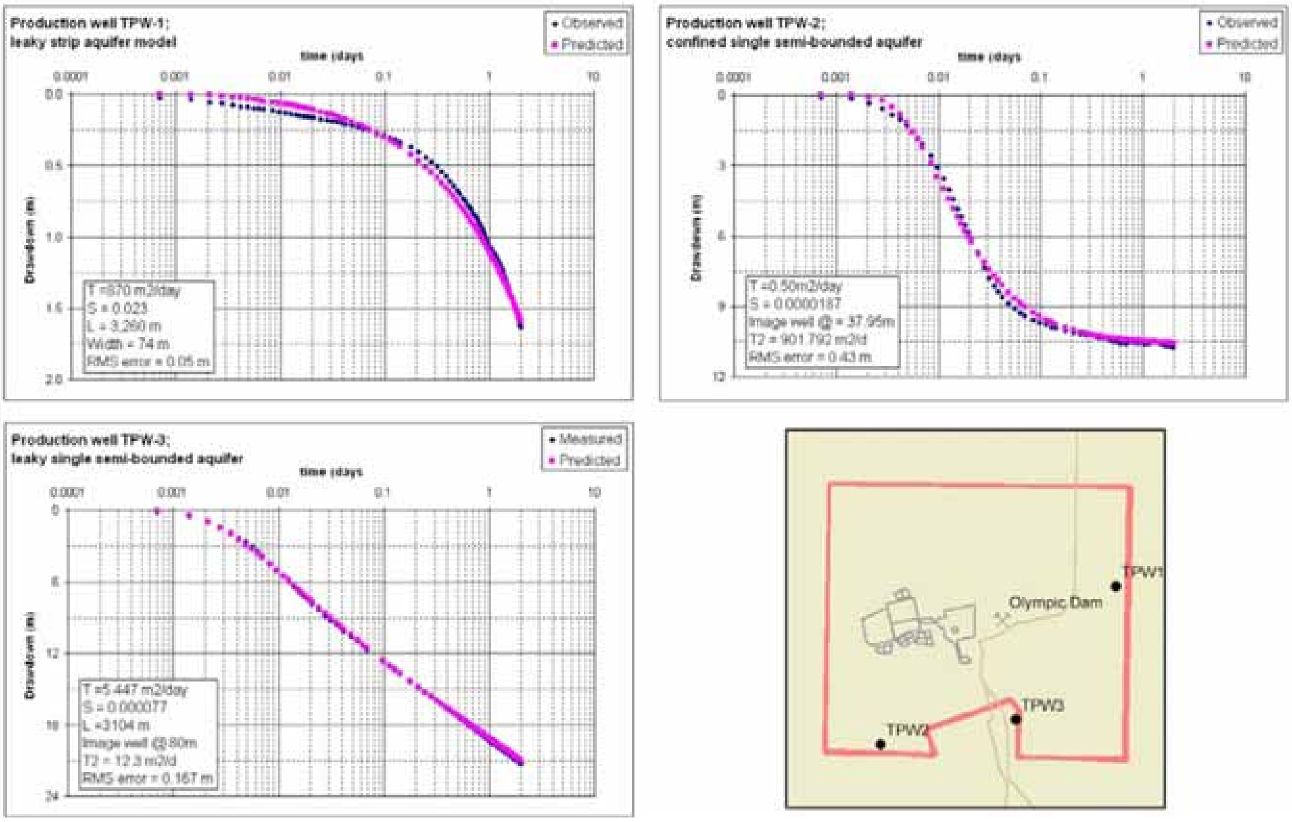


Figure 3-4 Groundwater flow models developed from test pumping the THA

3.2.3 Groundwater quality

As shown in Figure 3-3, regional THA groundwater salinity concentrations are high, typically ranging up to 75,000 mg/L (REM, 2007). Immediately west of the Andamooka Range, Golder (1995) reports salinities ranging between 20,000 and 40,000 mg/L. Closer to Lake Torrens, THA aquifer salinity has been observed to range up to more than 100,000 mg/L (REM, 2007b).

This spatially variability is consistent with observed aquifer heterogeneity and possibly is the result of evaporative concentration beneath playa lakes, and very low recharge rates. The range of groundwater salinities is attributed to : (i) variable transmissivity (and residence time) of the THA; (ii) fracture and rock matrix porosity, where the rock matrix likely hosts higher salinity water than do the fractures due to the sedentary nature of water held within primary porosity, a concept consistent with observations made in the Clare Valley of South Australia (Love, 2004), and (iii) variable recharge rates, where areas of higher recharge correlate with decreased salinity (for example along watersheds).

The pH of THA groundwater is generally slightly alkaline (between 7 and 8). Detailed laboratory analyses have been recently conducted on groundwater samples from over 30 wells installed in the THA in and around the SML (REM, 2007a, 2007b, 2007c, 2007d). The ionic signature of the THA waters is consistently sodium chloride dominated.

Analyses of several trace metals indicate low concentrations for the majority of wells. Uranium concentrations in THA groundwaters sampled from beneath the SML and regionally in the Lake Torrens are typically below 0.01 mg/L, although levels as high as 0.03 mg/L have been detected.

Arcoona Quartzite/Yarloo Shale aquitard

In the OD area, and for some distance north, the upper Arcoona Quartzite acts as a low permeability aquitard that separates the THA from the shallower ALA (Figure 2-5, Figure 2-6 and Figure 3-1). The aquitard ranges in thickness up to 120 m Further north of OD, the Yarloo Shale overlies the Arcoona Quartzite, further confining the THA (Figure 2-5 and Figure 2-6).

Analysis of pumping test data provides estimates of vertical hydraulic conductivity of the Arcoona aquitard of around $5x10^{-3}$ m/day (REM, 2007b).

Andamooka Limestone Aquifer (ALA)

Extent and general characteristics

The Andamooka Limestone (Figure 2-9 and Figure 3-1), where saturated, is the shallowest of the Stuart Shelf aquifers, and is generally analogous to the water table aquifer around OD. The water table typically occurs at depths of greater than 50 m in the area of OD. However, nearer to Lake Torrens the water table lies less than 10 m below ground level (bgl), consistent with Lake Torrens being the major regional Stuart Shelf groundwater discharge feature (Golder, 1998).

The ALA dips and thickens toward the north and east of OD where it becomes confined below the Palaeozoic (Sturt Shelf) Yarra Wurta Shale and the Mesozoic Bulldog Shale (the youngest member of the Eromanga Basin suite of sediments). South of OD, the extent and saturated thickness of the ALA is variable, because the base of the Andamooka Limestone rises above present day water table elevations in some areas.

Acoustic televiewer imagery (ATV) collected from four investigation sites located along a north-south transect through the northern section of the ALA, identified major fracture zones (mostly horizontal) at irregular depths, with a predominant dip direction to the north and north-east (REM, 2008b). The ATV data also identified clear dissolution features (vughs), particularly towards the base of the Andamooka Limestone. The ATV data supports evidence arising from extensive drilling and pumping test programs that permeability within the ALA is dominated by secondary porosity associated with fracturing and dissolution of the limestone matrix (REM, 2007d, 2008b). Figure 3-2, for example, shows sharp increases in groundwater yields with depth in the ALA at
RT-1.

Well yields and aquifer hydraulic parameters

The majority of drillholes intersecting the ALA in the area north of OD report large airlift yields during drilling typically in excess of 15 L/s (Figure 3-5). Aquifer pumping and injection tests conducted at six test sites in the northeast section of the ALA (REM, 2007d, 2008b) indicate that the ALA is a highly transmissive (100 to 4000 m^2/day), leaky confined aquifer with storativities ranging from 10^{-4} to 10^{-2}.

The transmissivity of the ALA decreases considerably toward OD, as suggested by drilling airlift yields shown in Figure 3-5, largely as a result of reduced saturated thickness. Testing around the immediate OD mine area has provided estimates of transmissivities ranging between 4 to 120 m^2/day and storage coefficients ranging between $8x10^{-5}$ and $2x10^{-2}$ (Woodward-Clyde, 1995), which is consistent with more recent results (REM 2008b). The significant difference in estimates of transmissivity around the SML compared with further north, is attributed to the fact that groundwater is typically intersected in the basal crystalline dolomitic unit of the Andamooka Limestone. Around the SML, solution features (observed in core samples) occur in the unsaturated portion of the limestone unit.

Although, at a local scale, the ALA appears to be heterogeneous with irregular transmissivity due to its karst nature and variable saturated thickness, on a regional scale the aquifer can be considered reasonably isotropic due to the extensive development of karst.

Groundwater quality

Regional groundwater salinity within the ALA typically ranges between 20,000 and 60,000 mg/L (REM, 2006), but closer to Lake Torrens groundwater salinity has been observed to range up to around 200,000 mg/L (REM, 2008b; refer Figure 3-5 and Figure 3-6).

The high salinities are primarily the result of the evaporative concentration of salts prior to recharge occurring as well as following discharge of groundwater to Lake Torrens sediments (with subsequent brine displacement from beneath the lake). The relationship of EC to depth in the ALA shown for RT-1 in Figure 3-2, provides an example of the salinity (density) inversion occurring towards the base of the limestone aquifer west of Lake Torrens. It is unclear how far west this deep ‘wedge’ of hypersaline water extends, however it has been detected in investigation wells installed by BHP-Billiton (PT48, PT50 and PT51, Figure 3-5) located roughly 30 km from Lake Torrens (REM, 2008b).

The pH of the ALA within the SML is neutral to slightly acidic. To the north of OD, it becomes slightly alkaline. Acidity is generally an order of magnitude lower than alkalinity, as expected given the calcareous nature of the aquifer host rock (i.e. limestone). Major ion water quality data for the northern section of the ALA indicates that there is a distinct speciation between groundwaters sampled from the deep and shallow parts of the aquifer (REM, 2008b). Shallower groundwater was found to have relatively higher concentrations of calcium and sulfate.

Uranium concentrations in regional groundwaters sampled from over 30 wells in the ALA typically range between 0.01 and 0.02 mg/L (REM, 2007b, 2007c, 2007d, 2008b), and a representative of background levels.

3.2.4 Groundwater processes

The groundwater catchment for the Stuart Shelf groundwater flow system (GFS) extends south of Woomera and west into the geological Arckaringa Basin (Figure 2-2). It is bounded to the north by the GAB GFS (both artesian and non-artesian) and to the east by Lake Torrens.

Groundwater level contours constructed from groundwater levels gauged in wells and drillholes that intersect a number of hydrostratigraphic units (presented in Appendix K2) have been used to interpret groundwater flow paths across the Stuart Shelf. In general terms, the GFS is comprised of the following (interconnected) groundwater systems:

(i) Arckaringa Basin sediments to the west of OD (confined Boorthanna aquifer);

(ii) Adelaide Geosyncline rocks to the north and east of the Torrens Hinge Zone (unconfined-confined aquifers);

(iii) Andamooka Limestone in the immediate area north of OD and south of the Torrens Hinge Zone, extending to Lake Torrens in the east (water table aquifer); and

(iv) Tent Hill Formation rocks (confined THA aquifer and Arcoona aquitard) south of OD.

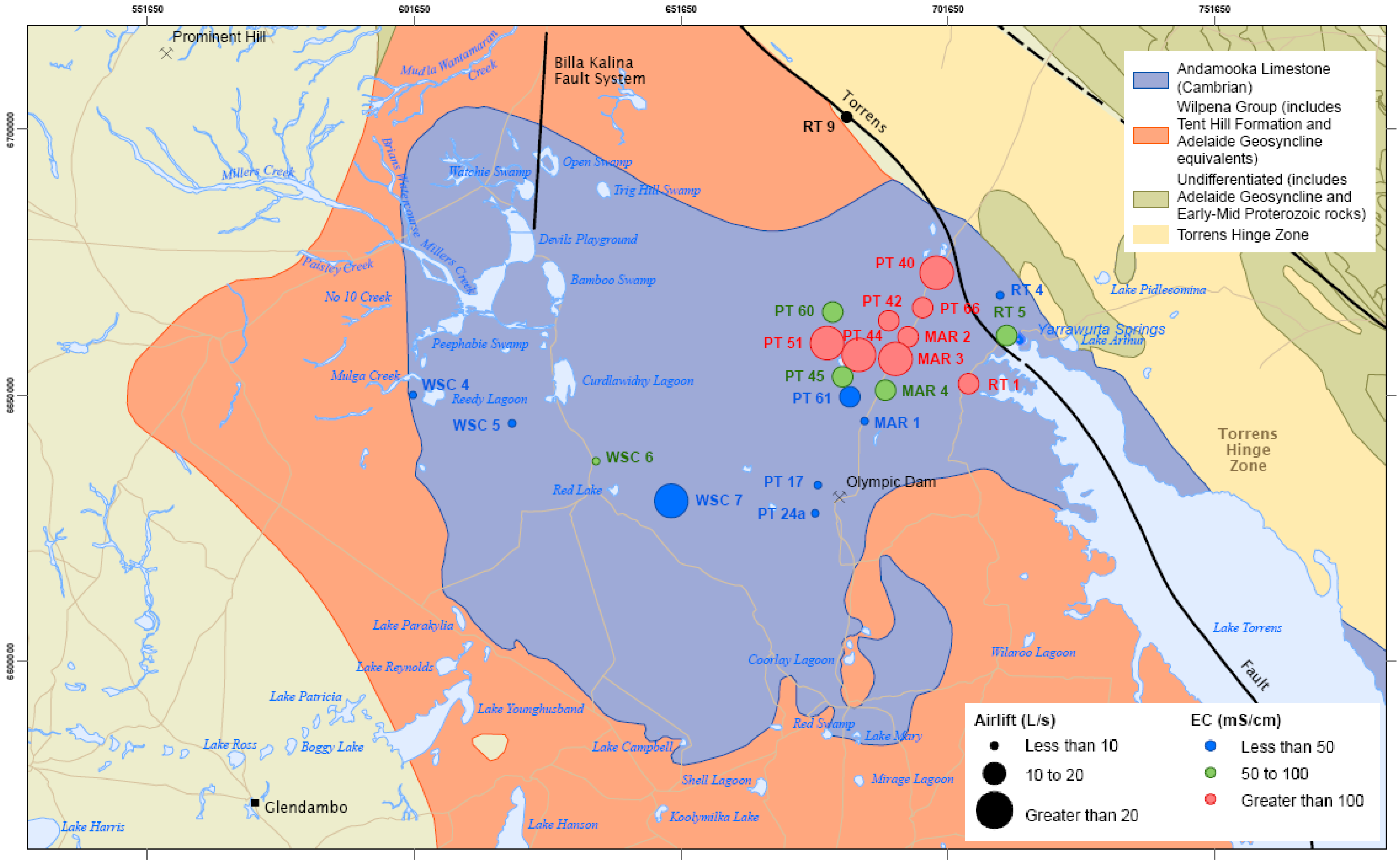


Figure 3-5 Andamooka Limestone Aquifer airlift yields and salinity

rem SKM

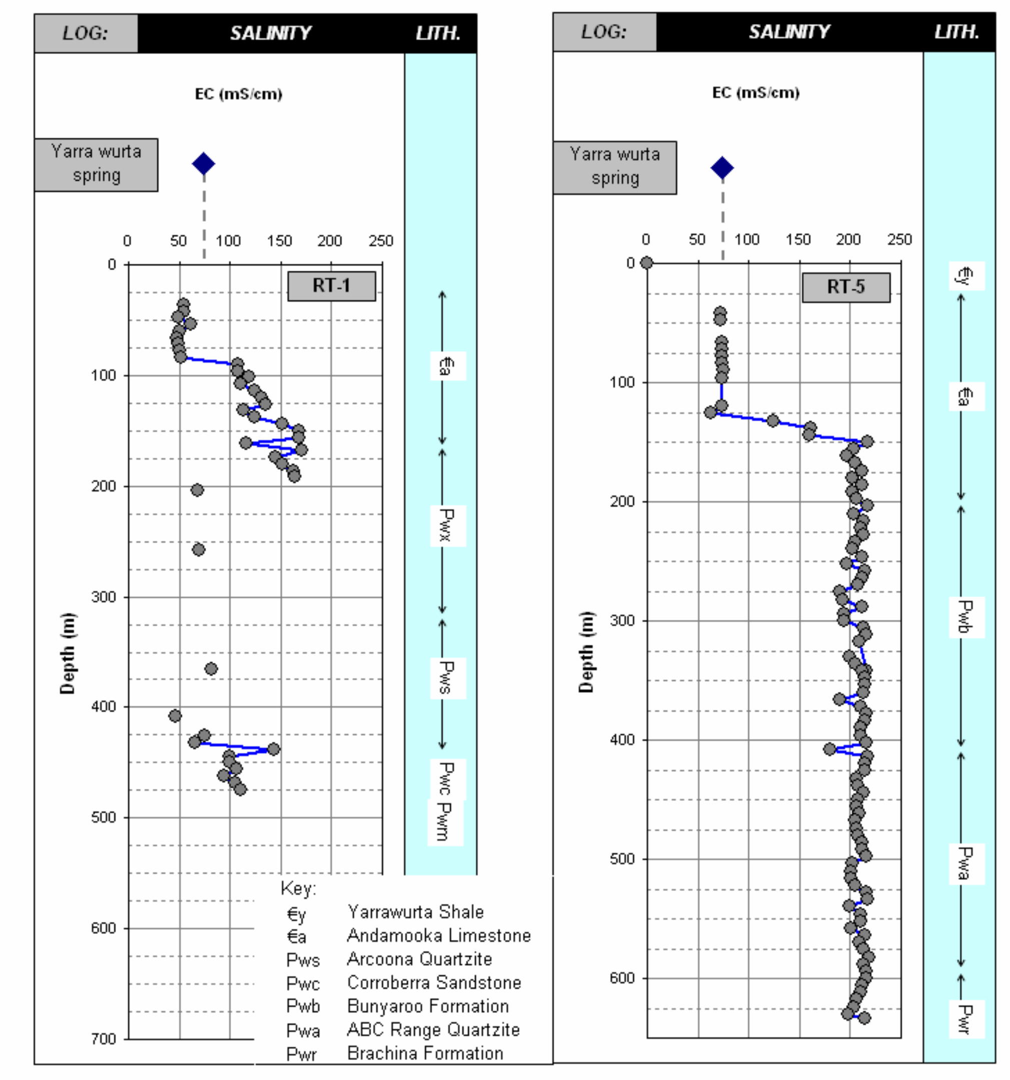


Figure 3-6 Salinity and airlift yield profile at site RT-1 and RT-5.

Non-artesian Eromanga aquifers in the west and northwest of the area shown in Figure 3-7 are not expected to be an integral part of the regional GFS, as groundwater is interpreted to predominantly flow toward low lying topography to the north from where it discharges via evaporation (Howe et al, 2008).

The essential elements of the Stuart Shelf GFS shown on Figure 3-7 can be summarised as follows:

1. *Lateral flow patterns*

The interpreted groundwater flow directions presented in Figure 3-7 strongly indicate that groundwater in the Stuart Shelf GFS generally moves towards the northern end of Lake Torrens from where it discharges via evaporative processes.

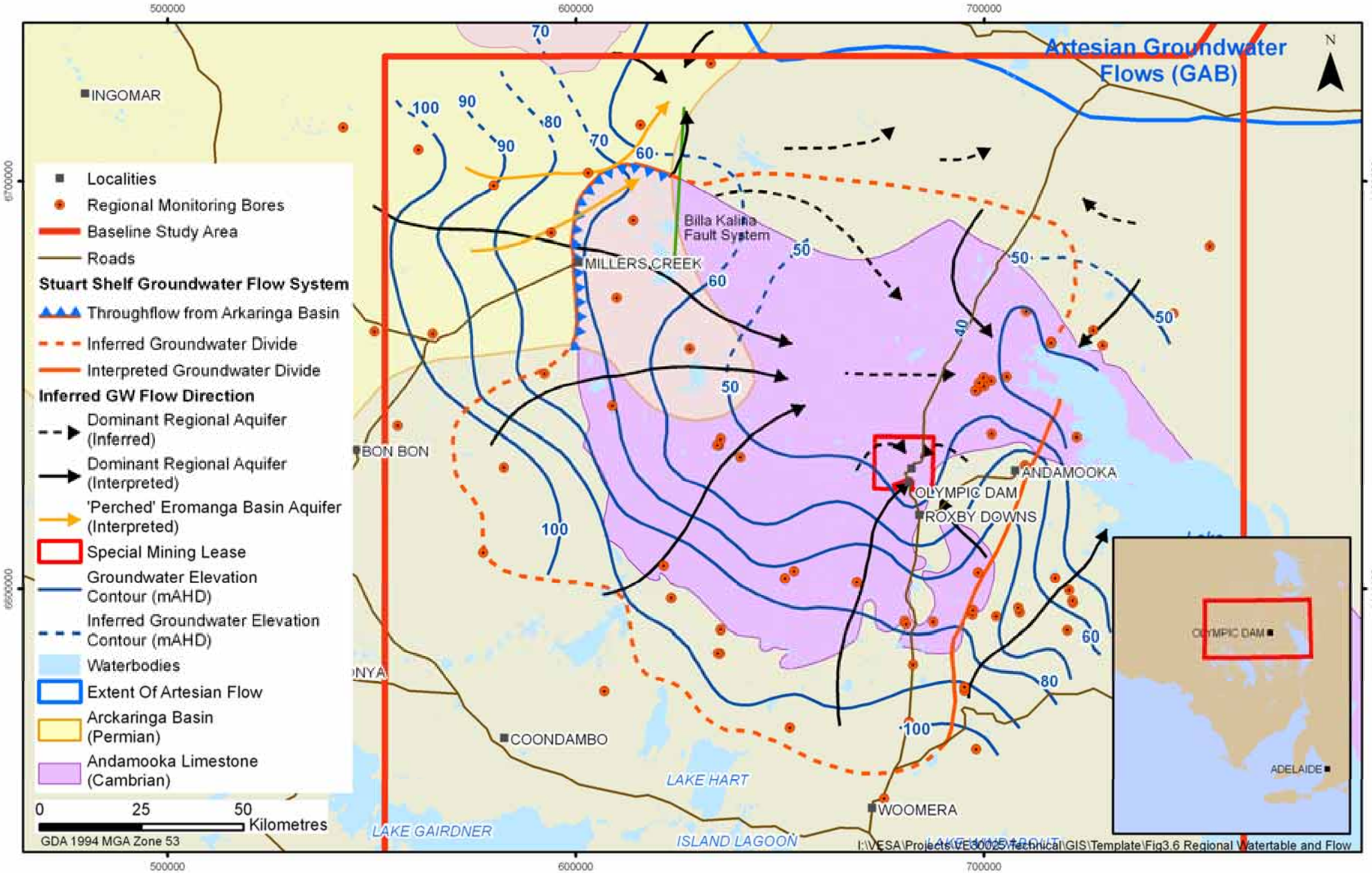


Figure 3-7 Interpreted water table contour plan and groundwater flow directions for the Study Area

Very low hydraulic gradients in the area of the groundwater catchment dominated by the ALA (immediately north of OD; Figure 3-7) are the result of high aquifer transmissivity and not evaporative losses (as the regional water table is too deep for this to be an important discharge mechanism). This observation is supported by aquifer testing conducted in this area during 2007 (REM, 2008b).

High ALA transmissivity suggests the potential for large volumes of water to be moving through the Stuart Shelf GFS. However, effective transmissivity of the ALA is likely to be reduced from the measured by the presence of brine in the lower parts of the aquifer beneath and adjacent to Lake Torrens (REM, 2008b).

Relatively steep hydraulic gradients occur within the groundwater systems to the south and west of OD, suggesting low permeability rocks and sediments (and possibly boundary faults) occur in those areas.

2. Groundwater divides

A subtle groundwater divide is evident in the southeast of the area shown on Figure 3-7, consistent with the Andamooka Ranges and the eastern surface water catchment divide (Figure 2-11), which appears to separate the regional GFS from a more local one largely restricted to the western shore of Lake Torrens. Waterhouse et al (2002) suggest that structure within the Arcoona Quartzite associated with the Pernatty Upwarp (REM-Golder, 2005), leading to compartmentalisation and anisotropy, could be a controlling feature of this groundwater divide.

An inferred groundwater divide that is probably consistent with the alignment of the Torrens Hinge Zone exists to the north of OD:

- Groundwater to the north of the divide flows toward the low lying salinised topography associated with the GAB springs, where it discharges via diffuse seepage and evaporation. Salinity concentrations and a lack of hydraulic head suggests it, is very unlikely this flowfield supports the GAB springs (REM, 2007c), consistent with the conclusions of Kellet at al. (1999), Golder (1995) and Waterhouse et al (2003).

- South of this divide, groundwater flows toward Lake Torrens from where it discharges via evaporation.

Data presented by Kellet et al (1999) indicate the existence of a groundwater divide (aligned approximately with the Stuart Highway) that separates the northern part of the Stuart Shelf and Gawler Craton from the southern parts. Large salt lakes are common to the south of this divide (e.g. Pernatty Lagoon and Lake Gaidner). Unlike the surface water catchment of Lake Torrens, which is isolated from the internally draining Stuart Shelf/Gawler Craton catchment (Figure 2-11), the groundwater catchment of the northern part of the Stuart Shelf is connected to Lake Torrens but separated from the southern salt lake systems.

3. ALA and THA inter-connectivity

Density-corrected groundwater level data for nested monitoring sites on the OD SML indicate downward hydraulic gradients between the ALA and the THA, which are potentially contributed to by mine dewatering activities (REM 2007c). The extent of leakage between the THA and ALA in the vicinity of OD is dependent on the extent and degree of structural control.

Further north, the effective hydraulic connectivity between the ALA and the THA is likely to decrease due to the increased distribution of the Yarloo Shale and a lowering of permeability in the THA. It is likely that further north and west of Lake Torrens, the ALA is effectively isolated from THA.

4. Recharge mechanisms

Recharge areas for the Stuart Shelf aquifers occur to the south (Arcoona Plateau) and west (most likely from Arckaringa Basin sediments, (Howe et al, 2008)), as well as from diffuse rainfall recharge over the entire Stuart Shelf.

Due to the nature of the geology, soils and climate, rainfall recharge over much of the Stuart Shelf is expected to be very low (0.1 to 0.2mm/yr; Kellett et al, 1999, Golder 1995, and Waterhouse, 2003) by comparison with rainfall (more than 150 mm/yr) as a result of large evaporative losses prior to effective recharge occurring. Plant transpiration will also contribute to these 'evaporative' losses, but to what extent is uncertain. While very low rates of diffuse recharge occur across the Stuart Shelf and broader region, enhanced rates of recharge are likely to occur at terminal lakes that lie above the water table and possibly via dolines formed in the Andamooka Limestone.

5. Discharge mechanisms

Geological structure or the presence of Tertiary palaeochannel sediments along the present day alignment of Andamooka Creek (to the southeast of OD) appears to be a preferred groundwater discharge zone from the Arcoona Plateau.

Closer to Lake Torrens, vertical hydraulic gradients (density-corrected) are reversed with head potentials in deeper parts of the groundwater system being above ground level, which is around 40 mRL (Table 3-2). Salinity data collected during groundwater investigations conducted north of OD indicate brine formation near the base of the ALA nearer to Lake Torrens (see RT-1, Figure 3-2). The effect of these density gradients near Lake Torrens is that groundwater moving from the west of Lake Torrens will be forced to discharge into Lake Torrens sediments at relatively shallow depths, i.e. causing a decrease in the effective transmissivity of the ALA.

Table 3-2 Density corrected groundwater levels [1]

Investigation site	**RT-1[3]**		**RT-2[3]**		**RT-16[4]**		**RT-17[4]**	
Well name	**LR-10**	**RT-1**	**RT-2a**	**RT-2b**	**RT-16a**	**RT-16b**	**RT-17a**	**RT-17b**
Screen mid-point [2]	17.3	-424.0	-21.0	-110.1	-37.4	-101.6	29.6	-140.1
Water level [2]	38.5	102.5	40.4	47.0	43.5	36.6	49.1	35.9

Notes: 1. source: REM (2007c)
2. mRL, rounded to nearest 0.1 m
3. located north of OD
4. located in the vicinity of OD

Hydrogeochemical data and shallow groundwater flow patterns strongly suggest the source of the spring discharge from Yarra Wurta Springs is either the Amberoona Formation of the Adelaide Geosyncline (located to the east; REM, 2007b) or the ALA. The springs are a discharge mechanism for what is likely a local GFS. Brine beneath and adjacent Lake Torrens effectively presents a density barrier to groundwater discharge from the THA.

Preliminary water balance

A preliminary water balance calculation (assuming an effective ALA transmissivity of 2,000 m^2/day based on a 50% reduction (Figure 3-6 shows brine to occupy around half the ALA saturated profile at RT-5) in aquifer thickness at the Lake Torrens discharge zone due to occurrence of brine, and a hydraulic gradient of 0.0001) suggests that about 0.4 m^3/day groundwater discharges to the Lake Torrens groundwater basin per metre width of the discharge zone. Assuming a discharge zone of roughly 20km, the losses from the ALA to the Lake Torrens system could be in the order of 3,000 ML per year. Aquifers to the east of Lake Torrens, including those formed within Adelaide Geosyncline rocks and Torrens Basin sediments, are also likely to contribute a significant discharge flux to the Lake Torrens groundwater system, possibly supporting shallow saline springs around the northern and eastern margin of the Lake (e.g. the ecologically important Yarra Wurta Springs, Figure 2-11). Groundwater discharging to the Lake Torrens Basin is accommodated by diffuse evaporative discharge (Golder, 1995) or possibly via through flow to groundwater systems in the south.

3.3 Sedimentary aquifers on and adjacent the Stuart Shelf

3.3.1 Eromanga Basin

Description

The Mesozoic Cadna-owie Formation and Algebuckina Formation together form what is commonly known as the Eromanga aquifers. The aquifers are utilised widely for stockwater and domestic purposes.

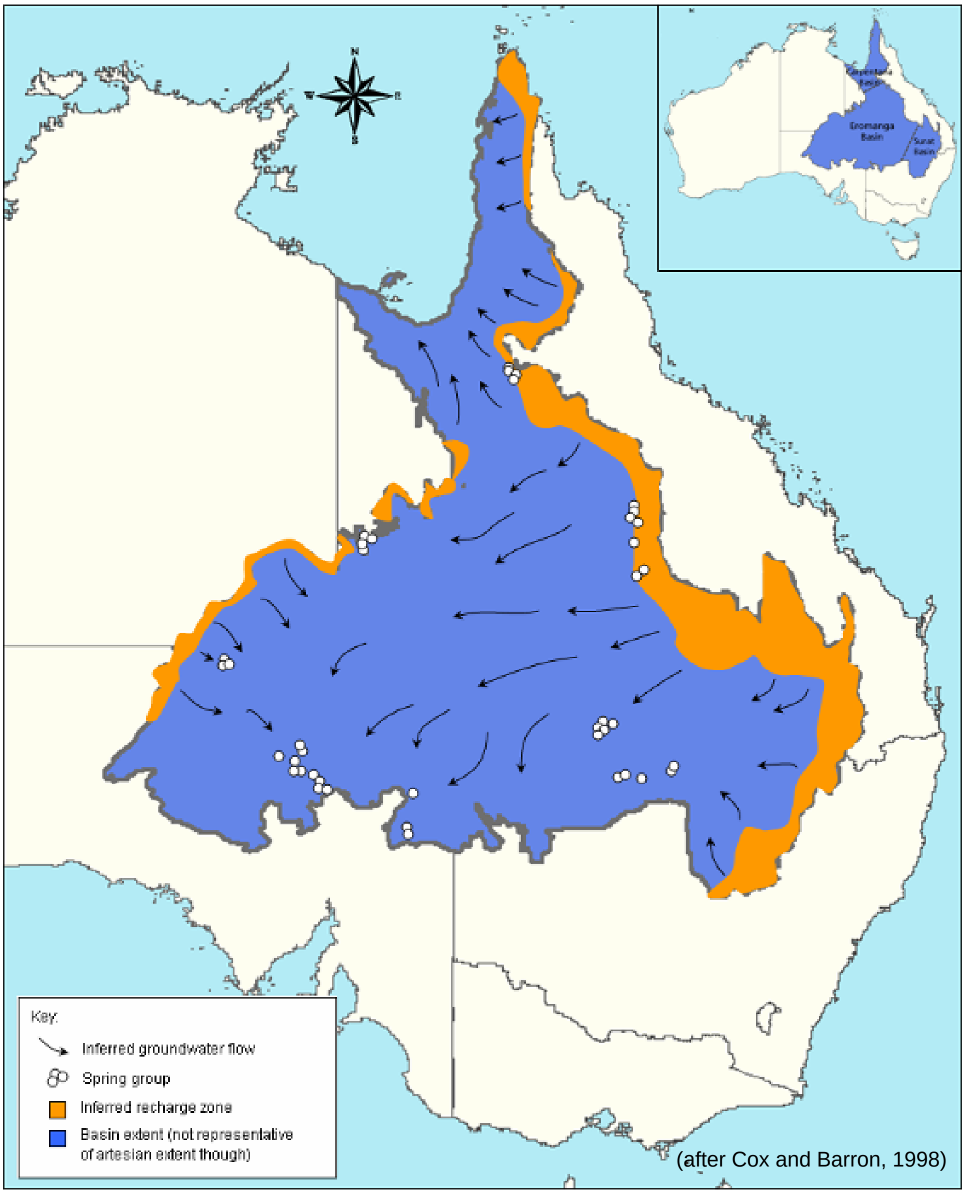
Approximately 100 km north of OD the Eromanga aquifers are artesian, i.e. their potentiometric surface lies above ground level.

Figure 3-8 shows the approximate westerly and southwesterly extent of artesian pressures in these aquifers, which are confined by the Bulldog Shale. For the purpose of this report these aquifers are referred to as the artesian Eromanga aquifers.

Further west and southwest of the artesian extent of artesian flows, the Eromanga aquifers become either sub-artesian (i.e. the potentiometric surface rises above the base of the confining Bulldog Shale but not to the ground surface) or form water table aquifers. For the purpose of this report these aquifers are referred to as the non-artesian Eromanga aquifers.

The hydraulic conductivity of non-artesian Eromanga aquifers ranges around 1 m/day, whilst the transmissivity of the confined artesian Eromanga aquifers typically ranges between 100 and more than 1,000 m2/day (Habermehl, 1980, WMC, 1997 and REM, 2005a).

The salinity of groundwater sourced from the artesian Eromanga aquifers ranges below 5,000 mg/L (Kinhill, 1997), whilst that sourced from the non-artesian Eromanga aquifers typically ranges above 5,000 mg/L (Howe et al., 2008).



(after Cox and Barron, 1998)

Figure 3-8 Plan showing the locality of the GAB, main recharge areas and discharge flow lines.

Groundwater processes

Artesian Eromanga aquifers

The artesian Eromanga aquifers are predominantly recharged along the eastern margins of the GAB (Figure 3-8), although recharge also occurs to both the artesian and non-artesian Eromanga aquifers around the western margins, where the Cadna-owie Formation or Algebuckina Sandstone outcrop or subcrop (Habermehl, various).

The artesian pressures observed in the artesian Eromanga aquifers are derived primarily from rainfall recharge along the Queensland portion of the Great Dividing Range, whilst groundwater production wells and the spring systems (located at the Basin periphery) act to release these pressures through the discharge of groundwater. Figure 3-9 presents a schematic showing this concept. Springs and diffuse upward leakage allow natural discharge to occur from the groundwater system, whilst production wells form an artificial discharge mechanism.

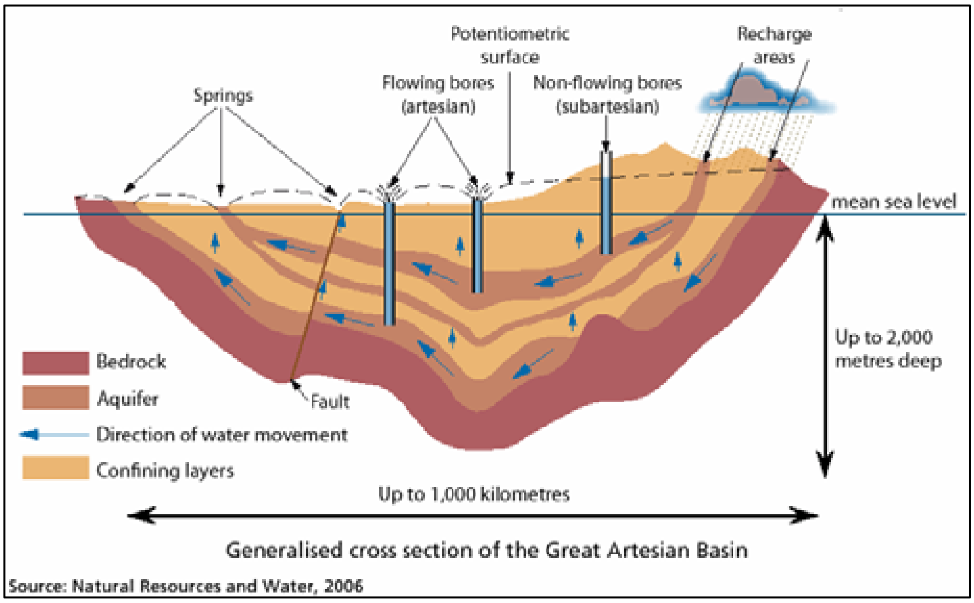


Figure 3-9 Schematic profile of the GAB showing recharge and discharge mechanisms

Water balance data presented in SAAL NRM Board (2006a) indicate, as at 2001, the average recharge rate for the entire GAB is in the order of 1,340 ML/day. Spring flows (discharges) are estimated to be around 5% of this figure (140 ML/day) and diffuse upward leakage and lateral flow account for another 45% (600 ML/day). However, when the 1,200 ML/day removed from the GAB by free flowing (artesian) and pumped (sub-artesian) wells is accounted for, it is evident that outflows exceed inflows by almost 45% (600 ML/day).

Figure 3-10 presents a comparison of the South Australian water balance outflow components for the GAB against those for the entire GAB. As shown, it is estimated by the SAAL NRM Board (2006a) that:

- spring flows and diffuse leakage in South Australia account for almost 50% of the total spring flow / diffuse leakage numbers for the entire GAB; and
- only around 10% (128 ML/day) of the total volumes of GAB groundwater lost to free flowing and pumped wells occurs in South Australia.

Non-artesian Eromanga aquifers

Non-artesian Eromanga aquifers of the western recharge zone of the Eromanga Basin appear to be largely recharged where they out-crop or sub-crop. Water table contours presented in Howe et al. (2008) show that groundwater in these aquifers, where they occur west of OD, very likely flows toward low lying (salinised) areas, such as that occurring along Margaret Creek in the northwest part of the area shown on Figure 3-7 (i.e. north of Millers Creek Homestead, see Figure 2-11), to discharge via diffuse seepage and evaporation.

Hydrogeochemical analyses of non-artesian Eromanga Basin aquifer groundwaters (REM, 2005b, Howe et al., 2008) strongly indicate that the water table aquifer in this area does not support GAB springs.

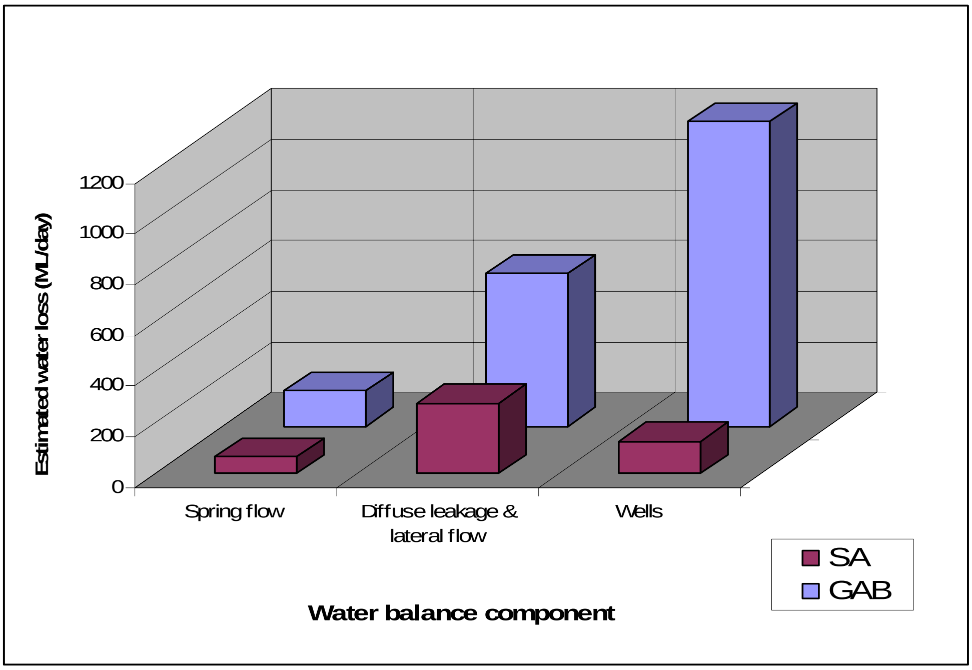


Figure 3-10 Comparison of outflow component of GAB water balance (South Australia vs. total)

Source: SAAL NRM Board 2006a

3.3.2 Arckaringa Basin

Description

The Arckaringa Basin on-laps Stuart Shelf rocks northwest of OD (Figure 2-2), where it underlies Eromanga Basin sediments. Historically, the Arckaringa Basin groundwater system has not been investigated in any detail, probably as a result of the ability to more easily develop groundwater supplies from the shallower non-artesian Eromanga aquifers (Cadna-owie Formation and Algebuckina Sandstone), and the absence of mining operations in the area west of OD. The SAAL NRM Board (2006a) identifies the Boorthanna Formation, the lowest unit of the sedimentary sequence, as possibly being the most important groundwater resource within the Arckaringa Basin.

Two recent studies provide some preliminary information concerning the nature of the groundwater systems of the Arckaringa Basin:

- Howe et al. (2008) – The Mount Toondina Formation, the shallowest unit of the Arckaringa Basin suite of sediments, is mostly absent south of the Boorthanna Fault (Figure 2-2) where the Boorthanna Formation forms an extensive confined aquifer. Groundwater level data for this area, which onlaps the Stuart Shelf, show that groundwater flows from the Arckaringa Basin groundwater system to the Stuart Shelf groundwater system. Reported Boorthanna aquifer transmissivities range up to 160 m^2/day (hydraulic conductivities of up to 2 m/day), storativities around $3x10^{-4}$ and groundwater salinity ranging from less than 10,000 mg/L to more than 30,000 mg/L.

- BHP (2005) – North of the Boorthanna Fault, the Mount Toondina aquifer occurs at relatively shallow depths and has possible hydraulic connection to overlying artesian Eromanga aquifers. A wide range of groundwater salinities are reported, mostly ranging above 5,000 mg/L. Estimates of hydraulic conductivity for this unit range around 3 m/day.

Groundwater processes

The Arckaringa Basin aquifers west of OD are sub-artesian. Drilling investigations and aquifer testing undertaken in support of the Prominent Hill Mine Project (Howe et al., 2008) show the Boorthanna aquifer has a potentiometric surface more than 5 m lower than the overlying non-artesian Eromanga aquifers. Groundwater surveys conducted in 2006 (see Appendix K2) provide data that strongly indicate groundwater from the Arckaringa Basin discharges to the Stuart Shelf (see Figure 3-7).

BHP (2005) identified the Mount Toondina Formation north of the Boorthanna Fault to be sub-artesian, with potentiometric surfaces ranging between around 10 and more than 30 m below ground level, depending on surface topography.

Hydrogeochemical analyses of Arckaringa Basin and groundwaters sourced from both artesian and non-artesian Eromanga aquifers (REM, 2005b) found Arckaringa Basin groundwater shares a similar hydrogeochemical signature to the non-artesian Eromanga aquifers of the western recharge zone, suggesting these aquifers are largely recharged where they out-crop or sub-crop within the western parts of the Eromanga Basin.

Groundwater flowlines interpreted from available groundwater level data (see Appendix K2) show Boorthanna aquifer forms an upstream component of the regional groundwater Stuart Shelf GFS.

3.3.3 Tertiary palaeochannels

Description

Various studies undertaken in the past (e.g. Martin et al, 1998) have shown that palaeochannel aquifers formed within the major palaeodrainages of the Gawler Craton present options for saline water supply development. The Challenger Gold Mine, which is located approximately 100 km south of Coober Pedy in the western part of the Gawler Craton, sources its mine water supply from such an aquifer.

Groundwater processes

The Andamooka Palaeochannel, which is associated with the modern day Andamooka Creek drainage, crosses the Study Area (Johns, 1968 and Waterhouse et al, 2003) south of Roxby Downs but is not well mapped. Geophysical surveys, including a recent airborne gravity survey undertaken by BHP Billiton, have delineated a distinctive low response feature running in a hook-shape from Andamooka Creek to the southeast for about 30 km, which may be a palaeochannel (or remnant). Relatively low groundwater salinity recorded in THA wells in the vicinity of the Andamooka Palaeochannel (less than 11 mS/cm EC; Appendix K2), suggest Tertiary aquifers contain low salinity groundwater that may be recharging the regional fractured rock groundwater system.

It is recognised that palaeochannel reaches occurring down gradient of large playa lakes, such as Lakes Younghusband and Gairdner on the Kingoonya Palaeochannel, will likely yield hypersaline (greater than 35,000 mg/L) groundwater, as has been shown during water supply development work conducted in support of the realignment of Stuart Highway (Read, 1981).

3.4 Infrastructure corridors

3.4.1 Southern Corridor

Description

General

Apart from a small number of documented water supply development studies, principally for road and rail construction works and the Kellet et al. (1999) study, there has been little work undertaken to collate information relating to the groundwater resources along and adjacent the Southern Infrastructure Corridor. Most water supply development that has taken place has been in relation to stock water supply and these remain largely undocumented, apart from well logs where they are available from State Government agencies.

Groundwater along the Southern Infrastructure Corridor is mainly characterized by fractured rock aquifer systems, such as the Proterozoic rocks comprising of (youngest to oldest) the Tent Hill Formation, the Whyalla Sandstone and the Pandurra Formation, where they occur. The occurrence of groundwater and the potential for developing useful groundwater supplies along most of the infrastructure alignment will mostly be constrained by the degree of secondary porosity existing within the host rocks.

Groundwater salinity

The spatial distribution of groundwater salinity (as total dissolved solids; TDS), sourced from a selection of groundwater sampling points located along the Southern Infrastructure Corridor (REM, 2006), is shown on Figure 3-11. As shown, and based on the limited available data, groundwater tends to be saline to hypersaline with the majority of sampling locations reporting salinities in excess of 5,000 mg/L. Kellet et al. (1999) presents a series of plans showing that groundwater salinity along the central and northern parts of the corridor typically exceeds 7,000 mg/L.

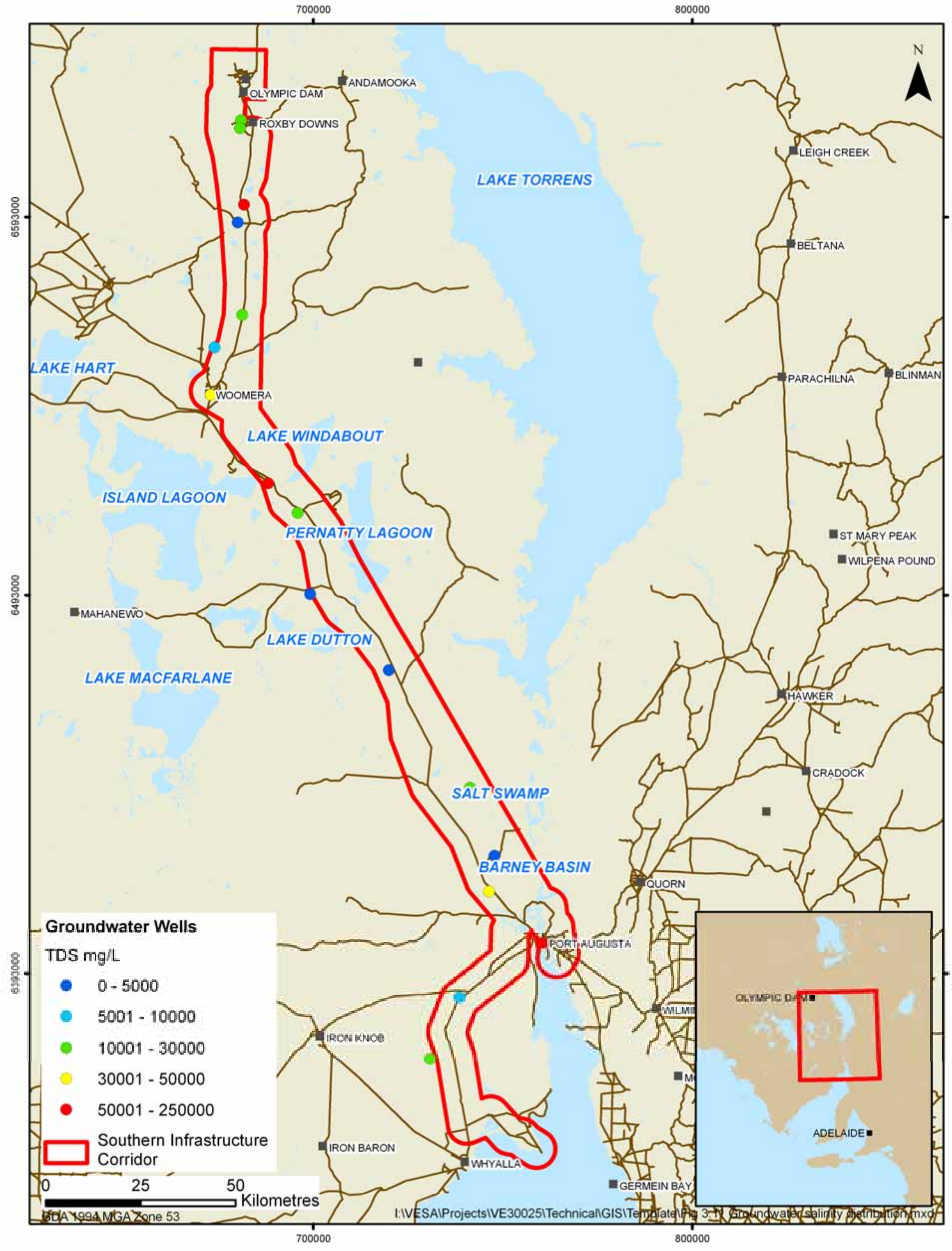


Figure 3-11 Groundwater salinity distribution – Southern Infrastructure Corridor

Low salinity groundwater (less than 5,000 mg/L) is unlikely to be widely occurring along the Southern Infrastructure Corridor, although the baseline groundwater survey conducted in 2006 (REM, 2006) shows some locations (possibly associated with Gawler Range Volcanics) where water quality of this salinity is found. Other sources of low salinity groundwater are likely to be associated with localised recharge, for example within weathered zones on basement highs or along creek lines where stream bed infiltration takes place during sporadic flow events.

In general:

- groundwater quality nearer and beneath the regional groundwater discharge features ranges from saline (more than 5,000 mg/L) to hypersaline (more than 50,000 mg/L), due to the evaporative concentration of salts prior to recharge and at discharge areas;
- the salinity of groundwater sourced from the Arcoona Quartzite is typically around 20,000 mg/L;
- the salinity of groundwater sourced from the Yudnapinna Beds, Tapley Hill and Pandurra Formations ranges between 20,000 and 50,000 mg/L; and
- brines can be expected to occur beneath most of the larger salt lake systems of the Stuart Shelf/Gawler Craton, where groundwater salinities of more than 150,000 mg/L have been recorded by Pacminex (1979) and Read and Beal (1988).

Coastal aquifers associated with dune sands possibly occur on the eastern side of the Southern Infrastructure Corridor between Whyalla and Port Augusta, but are unlikely to represent anything other than local groundwater flow systems.

Hydraulic parameters

A number of investigations have been conducted along the alignment of the Stuart Highway for the purpose of establishing road construction water supplies (Read, 1986, and Read and Beal, 1988). Testing of the THA in the area between Roxby Downs and Lake Windabout reported pumping yields ranging from less than 0.25 to 4 L/s, with estimates of transmissivity ranging from 3 to 45 m^2/day for those locations where pumping could be sustained. The Whyalla Sandstone has reported pumping yields of less than 1 and up to 2.5 L/s, with estimates of transmissivity ranging from 1 to 2.6 m^2/day. One well, located southeast of Pimba, which is interpreted as intersecting the Pandurra Formation, reported pumping yields of 8.5 L/s and an estimated transmissivity of 45 m^2/day.

In the area of Woomera and Pimba, the Woomera Shale has been described by Read (1986) as having low permeability except where intense fracturing has occurred.

Groundwater processes

As discussed in Section 3.2.3, recharge over most sections of the Southern Infrastructure Corridor is expected to be very low. Kellet et al (1999) presented estimates of recharge for areas north of Woomera to around mid-way between Woomera and Port Augusta as ranging from 0.1 to 0.2 mm/yr, respectively.

Martin et al (1998) suggest that 'fresh' (stockwater quality) groundwater typically occurs within weathered basement highs or in Quaternary sediments that support high recharge rates, and that palaeochannel aquifers, whilst representing reasonable supply targets, typically yield saline groundwater.

As discussed in Section 3.2.3, a groundwater divide separates the northern part of the Stuart Shelf and Gawler Craton from the southern parts of the Study Area. South of the divide, groundwater movement is dominated by large saline lake systems, e.g. Lakes Gairdner and Edward, and Island Lagoon (SAAL NRM Board, 2006b). Closer to Port Augusta and Whyalla, the groundwater catchments are likely to be closely aligned with surface water catchments (Figure 2-11), with groundwater discharging toward Spencer Gulf.

3.4.2 Northern Corridor

Description

General

Groundwater occurrence and flow in the area along the Northern Infrastructure (gas pipeline) Corridor is characterized according to particular geological provinces. There may be occasions, however, where shallow Quaternary sediments may form useful low yielding aquifers irrespective of the underlying geology.

The Stuart Shelf groundwater flow system has been previously described (Section 3.2). Where the Stuart Shelf becomes absent to the north of Lake Torrens, shallow groundwater occurrence is dominated by the typically artesian Eromanga aquifers. Additionally, thin discrete aquifers are a common occurrence within the overlying Bulldog Shale unit. Where the artesian Eromanga aquifers outcrop or sub-crop south and east of Lake Eyre South (Figure 2-5, Figure 2-14 and Figure 2-15), groundwater discharges via the numerous ecologically and culturally significant GAB spring systems.

Further northeast of the GAB spring systems, where the Eromanga Basin deepens and is overlain by the Lake Eyre Basin, the Tertiary Eyre Formation (and where present in the northern parts of the gas pipeline corridor, the overlying Namba Formation) hosts shallow but useful aquifers, and the artesian Eromanga aquifers become deeply buried.

Groundwater salinity

Low salinity shallow groundwater within Quaternary sediments (less than 5,000 mg/L) is unlikely to be widely occurring along the Northern Infrastructure Corridor, particularly in the southern parts. Where better quality groundwater does occur, it is likely to be associated with localised recharge along creek lines.

The spatial distribution of groundwater salinity (as total dissolved solids; TDS) from drillhole records located along the gas pipeline Infrastructure Corridor (source: SAGeodatabase) is shown on Figure 3-12.

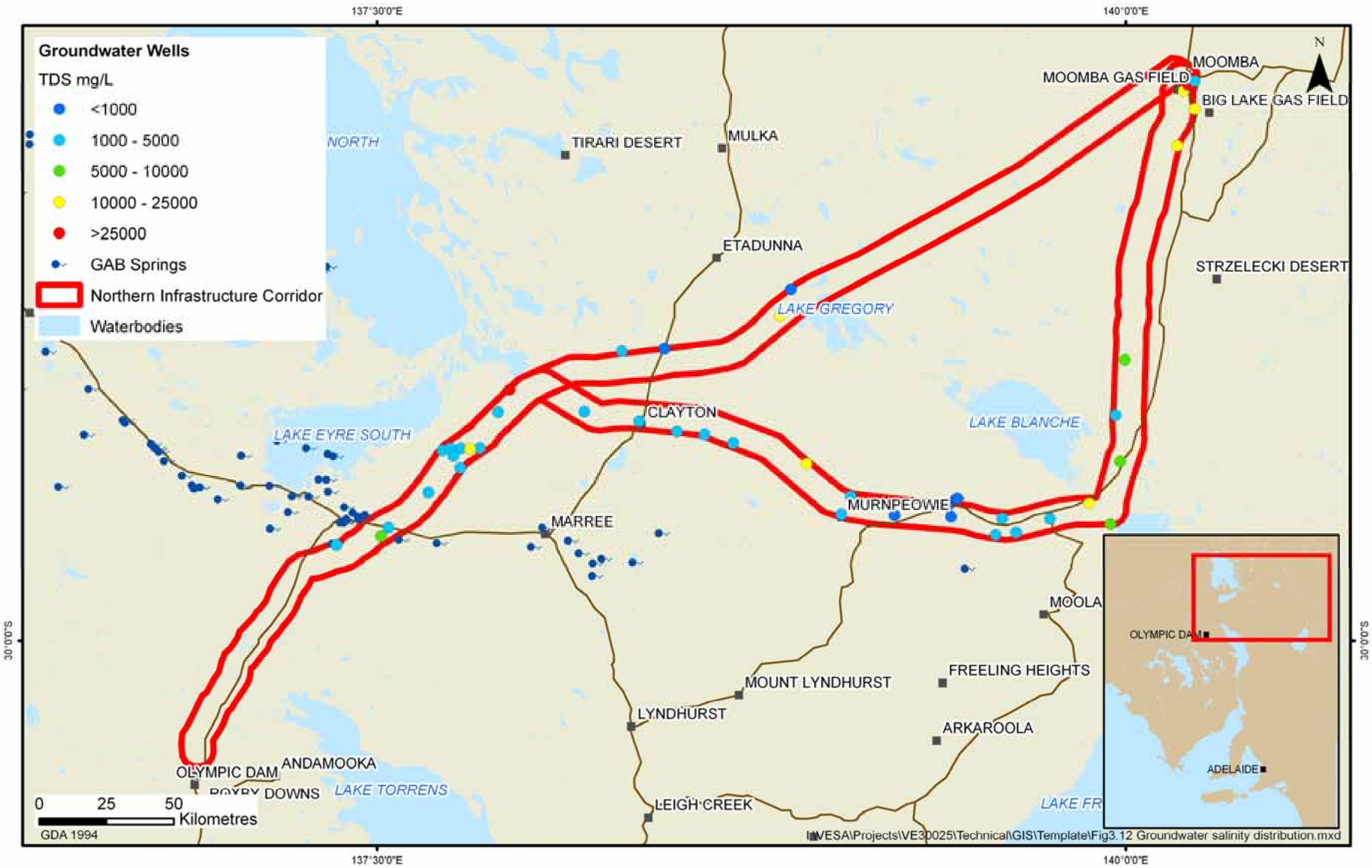


Figure 3-12 Groundwater salinity distribution – Northern Infrastructure Corridor

In general:

- within the basal Mesozoic aquifers of the GAB (Cadna-owie Formation and Algebuckina Sandstone), groundwater salinity ranges from less than 1,000 to 2,500 mg/L;
- groundwater in Tertiary aquifers (Namba Formation and Eyre Formation) to the northeast of the Study Area ranges from fresh to hypersaline, ranging from 1,000 to 34,000 mg/L; and
- in the north-east of the Study Area, isolated pockets of fresh (less than 1,000 mg/L) groundwater exist in aquifers hosted by quaternary sediments, most likely adjacent to intermittently flowing watercourses draining to Lake Eyre.

Hydraulic parameters

The characteristics of the Stuart Shelf aquifers have been documented in Section 3.2. In the central and northeastern parts of the gas pipeline corridor extensive groundwater investigations of the artesian Eromanga aquifers have been historically undertaken and are summarized in Section 3.3.

Due to relatively little exploitation as a groundwater resource, hydraulic parameters for the Tertiary Eyre and Namba Formations are largely unknown along the gas pipeline corridor. However, southeast of the Study Area, aquifer testing of the Eyre Formation aquifer has provided estimates of aquifer transmissivity ranging between around 40 and 1,800 m^2/day.

Groundwater processes

Recharge and discharge mechanisms for the artesian Eromanga aquifers have been discussed in Section 3.3.2. However, due to the nature of the geology, soils and climate, rainfall recharge over most sections of the gas pipeline corridor are expected to be very low. Kellet et al (1999) presented estimates of recharge for the southwestern portion of the corridor alignment of around 0.1 mm/yr.

The Tertiary aquifers (i.e. in the Eyre and Namba Formations) that overlie the GAB sediments north of the Torrens Hinge Zone (Figure 2-14 to Figure 2-16) are not as extensive as the GAB groundwater system. The Eyre and Namba Formations are recharged both by upward leakage from the deeper (pressurised) artesian Eromanga aquifers and rainfall infiltration. Enhanced recharge to the shallower Tertiary aquifers possibly occurs along creeklines and lakebeds, especially during episodic flood events. Discharge from the Tertiary aquifers is expected to primarily occur to saline lake systems such as Lake Eyre or the numerous smaller lakes that populate the corridor alignment, and (possibly) to the larger semi-permanent creeklines such as Coopers Creek.

4 CONCEPTUAL HYDROGEOLOGICAL MODEL OF THE STUART SHELF REGION

4.1 Regional flow system interconnectivity

Figure 4-1 presents a plan view of the Study Area showing recharge and discharge features of the area, as well as inferred groundwater flow directions. In summary:

- The Stuart Shelf GFS is non-artesian. It receives diffuse rainfall recharge as well as groundwater throughflow from other (upstream) groundwater systems to the west and southwest of OD, particularly the Arckaringa Basin, where groundwater likely moves from northwest of the Peake-Dennison Inliers along structural corridors (troughs and faults) to merge with groundwater moving from further west (Howe et al, 2008). Some watercourses and freshwater swamps (creek floodouts) form important recharge areas, as shown on Figure 4-1. Groundwater discharge to the south and southwest may also occur via Tertiary palaeochannels.

- The Stuart Shelf GFS possibly supports the ecologically important Yarra Wurta Spring complex, which occurs at the northern end of Lake Torrens on the eastern side of the Torrens Fault. Although, hydrogeochemical data and groundwater elevation contours strongly suggest that groundwater moving from Adelaide Geosyncline aquifers also support the spring complex.

- The artesian Eromanga (GAB) GFS is recharged along the Great Dividing Range of Australia's eastern seaboard and around the Northern Territory-South Australian border (Habermehl, 1980), both of which are located outside the area presented in Figure 4-1. Groundwater moves from the recharge areas to converge on the southwestern extent of the artesian Eromanga Basin, to discharge either via the ecologically significant GAB springs or as diffuse evaporative losses from low lying areas.

The GAB (or artesian Eromanga Basin) GFS is considered hydraulically separate from the Stuart Shelf GFS for a number of reasons:

- A combination of low lying topography and shallow water tables between the Stuart Shelf and GAB GFSs gives rise to a groundwater discharge (evaporation) divide that diminishes any effective interconnectivity. Groundwater levels across this divide would have to be significantly altered for effective interconnectivity to occur, and only then via very low permeability Adelaide Geosyncline rocks.

- Geological and structural controls associated with the Torrens Hinge Zone separate the artesian Eromanga aquifers from the Stuart Shelf aquifers.

- Major ion hydrogeochemical data (see Figure 4-2) show the composition of groundwater from the GAB (as sampled from springs) differs significantly from groundwater sampled from the Stuart Shelf GFS and bounding flow systems (Arckaringa Basin and Adelaide Geosyncline).

- Isotope data (chloride-36; see Figure 4-3) also shows the distinction between Stuart Shelf Arckaringa Basin and artesian GAB groundwaters.

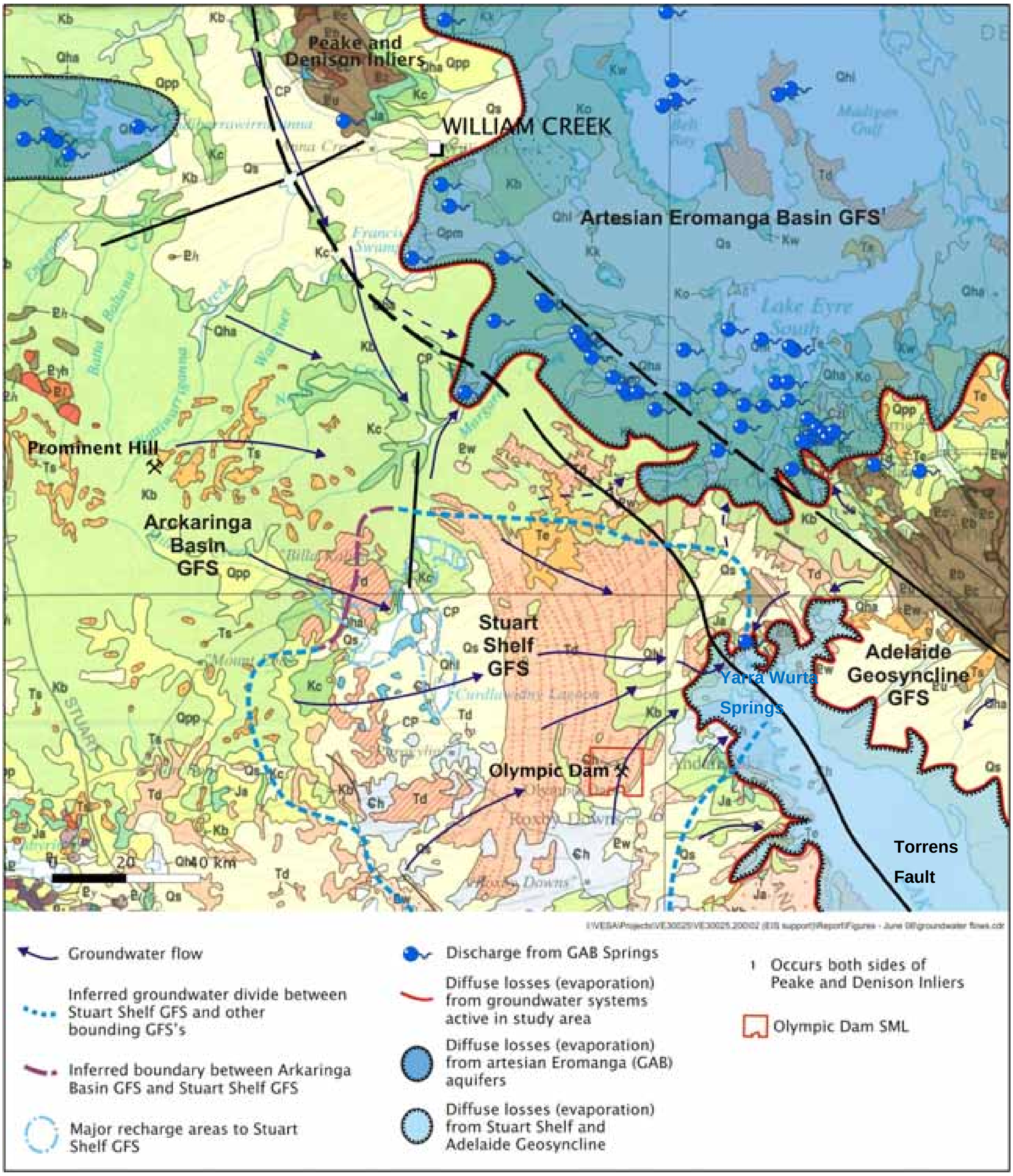
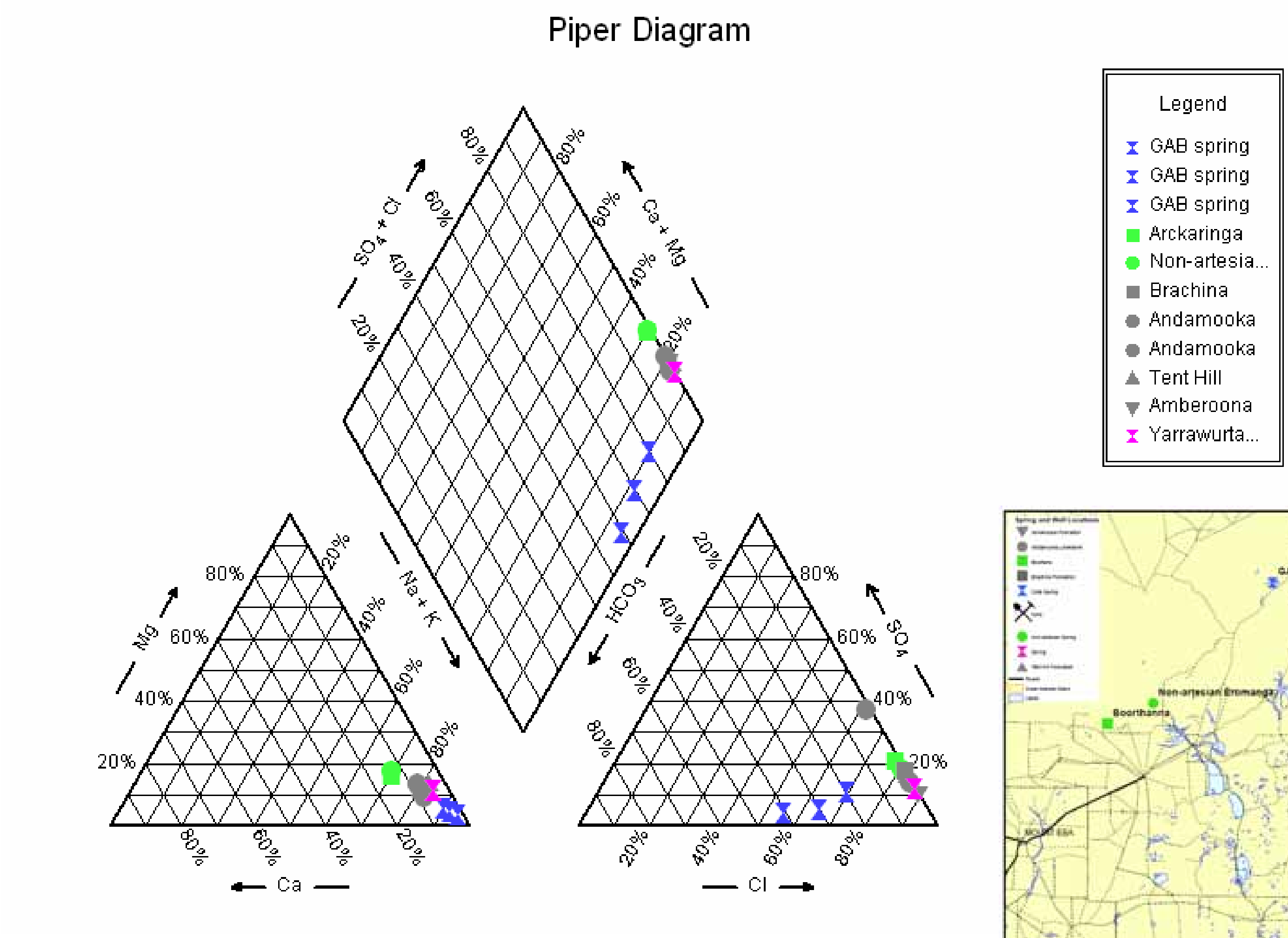


Figure 4-1 Recharge and diffuse groundwater discharge in the northern Stuart Shelf

Figure 4-2
Piper Plot for Stuart Shelf aquifers and surrounding groundwater systems



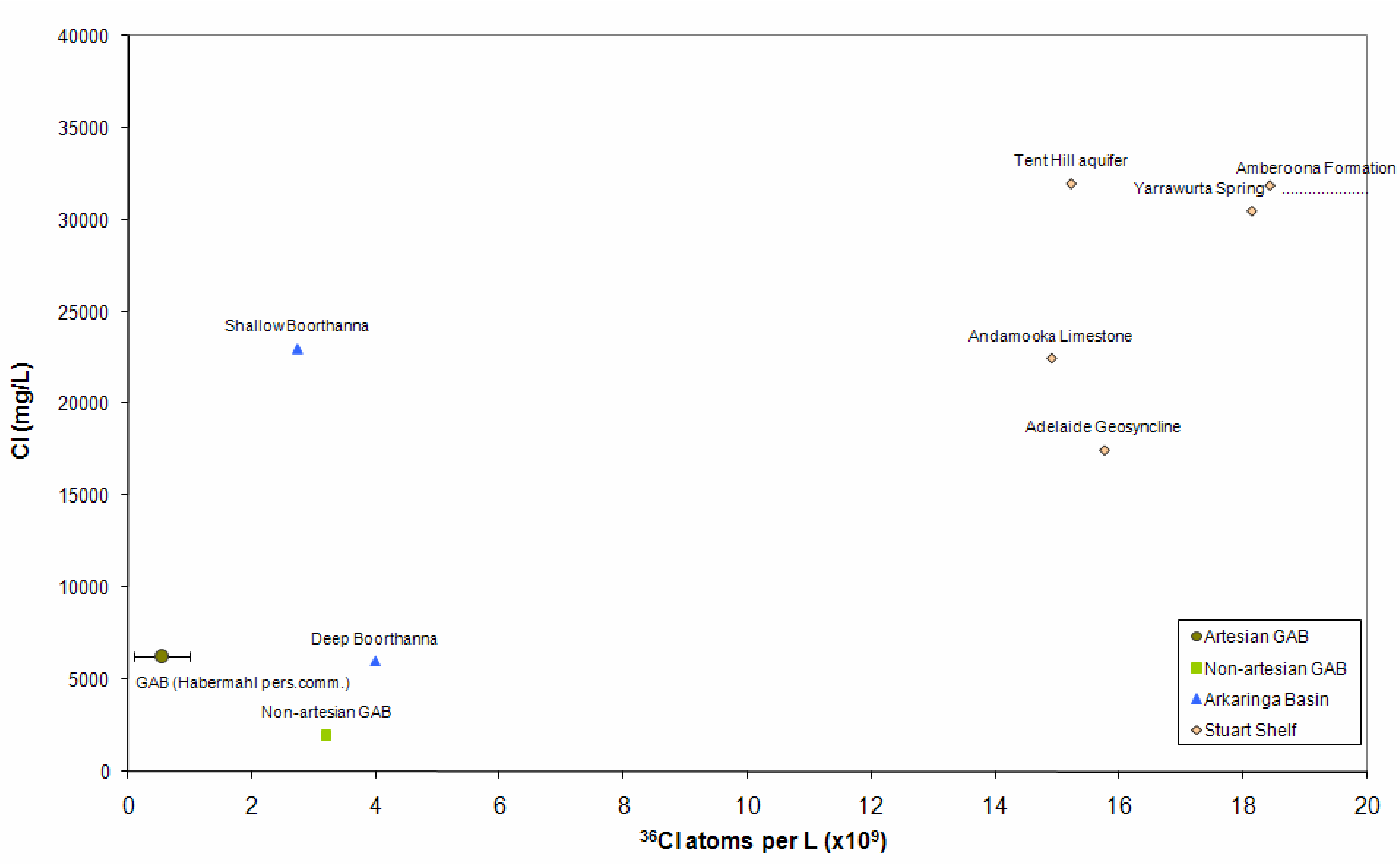


Figure 4-3
Isotope data
(^{36}Cl) for Study
Area
groundwater

4.2 Stuart Shelf groundwater processes

Groundwater flow on the Stuart Shelf is dominated by the ALA to the north and the THA to the south. ALA permeability and yield is largely associated with karst features, while THA permeability is largely associated with brittle fracturing. A significant increase in groundwater salinity occurs in the ALA to the north of OD at depths below 200 m, and at greater depths beneath the SML in the THA. Aquifer connectivity between the ALA and the underlying THA is dependent upon the degree of leakage induced from vertical faulting and vertical flow gradients and, to the north of OD, by the presence of intervening confining shales.

Surface water catchments of the Study Area typically terminate at large salt lakes, salt pans and ‘swamps’, and surface water outflow from these catchments does not normally occur. Evaporative losses from low-lying salt lakes and shallow water tables form the greater component of water losses from the Study Area, hence the elevated salinity concentrations observed in groundwater right across the area.

Lake Torrens is one of the more important groundwater ‘sinks’ of the broader region (Figure 4-1 and Figure 4-4 present this concept), as well as a surface water ‘sink’ at those times when rainfall is sufficient to generate significant run-off into the Lake, principally from the Flinders Ranges. The evaporative discharge of water from Lake Torrens has caused salinity stratification (and brine formation) near and beneath Lake Torrens (REM, 2007a, Figure 3-6). The presence of brine very likely causes regional groundwater flowing toward Lake Torrens to discharge predominantly into the shallower lake sediments under density controlled gradients.

Because of the density stratification of groundwater beneath Lake Torrens, it is considered very unlikely that THA groundwater supports Yarra Wurta Springs. However, it is possible that shallow groundwater moving from Adelaide Geosyncline rocks toward Lake Torrens supports some or all of the springs’ environmental flows (Figure 4-3 shows Amberoona groundwater and Yarra Wurta Spring water are most similar). ALA waters may also contribute to spring discharge.

Groundwater outflow from the Stuart Shelf / Torrens Basin groundwater system is not expected to form a large component of the regional water budget, if at all. Digital elevation models of the region between the southern tip of Lake Torrens and Port Augusta suggest groundwater might discharge along structural corridors or palaeochannel aquifers extending through to Gulf St Vincent (REM, 2007b).

4.3 Conceptual hydrogeological model

To place the proposed expansion of OD into context, an understanding of the interactions between groundwater systems, and groundwater and surface water systems is required at a regional-scale. Based on the information presented in this report, Figure 4-4 presents a schematic hydrogeological cross-section that describes the essential elements of the regional conceptual hydrogeological model, particularly in relation to the Stuart Shelf and GAB GFSs. Importantly:

① A (subtle) groundwater divide formed within low permeability Adelaide Geosyncline rocks separates the Stuart Shelf GFS and GAB GFS;

② Evaporative loss of shallow groundwater at the margins of each GFS is an important groundwater discharge process, causing salinisation of shallow and deep soil profiles and groundwater. Brine beneath Lake Torrens causes 'fresher' hypersaline groundwater to discharge to shallow lake sediments.

③ Spring discharges supported by flow from the eastern recharge areas are also a loss mechanism for the GAB GFS, but these springs are not supported by Stuart Shelf groundwater.

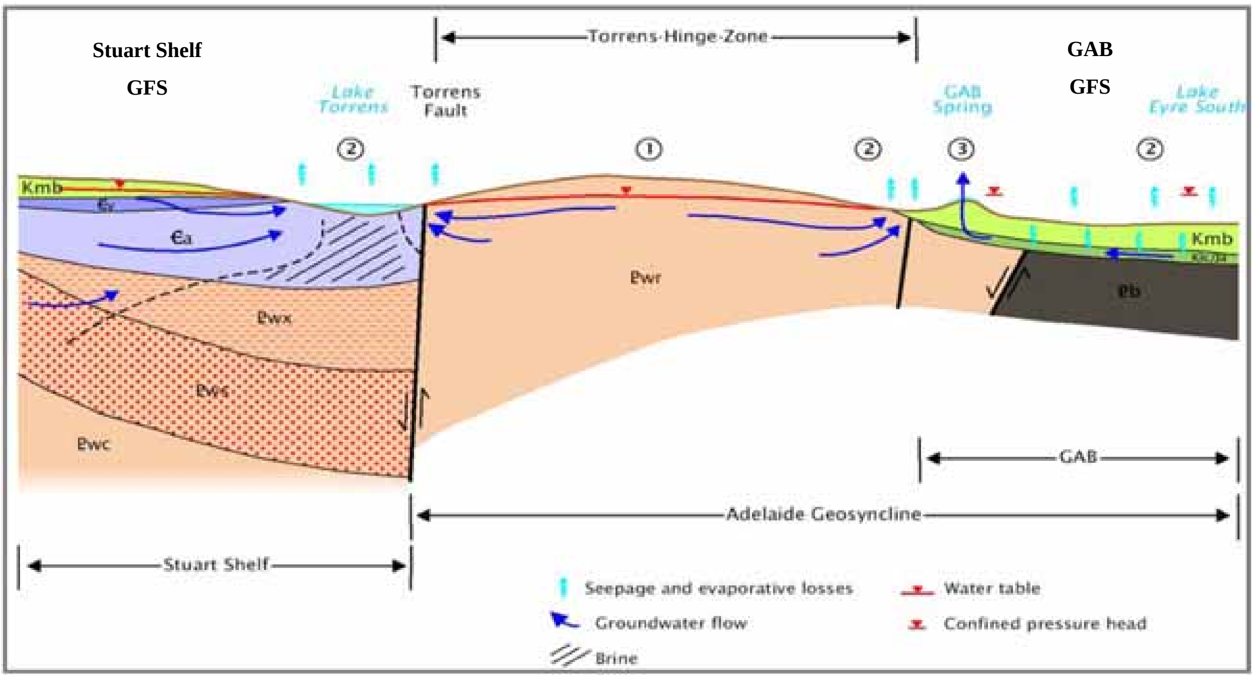


Figure 4-4 Conceptual model of Stuart Shelf and artesian Eromanga Basin GFSs

The lack of demonstrated connectivity between the Stuart Shelf and GAB GFSs strongly suggests that ODX will not impact adversely on the artesian GAB.

5 GROUNDWATER USERS

5.1 Stuart Shelf and adjacent sedimentary basins

5.1.1 Third party users

The main third party water users accessing Stuart Shelf groundwater resources are pastoralists (for stock and domestic supply). Further afield, the Arckaringa Basin, and the non-artesian and artesian (GAB) Eromanga Basins are also used for pastoral supply as well as for mining, energy, town, industrial, tourism, road maintenance and bore-fed wetland supply.

Figure 5-1 presents a map showing the locations of pastoral stations located on the Stuart Shelf and broader Gawler Craton. Based on a recent pastoralist survey, average groundwater use for the different pastoral properties presented is around 0.5 ML/day for a total water use of around 5 ML/day. Apart from two wells on the Billa Kalina pastoral lease, the majority of pastoral water supplies shown on Figure 5-1 is sourced from either non-artesian Eromanga aquifers or fractured rock aquifers. The available data indicate that the Boorthanna aquifer is not generally utilised for pastoral water supply, possibly because of required drilling depths.

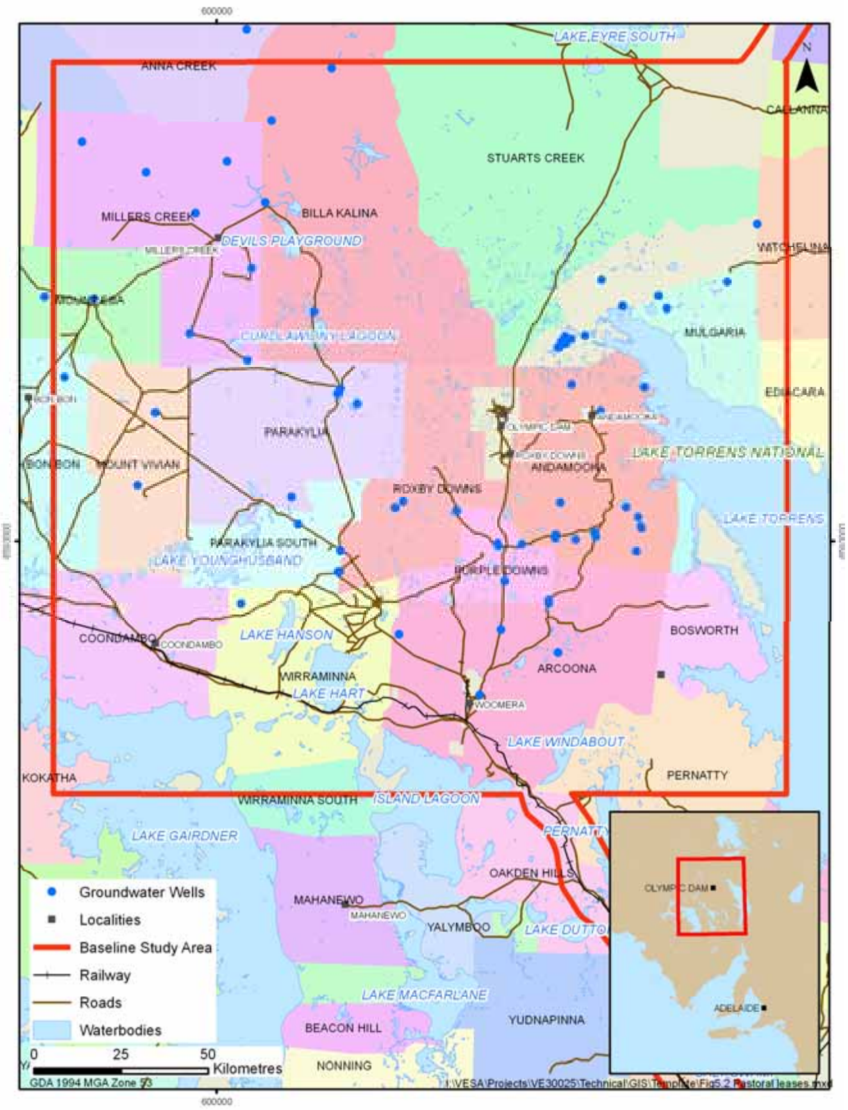


Figure 5-1 Pastoral stations and water wells located in Baseline Study Area around OD

Based on a comprehensive assessment of South Australia's portion of the GAB for the purpose of developing the Far North Water Allocation Plan, the South Australian Arid Lands Natural Resources Management Board (SAAL NRMB) has determined that 350 ML/day is available for use by third parties, such as pastoralists, miners and energy producers, communities and tourism. Currently, around 128 ML/day has been taken up for third party use, including the existing OD mine water supply. Importantly, in terms of continued operation of BHP Billiton's water supplies currently drawn from Wellfields A and B (Figure 5-2; averaging around 34 ML/day for the 2005-06 reporting period), the Southwest Spring (Groundwater Management) Zone of the Far North Prescribed Wells Area (FNPWA) has an indicative threshold of 170 ML/day.

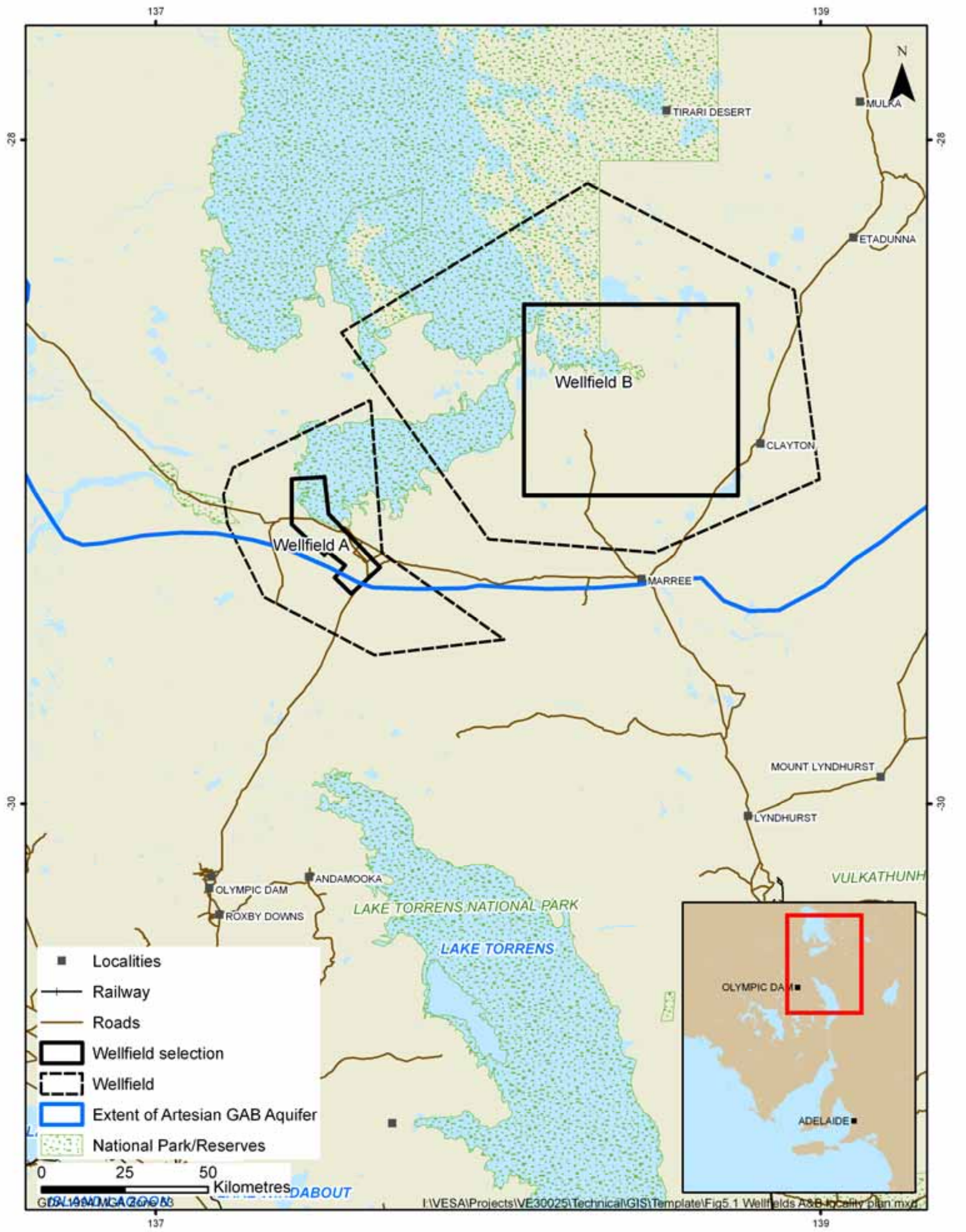


Figure 5-2 Wellfields A and B locality plan

Third party water use from the artesian Eromanga aquifers as at 2003 was in the order of 123 ML/day, including stock and domestic supplies, mining and energy (including oil and gas, and geothermal power), bore fed wetlands, town use, tourism and road maintenance (SAAL NRM Board, 2006a). Of this total:

- stock and domestic supplies account for around 50 ML/day;
- mining and energy supplies account for around 51 ML/day (including OD's existing water supply);
- town, industrial, tourism and road maintenance supplies account for slightly more than 5 ML/day; and
- bore fed wetlands account for around 12 ML/day.

Data presented by SAAL NRM Board (2006a) suggests that the long-term water demand for stock and domestic water supplies sourced from the artesian aquifers of the GAB will decline over time to average around 33.5 ML/day.

5.1.2 Environmental receptors

Groundwater sometimes forms an important water source for meeting the environmental water requirements (EWRs) of ecosystems in South Australia's Far North. Not all ecosystems, however, will be dependent on, or interact, with groundwater, and some ecosystems that do interact with groundwater may only have a facultative form of dependence. For example:

- the ephemeral wetland ecosystems of the Lower Cooper Creek and Coongie Lakes rely on surface water inundation following large flooding events to meet their EWRs, and groundwater is probably not an important component of the EWRs for these ecosystems; and
- ecosystems associated with Lake Eyre (North and South), as well as other saline lake systems of the Stuart Shelf and broader Gawler Craton, whilst forming major groundwater discharge features, will also rely almost entirely on surface water inundation to meet their EWRs.

GAB springs and seeps, however, are obligate groundwater dependent ecosystems (GDEs) of South Australia's Far North, i.e. they rely entirely on groundwater to maintain biodiversity and other ecosystem services. Figure 5-3 presents a locality plan for important South Australian spring groups (the Dalhousie spring group is located further to the northwest), including those situated within the Study Area. Figure 3-9 presents a schematic illustrating that the South Australian GAB springs and seeps, in particular, are at the discharge end of a very large regional groundwater flow system.

The springs support flora and fauna that can be endemic to individual spring groups, as well as transitory fauna. They represent sites of great ecological, social and economic value (SAAL NRM Board, 2006b), and are listed as endangered ecosystems under the *Environment Protection and Biodiversity Conservation Act (1999)*, and the *South Australian National Parks and Wildlife Act (1972)*. Their listing as endangered is a result of reduced extent as a result of declining artesian pressures within the artesian Eromanga (GAB) aquifers (due largely to groundwater development since European settlement) and their susceptibility to disturbance (SAAL NRM Board, 2006b), for example by human and stock activity, as well as pest and weed invasion. Recently undertaken rehabilitation works on uncontrolled flows from GAB wells, which has been supported financially by BHP Billiton, has resulted in the return of environmental flows to some springs, depending on proximity to rehabilitated wells, e.g. the previously estimated average 50 ML/day lost to 'bore fed' wetlands has now been reduced to 12 ML/d, representing a saving of 38 ML/day (SAAL NRM Board, 2006a).

Little is known of the location and hydraulics of springs in the Far North that are not associated with the GAB. Many of the watercourses of the Flinders Ranges, which occur on the eastern side of Lake Torrens, are characterised by springs and waterholes. SAAL NRM Board (2006b) identifies that there are a number of freshwater soaks on Lake Gairdner, but little is known of the origins of these soaks. Notably, neither of these areas occur within the same surface water or groundwater catchment as OD.

As indicated in Section 3.2, Lake Torrens forms a groundwater discharge zone within the Study Area. The major source of Lake Torrens' groundwater reservoir is streams that drain the western flanks of the Flinders Ranges (Schmidt, 1986), and groundwater discharge from the aquifers of the Stuart Shelf and Adelaide Geosyncline. Johns (1967) presents evidence that shallow water found in Quaternary sediments is derived largely from evaporated flood waters.

A number of springs are located along the axis of Lake Torrens, most probably along the alignment of the Torrens Fault, one group including Mountford Spring is located near the centre of the axis and another, the Yarra Wurta Springs, is located at the very northern end of the Lake on the eastern side of the Fault. REM (2007c) presents locality plans for these features. Mountford Spring occurs where Tertiary-aged Lake sediments are more than 300 m deep (Johns, 1967 and Schmidt, 1986), whilst the Yarra Wurta Springs are located in an area of Andamooka Limestone outcrop. An assessment of the hydrogeochemical signatures of regional groundwaters suggests that Yarra Wurta Springs discharge is likely supported by Adelaide Geosyncline groundwater systems occurring on the eastern side of the Torrens Fault (Figure 2-2), with some contribution from the shallow ALA (REM, 2007c).

Other springs along the western edge of Lake Torrens have also recently been identified during survey work conducted to assess the Yarra Wurta and Mountford Spring groups, but none of these springs is thought to be ecologically significant. REM (2007c) presents additional details concerning these springs, including locations.

Ecological studies undertaken by Ecological Associates (2006) identified patches of vegetation within the drainage lines near Yarra Wurta Springs that could be reliant on groundwater seeps. In addition, a number of surveys of aquatic flora and fauna have been undertaken recently, focussing on populations of the Lake Eyre Hardyhead fish species that have an obligate dependence on groundwater.

Waterholes and rockholes are common along many of the ephemeral watercourses of South Australia's Far North, and SAAL NRM Board (2006b) notes these to be predominantly maintained by rare rainfall run-off events. However, some may be maintained by groundwater baseflow, for example many of those found in the Flinders Ranges. Where waterholes and rockholes are maintained by baseflow they may be associated with lenses of relatively low salinity water that are either perched on low permeability clay layers or sit over higher salinity groundwater. The 'freshwater' swamps that bound the western portion of the Stuart Shelf (e.g. Peephabie Swamp, Figure 2-11) appear to be areas where surface water accumulates after major rainfall events, following which it evaporates or recharges the underlying non-artesian Eromanga aquifers.

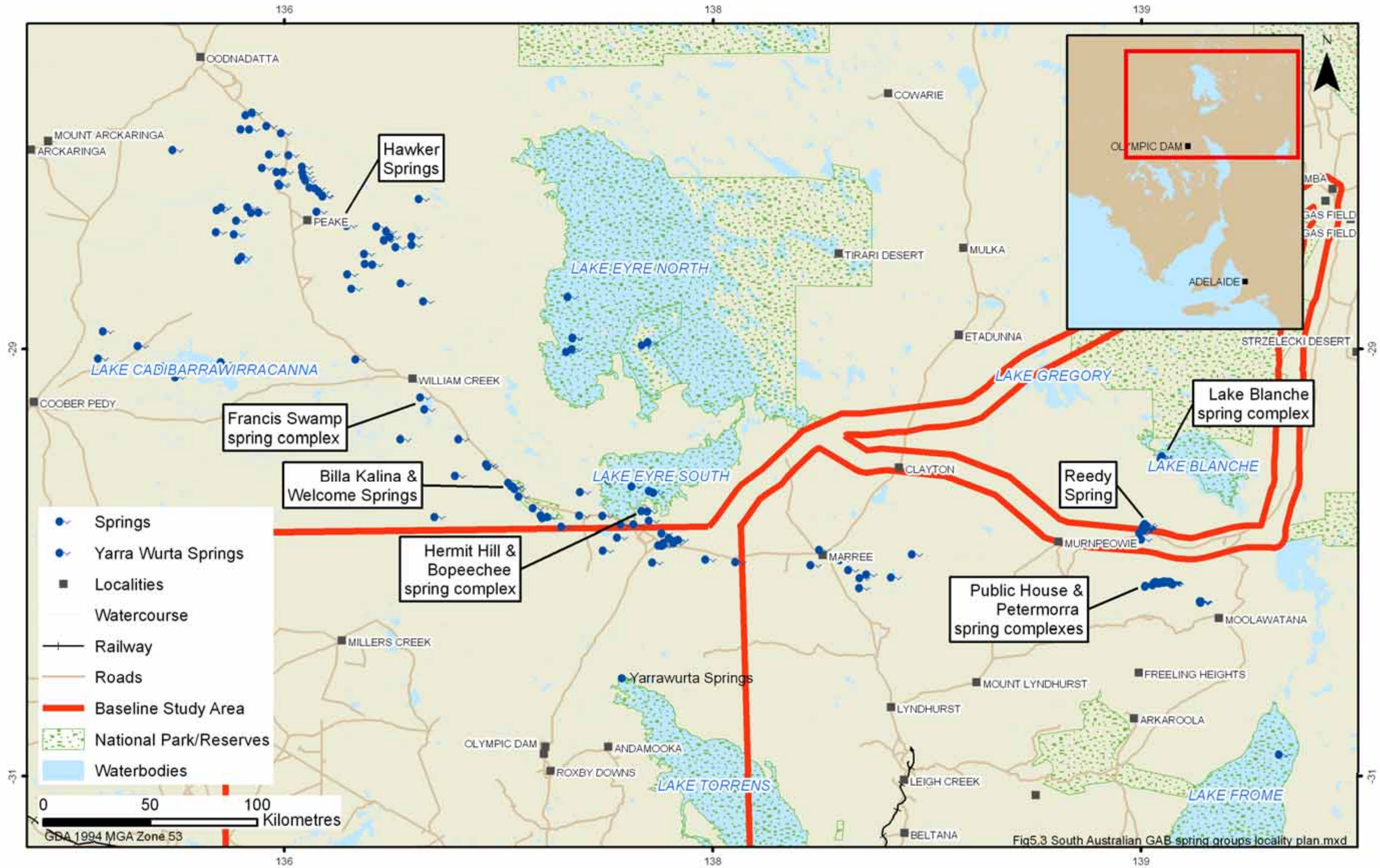


Figure 5-3
South Australian GAB spring groups locality plan

5.2 Infrastructure corridors

5.2.1 Southern Infrastructure Corridor

Third party water users

Figure 5-1 (north of Woomera) and Figure 5-4 (south of Woomera) present plans showing all of the pastoral leases located along the Southern Infrastructure Corridor (source: South Australian Government Drillhole Enquiry System).

Salinity and depth to water table data collected during groundwater baseline surveys of the Southern Infrastructure Corridor (REM, 2006d) are presented on Figure 3-11 and Figure 5-5:

- there are around 142 wells/water points located on the pastoral properties within the corridor that are possibly used for domestic and stock water supplies;
- reported groundwater salinities range from less than 5,000 to more than 50,000 mg/L; and
- depths to groundwater in sampled wells range from 0.5 below ground level (m bgl), near Port Augusta, to around 50 m bgl near Roxby Downs.

Environmental water users

Along the Southern Infrastructure Corridor:

- Obligate groundwater dependent ecosystems (i.e. that are totally dependent on groundwater) are unlikely to occur within or near to the Infrastructure Corridor.
- Ecosystems associated with the saline lake systems of the broader Gawler Craton will rely almost entirely on surface water inundation to meet their EWRs.
- SAAL NRM Board (2006b) identifies a number of 'freshwater soaks' on Lake Gairdner, but little is known of the characteristic of these soaks. However, SAAL NRM Board (2006b) notes that ecosystems associated with the lake are not reliant on groundwater discharge.
- Waterholes and rockholes may occur along some of the ephemeral watercourses occurring with the Infrastructure Corridor, and may be maintained by groundwater baseflow.

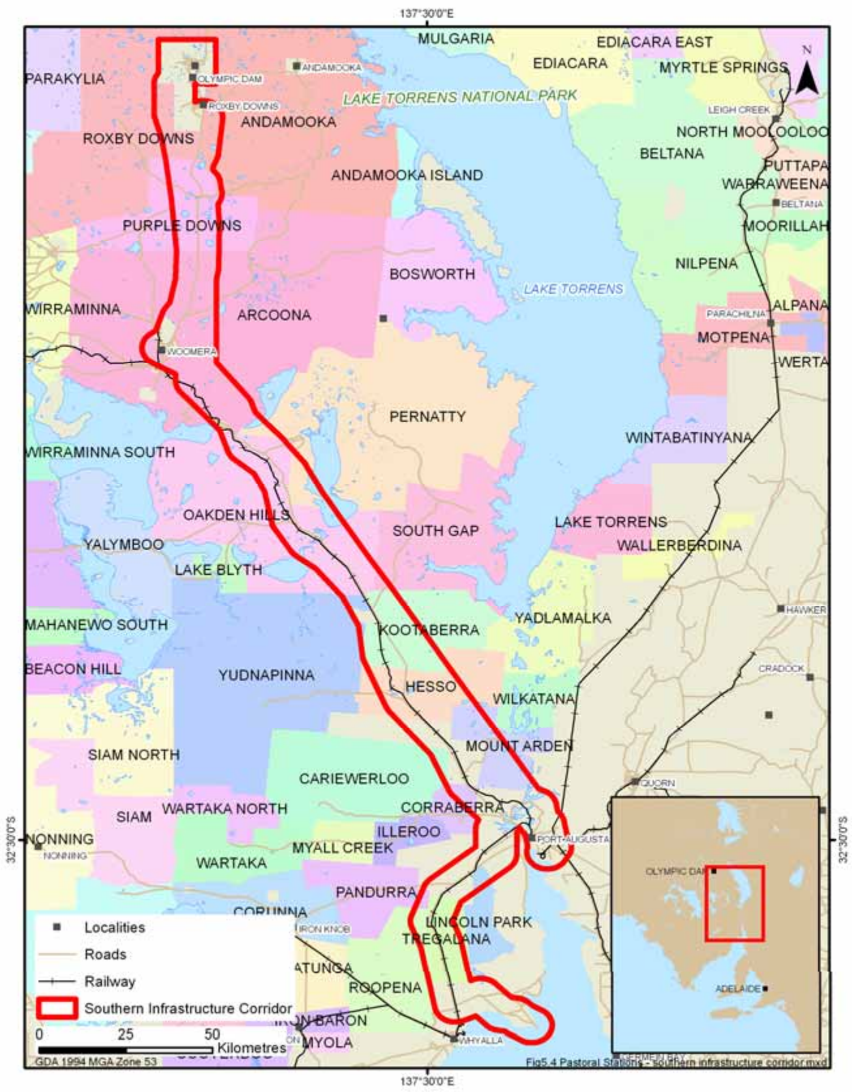


Figure 5-4 Pastoral Stations – Southern Infrastructure Corridor

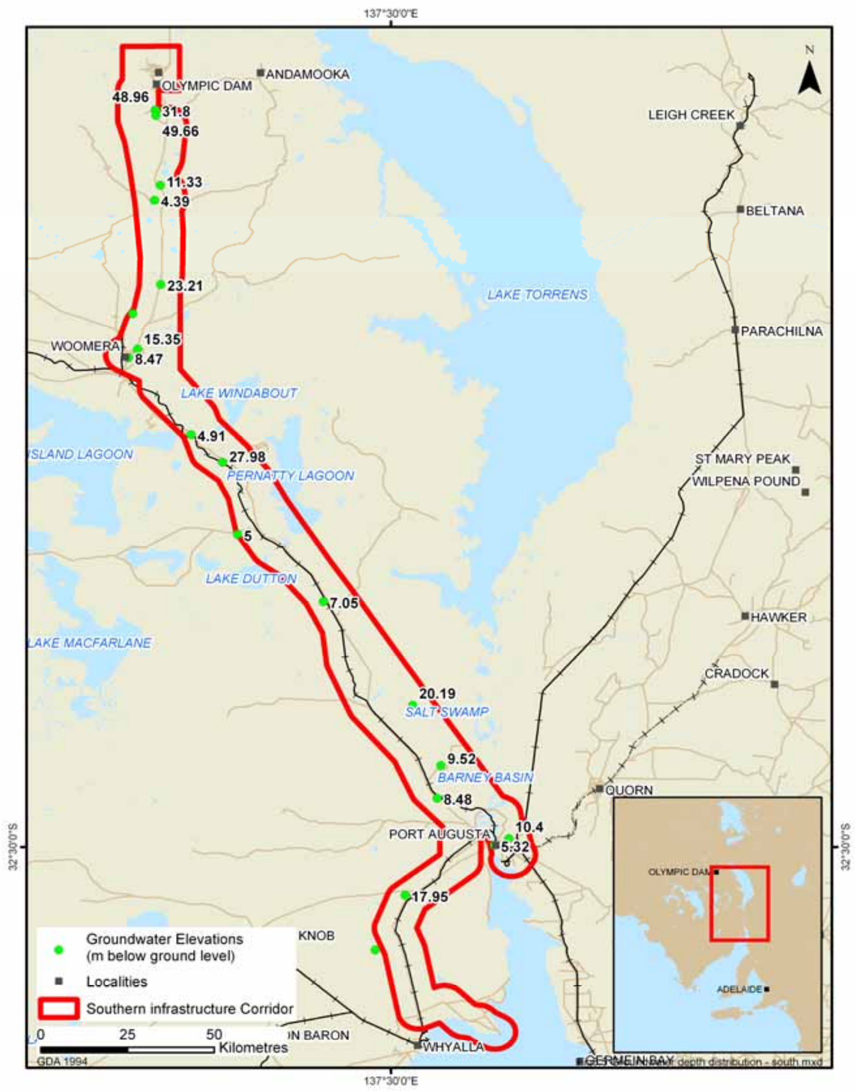


Figure 5-5 Groundwater depth distribution – Southern Infrastructure Corridor

rem SKM

5.2.2 Northern Infrastructure Corridor

Third party water users

Along the Northern Infrastructure (gas pipeline) Corridor there are a number of pastoralists who rely on groundwater to meet some or all of their stock and domestic water requirements.

Figure 5-6 presents a locality plan showing the pastoral leases located along the gas pipeline corridor, as well as the location of all water wells identified from records held in the South Australian Government Drillhole database. Based on the available data, there are 138 potentially operation water wells located within the gas pipeline corridor (Figure 5-6).

While it is evident from the available well construction details that groundwater has been accessed from shallow wells in the past, the majority of operational wells located along the gas pipeline corridor are constructed to take groundwater from depths greater than 20 m.

In the area between OD and the Oodnadatta Track there are currently five operational wells on record (Figure 5-6). Four of these wells are BHP-Billiton monitoring wells, and the other is assumed to be used by a third party. The location of the third party well is co-incident with the general GAB spring alignment where it crosses the gas pipeline corridor and, based on the reported well depth and the proximity to the GAB springs, it almost certainly draws water from the artesian Eromanga aquifers.

Between Lake Eyre and Lake Blanche (Figure 5-6) the number of relatively shallow (less than 150 m) groundwater wells becomes greater, coincident with the thickening and deepening of the Lake Eyre Basin (Namba and Eyre Formations) sedimentary sequence. On the Clayton pastoral lease, five wells within the gas pipeline corridor are interpreted as sourcing groundwater from the Eromanga aquifers solely, but on the adjoining Murnpeowie pastoral lease, southwest of Lake Blanche, seven wells within the gas pipeline corridor are interpreted as intersecting groundwater from the Namba or Eyre Formations with three others interpreted as intersecting Eromanga aquifers.

All wells within the Northern Infrastructure Corridor on the Etadunna and Dulkaninna pastoral leases source water from the deep artesian Eromanga aquifers, with the exception of one Etadunna well interpreted as intersecting the Namba Formation. North of approximately Lake Blanche, the Namba Formation forms the main pastoral aquifer along the gas pipeline corridor, as well as the main industrial water supply aquifer in the general Moomba gasfields area.

Figure 3-12 presents available salinity data for groundwater drawn from wells located along the gas pipeline corridor. There are three wells where groundwater of less than 5,000 mg/L salinity is reported from depths of less than 20 m, two are located within 5 m of each other on Mullorina station (at the northern end of the OD to Lake Eyre South spur of the corridor, and the third is located east of Lake Blanche on the Tinga Tingana pastoral lease.

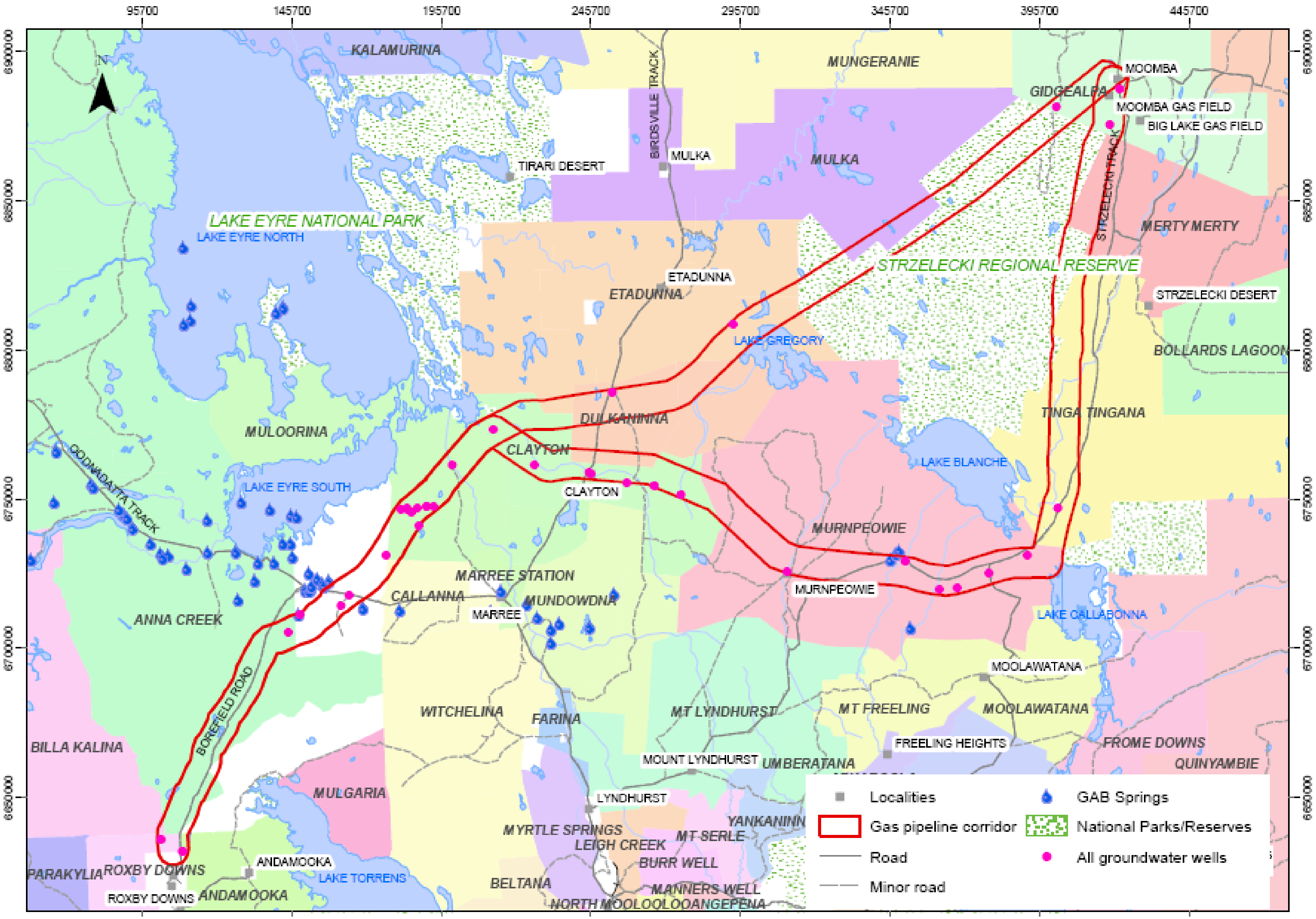


Figure 5-6
Pastoral leases and operational groundwater wells along northern infrastructure corridor

rem SKM

Environmental water users

Significant groundwater dependent ecosystems (GDEs) along the proposed Northern Infrastructure Corridor are present within and immediately adjacent to the numerous GAB springs that bisect the OD to Lake Eyre South sector of the corridor (Figure 3-12). The gas pipeline corridor passes close to (but not through) a spring group located near the junction of Borefield Road and the Oodnadatta track, south of Lake Eyre. The springs are driven by artesian pressures that occur within the Eromanga aquifers (Cadna-owie Formation and Algebuckina Sandstone).

Riparian vegetation occurring along and within the watercourses of the South Australia's Far North (Figure 2-21) that relies to some extent on groundwater to meet EWRs will likely draw water from lenses of fresh groundwater that are either perched or lie over more dense saline groundwater. These lenses arise primarily from infrequent stream flow and flood events.

Away from the watercourses and springs, vegetation can be expected to be vadophytic (i.e. reliant on soil water rather than groundwater).

6 ASSESSMENT OF GROUNDWATER SYSTEM RESPONSE TO EXISTING MINING OPERATIONS

6.1 Existing groundwater affecting activities

The existing underground mining operation is supported by a number of activities having the potential to modify both local- and regional-scale groundwater systems. These activities include:

- operation of wellfields that source groundwater from the GAB and Stuart Shelf aquifers;
- storage of mine process tailings in specially designed and built tailings storage facilities (TSFs);
- dewatering of the underground mining operations via infrastructure that intersects the ALA, THA and the orebody 'aquifer' (i.e. shafts, service decline and ventilation raises); and
- various water storage facilities.

Figure 6-1 presents a locality plan for potential water affecting infrastructure located on the SML. The following presents an assessment of groundwater system response to these and other water affecting activities.

6.2 Mine water management impacts

6.2.1 Overview

Figure 6-2 presents a schematic cross-section of the OD mine site, which conceptually shows the response of the mine site groundwater system to two main site activities: (i) dewatering of underground workings (substantial localised drawdown in the THA); and (ii) tailings storage facility (TSF) leakage (groundwater mounding on the Arcoona Quartzite, within the ALA.

More than 80 dedicated groundwater monitoring wells have been established within 20 km of the OD mine site (Figure 6-3) complemented by a further 9 wells installed by BHP Billiton in the region further north of OD (Figure 6-5). These wells are used to monitor, either quarterly, bi-annually or annually (depending on location) the changes in groundwater levels in the ALA and THA in response to mine related activities. A smaller number of wells are also monitored for a range of water quality parameters, including salinity, major ions and metals.

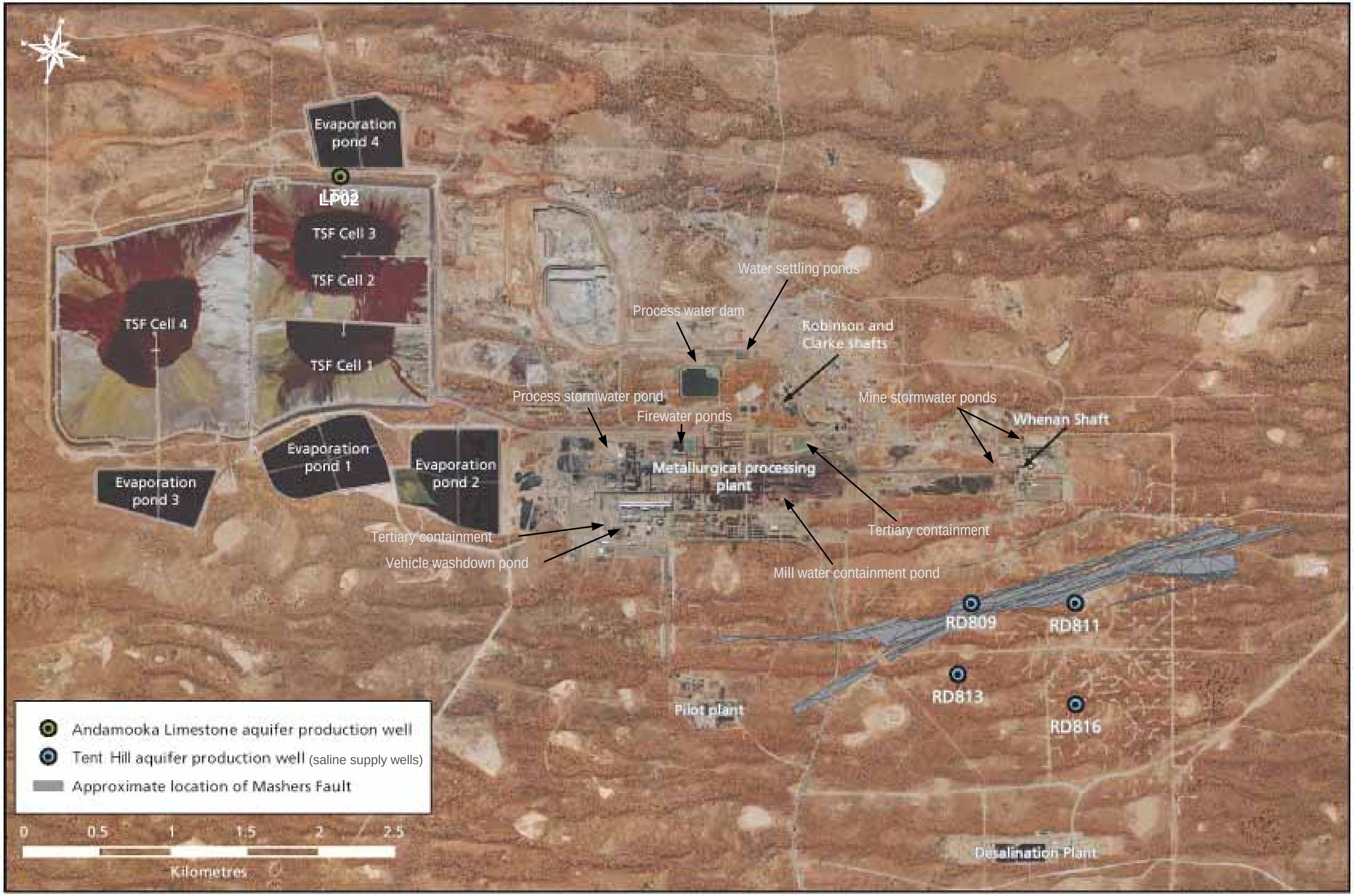


Figure 6-1 Infrastructure locality plan for the SML

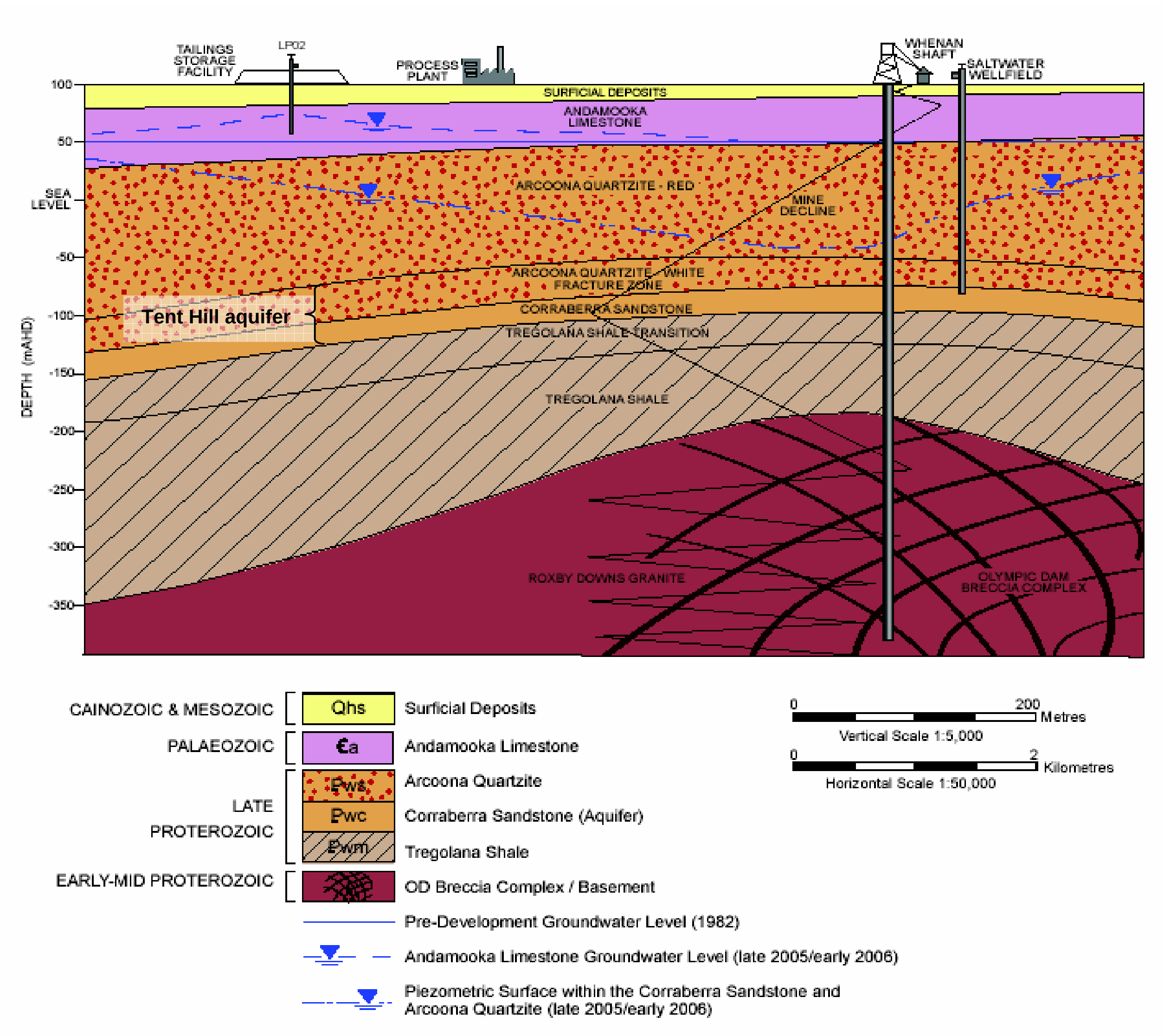


Figure 6-2 Schematic geological and hydrogeological cross-section of OD mine site

6.2.2 Dewatering impacts associated with underground workings

In the vicinity of the mine site, the THA has responded to drainage into the underground workings by a number of raise bores constructed to intersect the underground workings, operation of the Saltwater Wellfield (Figure 6-1), and leakage through the Tregolana Shale under vertical hydraulic gradients established as a result of drainage of the basement rocks. Raise bores alone have abstracted, on average, between 14 and 24 L/s per year since 1984 (BHP Billiton, 2007a).

A cone of depression has developed in the THA, extending up to 10 km from the mine to the north and east (toward Lake Torrens) and less than 5 km from the mine to the southwest. Figure 6-6 presents an interpreted groundwater level contour plan for the THA showing this cone of depression.

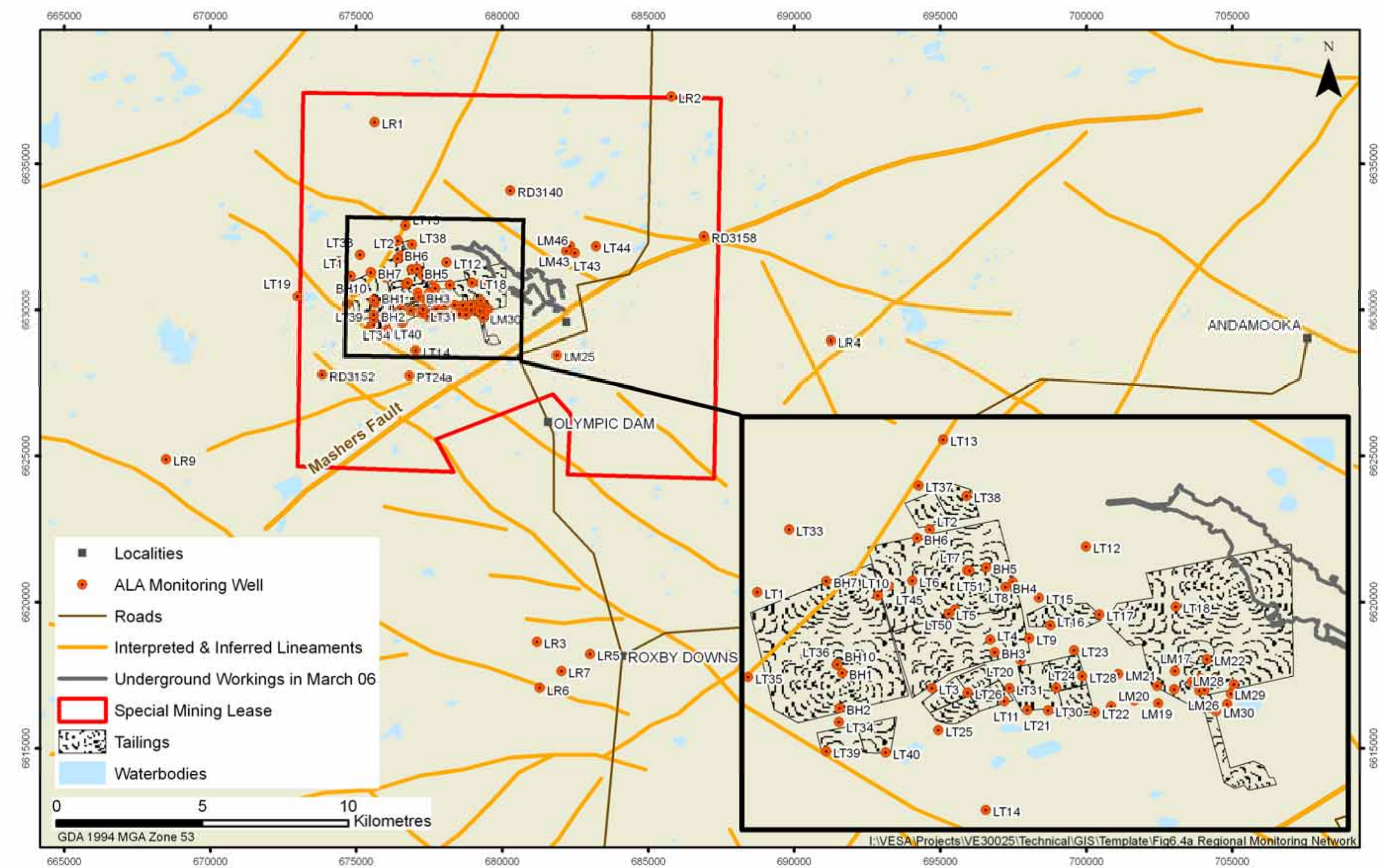


Figure 6-3
OD mine groundwater monitoring network (ALA)

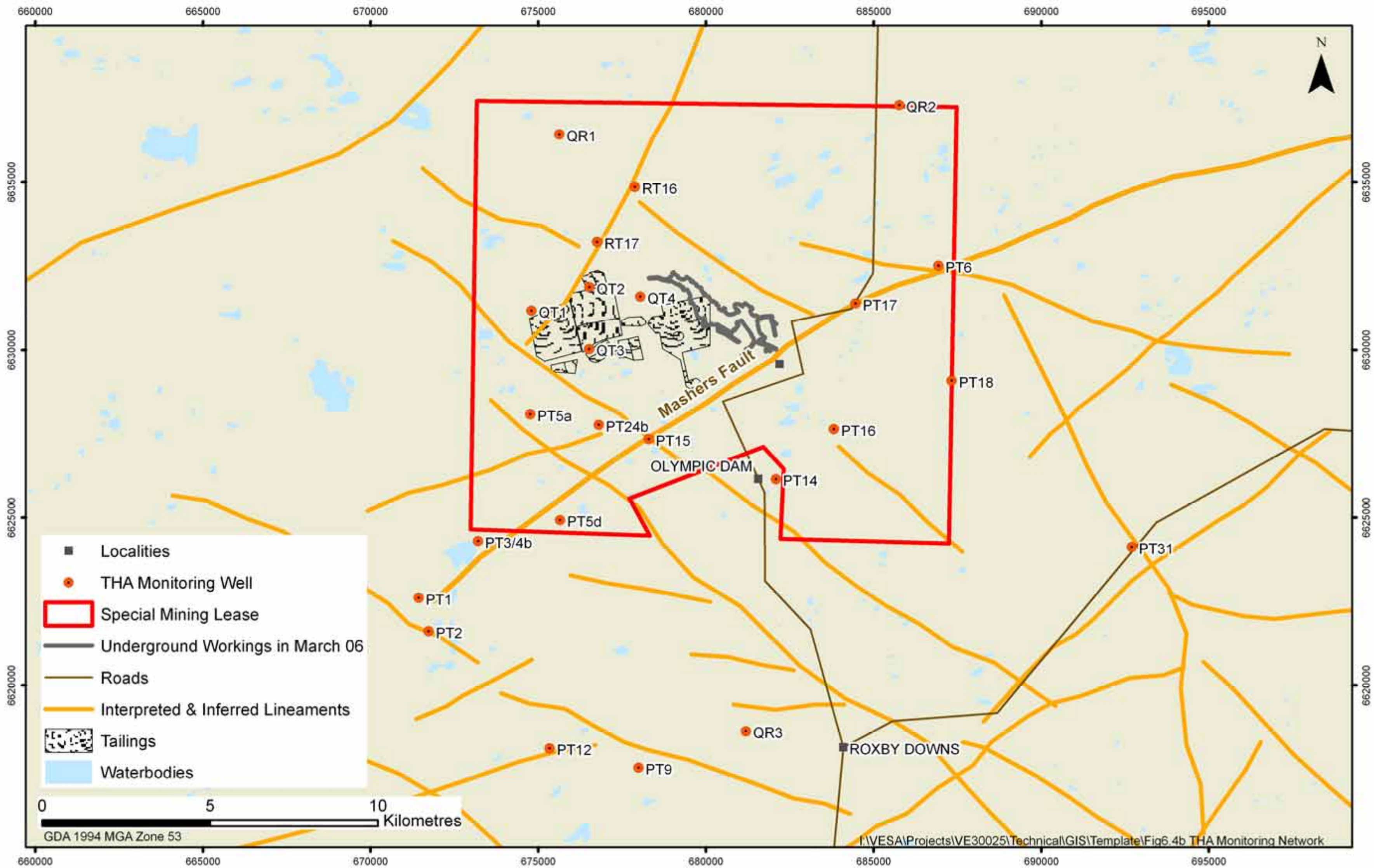


Figure 6-4
OD mine groundwater monitoring network (THA)

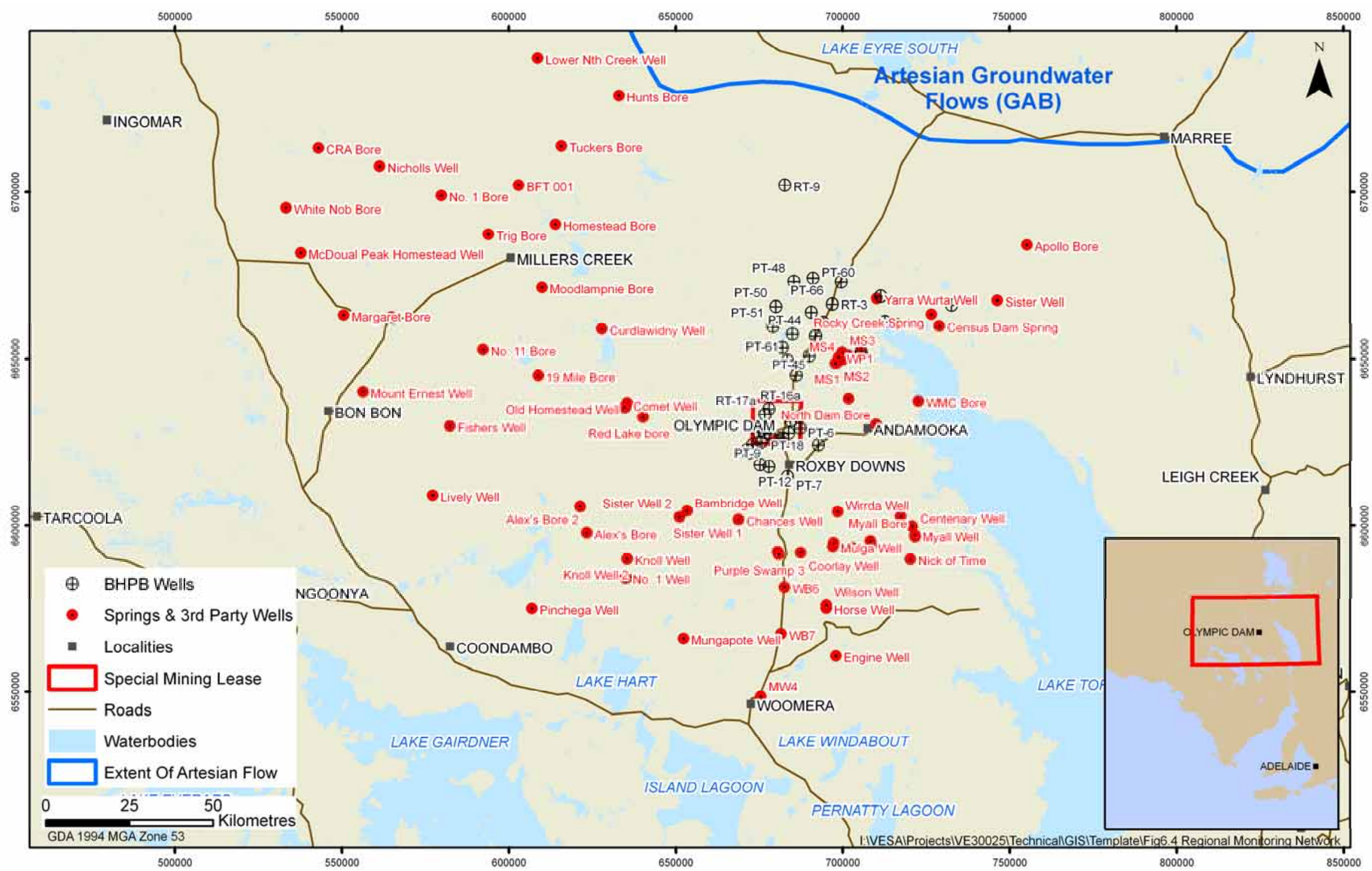


Figure 6-5
Other regional wells in OD mine groundwater monitoring network

THA potentiometric contours (Figure 6-6) show that the aquifer responds to dewatering in a manner consistent with a homogeneous porous media, i.e. almost radial drawdown around the underground workings). However, other factors appear to influence the THA response to dewatering, e.g. :

- geological structure associated with Mashers Fault appears to influence the elongate the zone of influence along strike to the northeast; and
- the TSF, located southwest of the underground workings, appears to contribute a source of recharge to the THF, which manifests as a steepening of potentiometric contours up-hydraulic gradient of the workings.

ALA response to dewatering (underground workings and pumping) is masked by other activities such as operation of the tailing storages and a response to dewatering within that aquifer is not readily discernable due to these other activities (refer Figure 6-7).

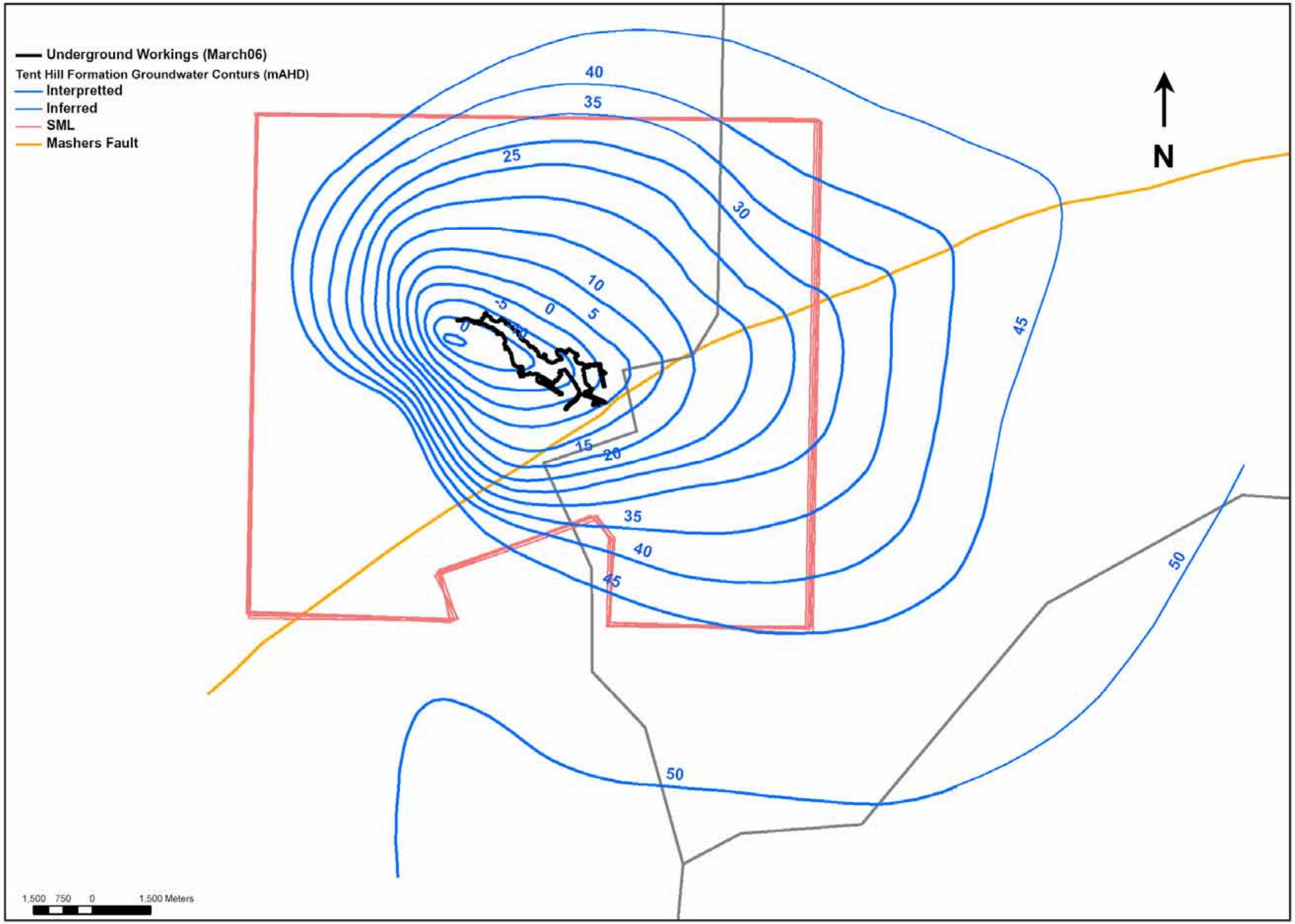


Figure 6-6 Interpreted potentiometric contours for the THA (mAHD; 2007 data)

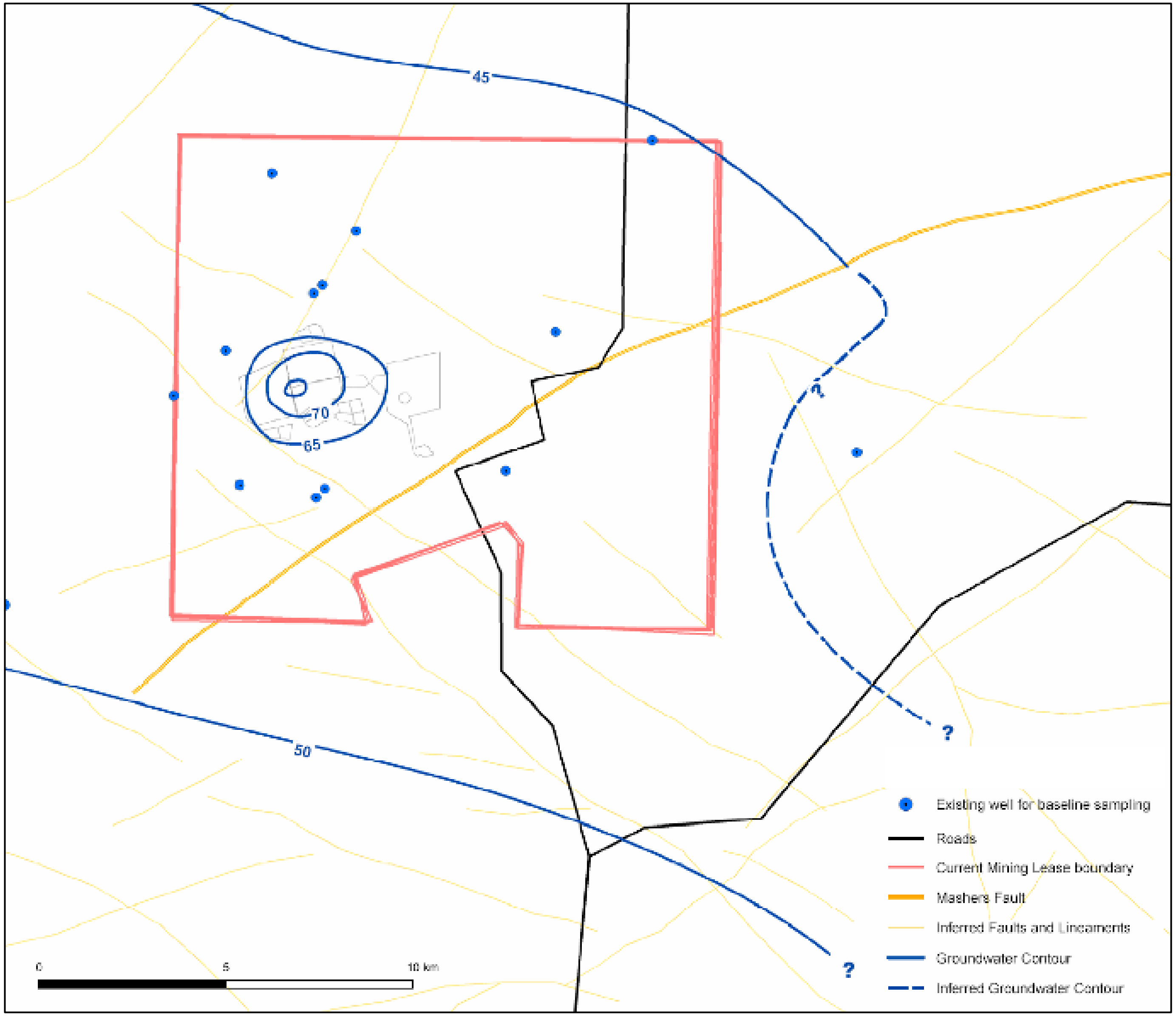


Figure 6-7 Interpreted potentiometric contours for the ALA (mAHD; 2007 data)

Figure 6-8 presents hydrographs for selected THA monitoring wells that show the level of drawdown observed in the aquifer in response to drainage to the mine workings. As shown:

- the THA has recorded a variable response (up to 100 m drawdown) depending on proximity to the mine decline, ventilation shafts and raise bores; and
- the tails of most hydrographs have flattened, suggesting a new dynamic equilibrium has been reached within the THA.

Table 6-1 presents details of a selected number of monitoring wells in relation to groundwater system response to mine operations.

Table 6-1 Mine site (THA) groundwater system response to mine operations

Well ID	Mine location	Observed response
QR-01	Northern SML	Drawdown of around 2 m since 1994, likely response to mine dewatering
QT-01	North of TSF cell 4	Drawdown data around 1994 appears spurious, groundwater levels since 1995 appear relatively stable
QT-02	Between TSF cell 3 and EP4	Drawdown response to mine dewatering
QR-03	Near Roxby township water storage dam	Possible subtle response to leaking water storage pond
QT-03	South of TSF cell 1	Groundwater level rise of around 5 m between 1994 and 1996 in possible response to leaking tailings dams, subsequent decline of around 10 m before around 2 m rise since 2002
QT-04	Near mine water disposal pond	35 m drawdown observed since 1995 in response to raise bore abstractions
RD-148	Underground workings	90 m drawdown observed since 1985 in response to draining of aquifer by raise bore operation
RD-299	Saltwater Wellfield	Almost 60 m drawdown observed since 1985 in response to operation of the Saltwater Wellfield, recovery of around 20 m since 2003 in likely response to reduced rates of abstraction

Notes: 1. see Figure 4.5 for well location and hydrograph

Figure 6-9 presents groundwater salinity plots for selected THA monitoring wells. There is an apparent trend toward increasing salinity concentrations in THA groundwater in the area where drawdown has occurred in response to mine dewatering (e.g. at wells QT-02 and QT-03), although fluctuations are evident. This response is likely the result of leakage into the THA from bounding aquitards (e.g. underdrainage of the TSF) or possibly from the rock matrix as fracture related secondary porosity has become increasingly depressurised.

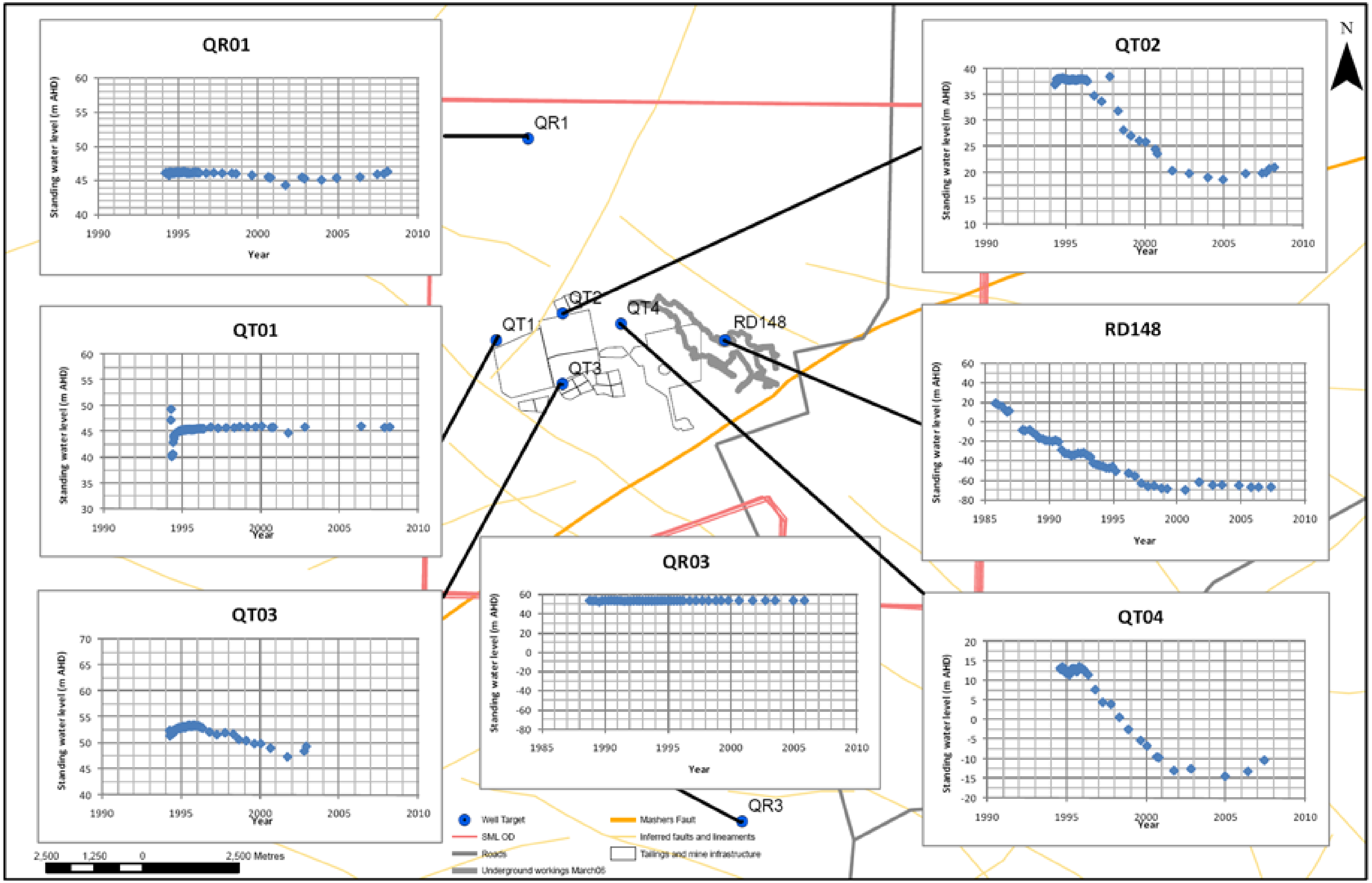


Figure 6-8 Hydrographs for selected THA groundwater monitoring wells

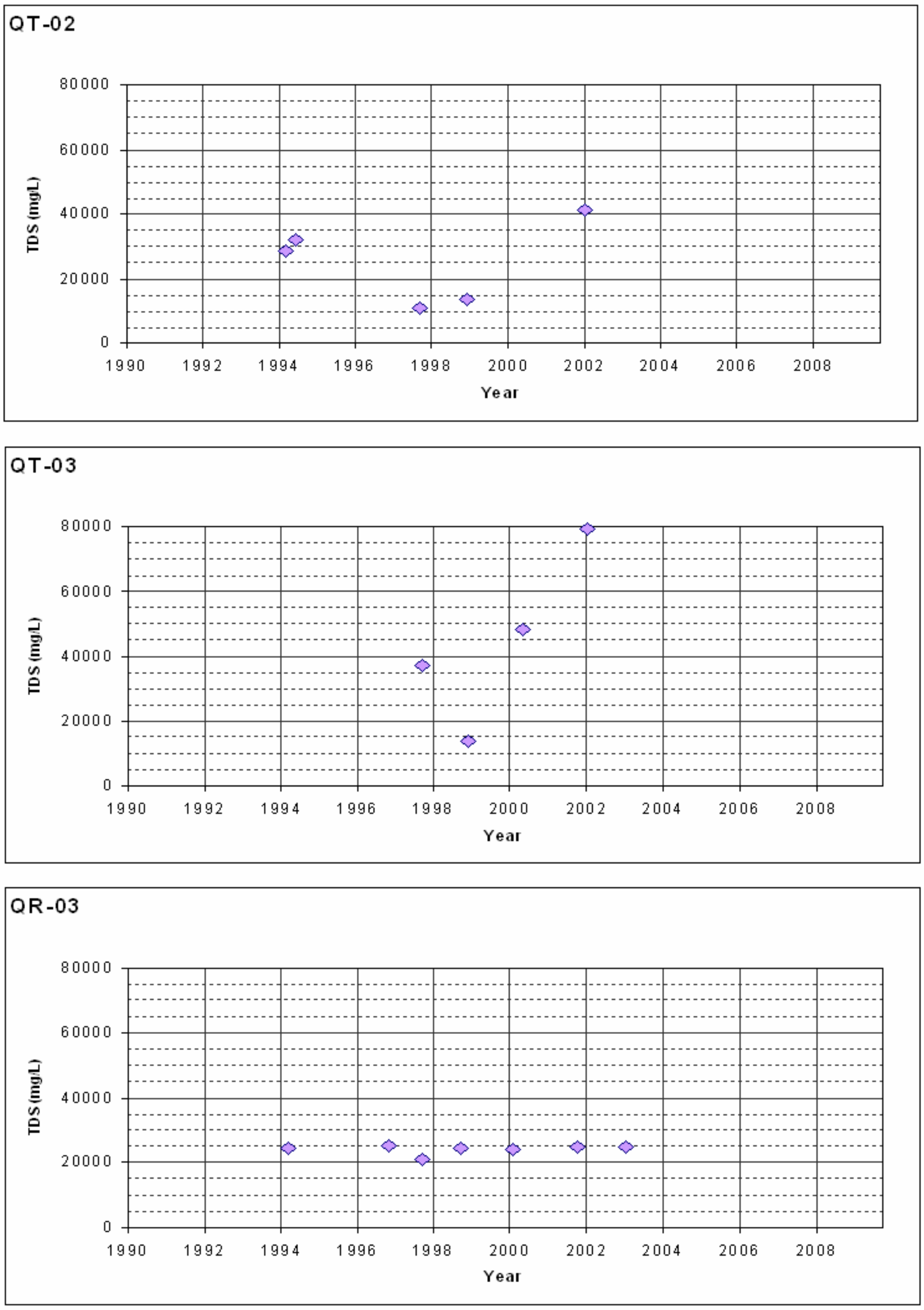


Figure 6-9 Salinity plots for selected THA groundwater monitoring wells

6.2.3 Tailings impoundments and water storages

The ALA, being the shallowest of the site groundwater systems, is the aquifer that will first respond to potential leakage from water storages and the TSFs. Figure 6-7 presents interpreted water table elevation contours for the ALA, and shows that a mound has formed beneath the TSFs in response to historic seepage from those facilities. To the east of the SML, structural control on ALA saturation is evident (refer Figure 2-4).

The presence of the underlying Arcoona aquitard will retard ALA response to mine dewatering. However, potentiometric contours within the THA do suggest a degree of hydraulic connection exists between the two aquifers (Figure 6-6), which is manifested in steep hydraulic gradients within the THA beneath the TSFs.

Figure 6-10 and Figure 6-11 present hydrographs for selected ALA monitoring wells. Table 6-2 presents details of these wells in relation to groundwater system response to mine operations. There is no direct evidence in any of the hydrographs of ALA response to THA dewatering.

Table 6-2 Mine site (ALA) groundwater system response to mine operations [1]

Well ID	Mine location	Observed response	Figure no. [1]
LM-11	Near Met. Plant	Monitoring since 2000 shows slight (~2.5 m) rise, possibly in response to operation of Mine Water Storage Pond	6.9
LR-03	Roxby township Water Storage Dam	Seepage from the water storage dam for the Roxby Downs township has resulted in the formation of a groundwater mound beneath the storage facility within the ALA. The liner to the storage was replaced in 2001, and the mound has since dissipated.	6.9
LR-05	Roxby township Water Storage Dam	No obvious response to leakage from Water Storage Dam even though located less than 2 km away	6.9
LR-02	Northeastern SML	No obvious response to site water management practices	6.9
LM-43	East of Met. Plant	Water level rise of between 10 and 15 m since 2000 after installation of the mine water storage pond, now stabilised	6.9
LT-41	Northwest of TSF cell 4	Slight water level rise of less than 2 m since 1998, likely a response to commissioning of TSF cell 4	6.10
LT-01	Northwest of TSF cell 4	Slight water level rise of less than 5 m since 1998, likely a response to commissioning of TSF cell 4, has stabilised since around 2005 and now reports a slight declining trend	6.10
LT-19	Western boundary of SML	Very slight rise in groundwater levels since around 1995, has stabilised since around 2005	6.10
LT-36	Centre of TSF cell 4	Water level rise of around 10 m since 1999, possibly in response to leakage from TSF cell 4, may be stabilising	6.10
LT-03	Between TSF cell 1 and Evaporation Pond 1	Steady rising trend (~5 m) since around 1997, has stabilised since around 2005	6.10
LT-14	Southern SML	Very slight rise in groundwater levels since around 1995, has stabilised since around 2005	6.10
LT-22/30	Southern edge of EP-2	Groundwater level rise of around 5 to 10 m since 1995, in likely response to operation of EP-2	6.10
LT-18	Near Process Water Dam	Groundwater level rise of around 5 m since 1995, in response to operation of Process Water Dam, stabilised since 2000	6.10

Notes: 1. Continued over page

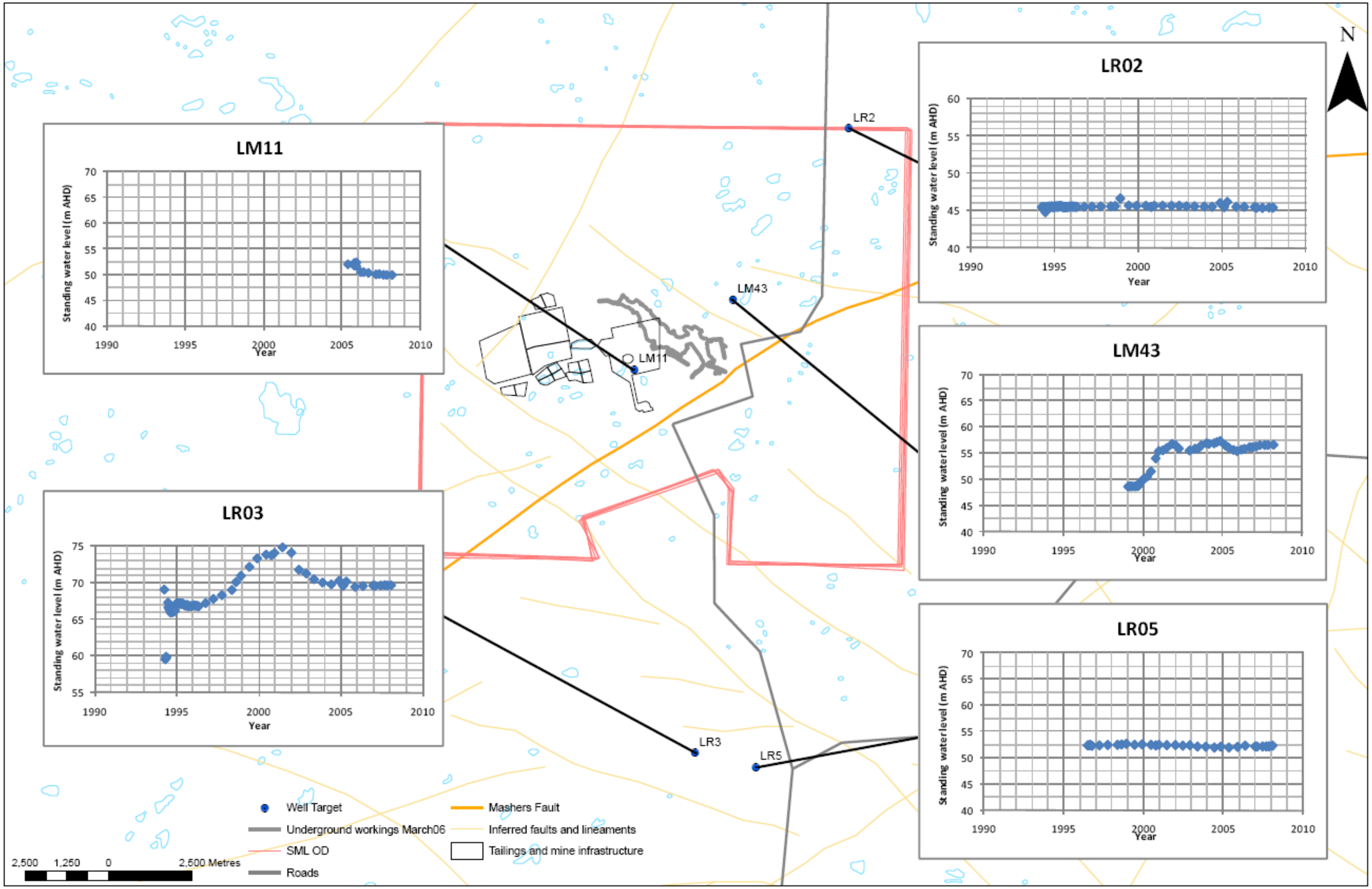


Figure 6-10 Hydrographs for selected ALA groundwater monitoring wells located away from TSFs

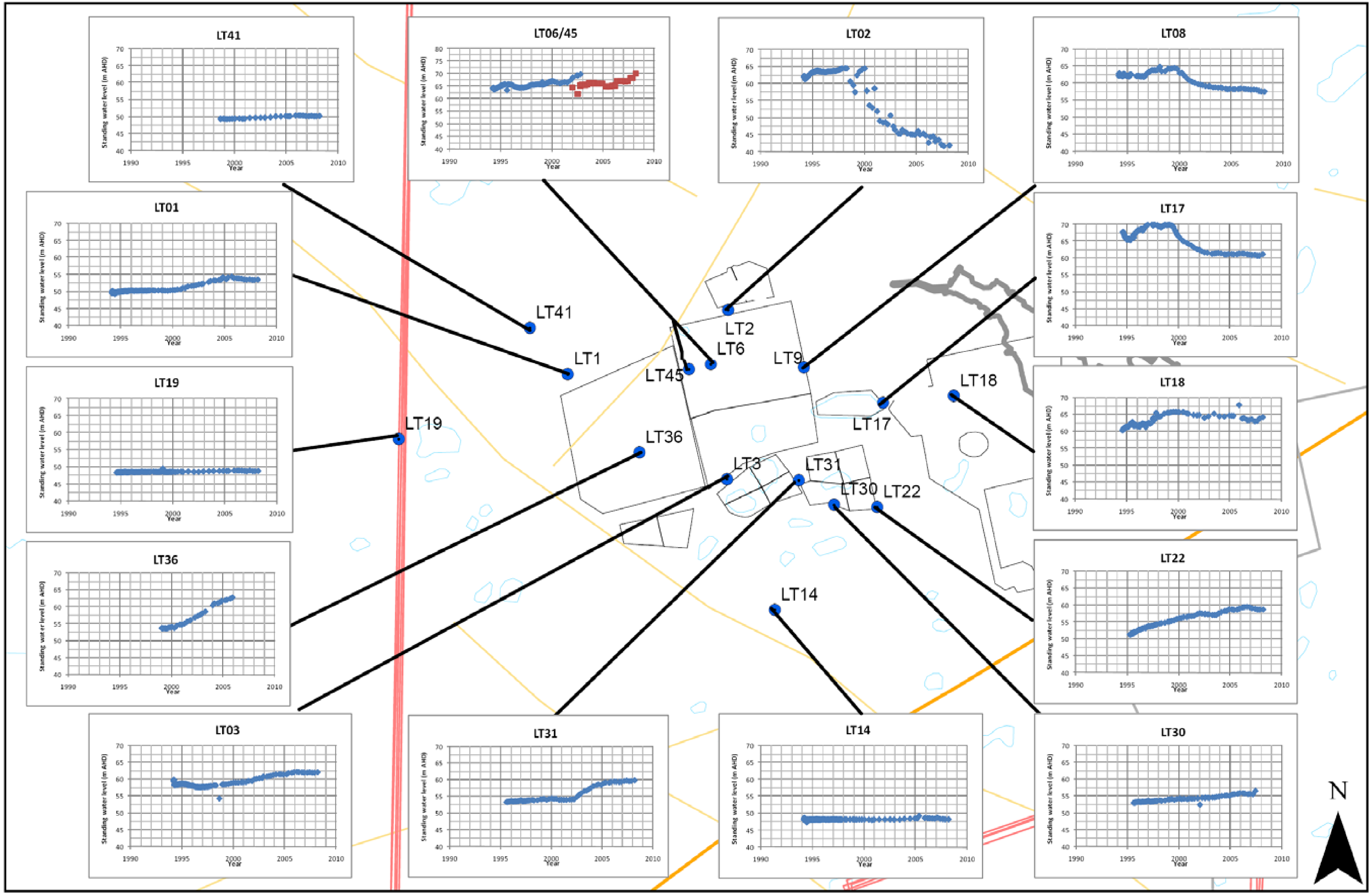


Figure 6-11
Hydrographs for selected ALA groundwater monitoring wells located near TSFs

Table 6.2 Mine site (ALA) groundwater system response to mine operations (cont.)

Well ID	Mine location	Observed response	Figure no. [1]
LT-17	Near old Mine Water Disposal Pond	Groundwater level rise of ~5 m between 1995 (when monitoring commenced) and 1997, then decline of ~10 m from 1999 as a likely response to decommissioning of the adjacent disposal pond, now stabilised	6.10
LT-06	East side of TSF cell 2 & northwest of old Mine Water Disposal Pond	Groundwater level rise of ~2.5 m between 1994 (when monitoring commenced) and 1997, then decline of ~5 m from 1999 as a likely response to decommissioning of the adjacent disposal pond, now stabilised	6.10
LT-02	Between TSF cell 3 and EP-4	Groundwater level rise of ~ 5 m between 1994 (when monitoring commenced) and 1998, then decline of ~20 m as a response to groundwater recovery operations (at well LP-02), now stabilised	6.10
LT-06/45	Between TSF cells 2 and 3 (two sites combined)	Groundwater level rise of up to 7.5 m between 1994 and 2003 (LT06) and 2002 and 2008 (LT15)	6.10

Notes: 1. see identified figure number for well location and hydrograph

Reported groundwater salinity data for well LT-02 do not show any change that can be associated with TSF leachate escape to the ALA (Figure 6-12). Salinity data for other wells screening the ALA within the SML generally show no response that can be attributed to mine water management practices, although an apparent freshening of groundwater beneath the old Mine Water Disposal Pond may be evident (see LT-17 plot presented in Figure 6-12).

6.2.4 Mine and process water supply

GAB wellfields

The existing water supply for OD (including mine, process and potable town supplies) is sourced almost entirely from the GAB through the operation of Wellfields A and B (Figure 5-2).

The GAB monitoring program is designed to monitor impacts of OD wellfield abstractions on the artesian aquifers of the GAB in the areas of, and well beyond, Wellfields A and B, and uses data obtained from the extensive monitoring network initially established before the commencement of mining in the late 1980s. Wellfield A currently comprises of six operational production wells whilst Wellfield B contains three, all of which are located within the Southwest Spring Zone of the Far North Protected Well Area.

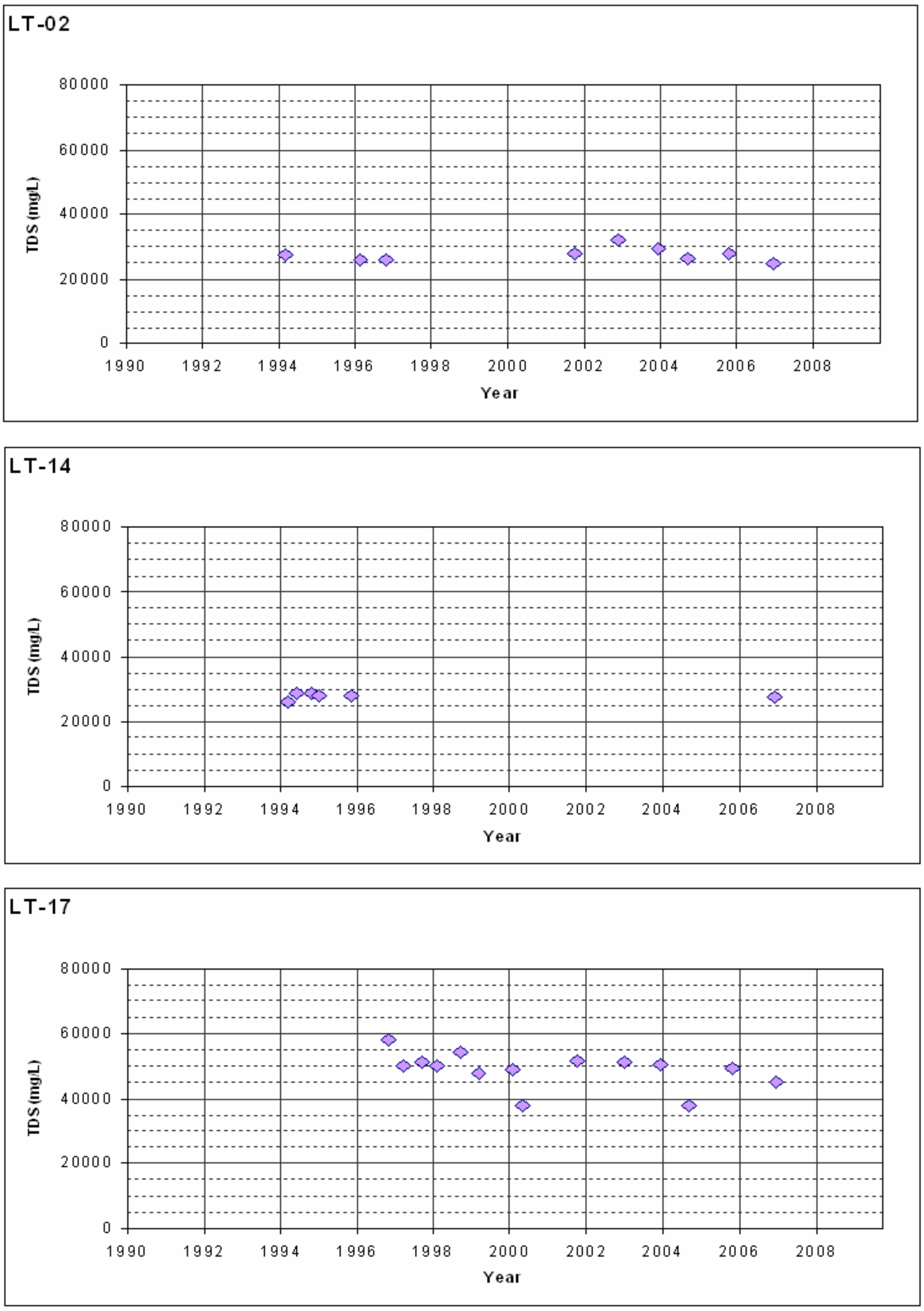


Figure 6-12 Salinity plots for selected ALA groundwater monitoring wells

Wellfield A is located at the southwesterly margin of the artesian Eromanga aquifers in an area of complex Basin structure that presents a strong influence of aquifer boundary effects in response to abstractions (BHP Billiton, 2007b). Wellfield B, however, has been sited further north in an area where aquifer zonation due to structural effects is less marked and the Eromanga aquifers are thicker (more transmissive) and more homogeneous (BHP Billiton, 2007b) compared to Wellfield A.

Wellfield A was established with an initial capacity of 9 ML/day but average abstractions rose to 15 ML/day between 1988 and 1996 (Figure 6-13). This larger demand had, as predicted, adverse impacts on GAB springs (seen as reduced pressures and flows). With the commissioning of Wellfield B, which has a capacity in excess of 30 ML/day, Wellfield A abstractions were substantially reduced from 1995-96 levels (by around 5 ML/day; Figure 6-13) to allow spring flows to recover.

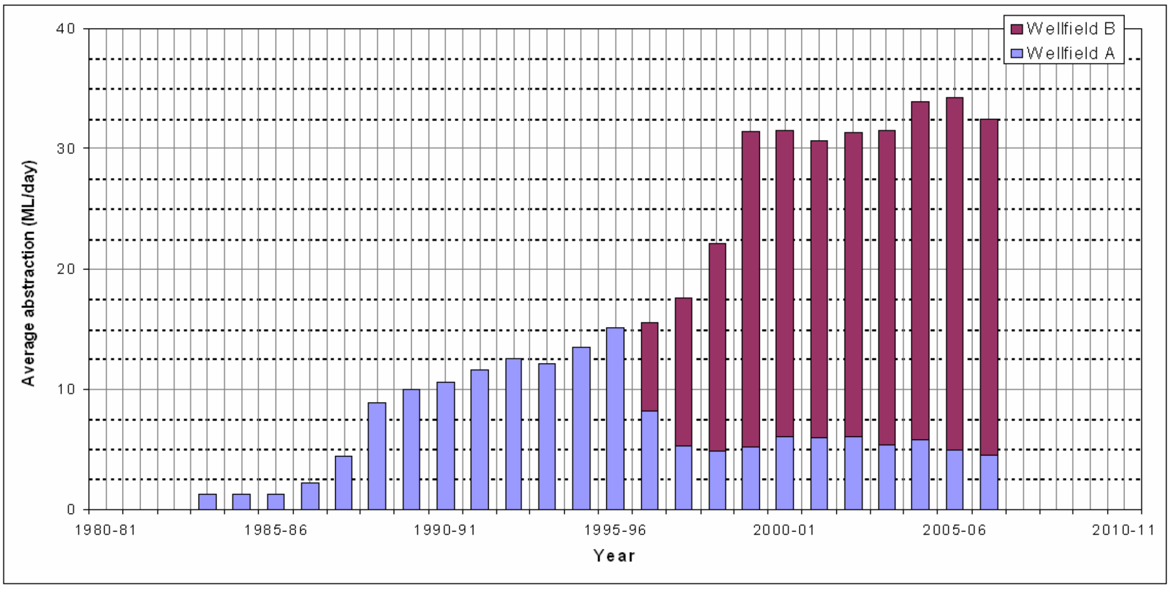


Figure 6-13 Abstraction data for GAB wellfields

From 1996, with the commissioning of Wellfield B, total average daily mine water demand has increased to around 32.5 ML/day in 2006-07 with average abstractions from Wellfields A and B of approximately 5 and 27.5 ML/day, respectively. Between 2004 and 2007, average abstractions ranged up to approximately 34 ML/day (Figure 6-13).

The Wellfield A monitoring network consists of 34 dedicated monitoring wells in addition to a number of other wells or springs where environmental flow monitoring is undertaken. The Wellfield B monitoring network consists of 23 monitoring wells (some of which are pastoral production wells) and two environmental flow monitoring spring sites. Figure 6-14 presents a plan showing the extent of the BHP Billiton GAB monitoring network.

Importantly, flow rates are monitored at 37 regional GAB springs to assist in assessing spring response to wellfield abstractions. It is recognised that the results of the monitoring program represent not only response to abstractions from the Eromanga aquifers but also natural spring dynamics, which include ebb and flow responses to atmospheric pressure, disruption to the spring vents (due for example to natural processes such as clogging) and response of wetted areas to climatic conditions. Apart from the period between 1988 and 1996 when Wellfield A abstractions ranged between 9 and 15 ML/day, environmental flow rates at GAB springs in the Wellfield A area (Figure 6-15) now remain relatively consistent and inline with historical averages (BHP Billiton, 2007b).

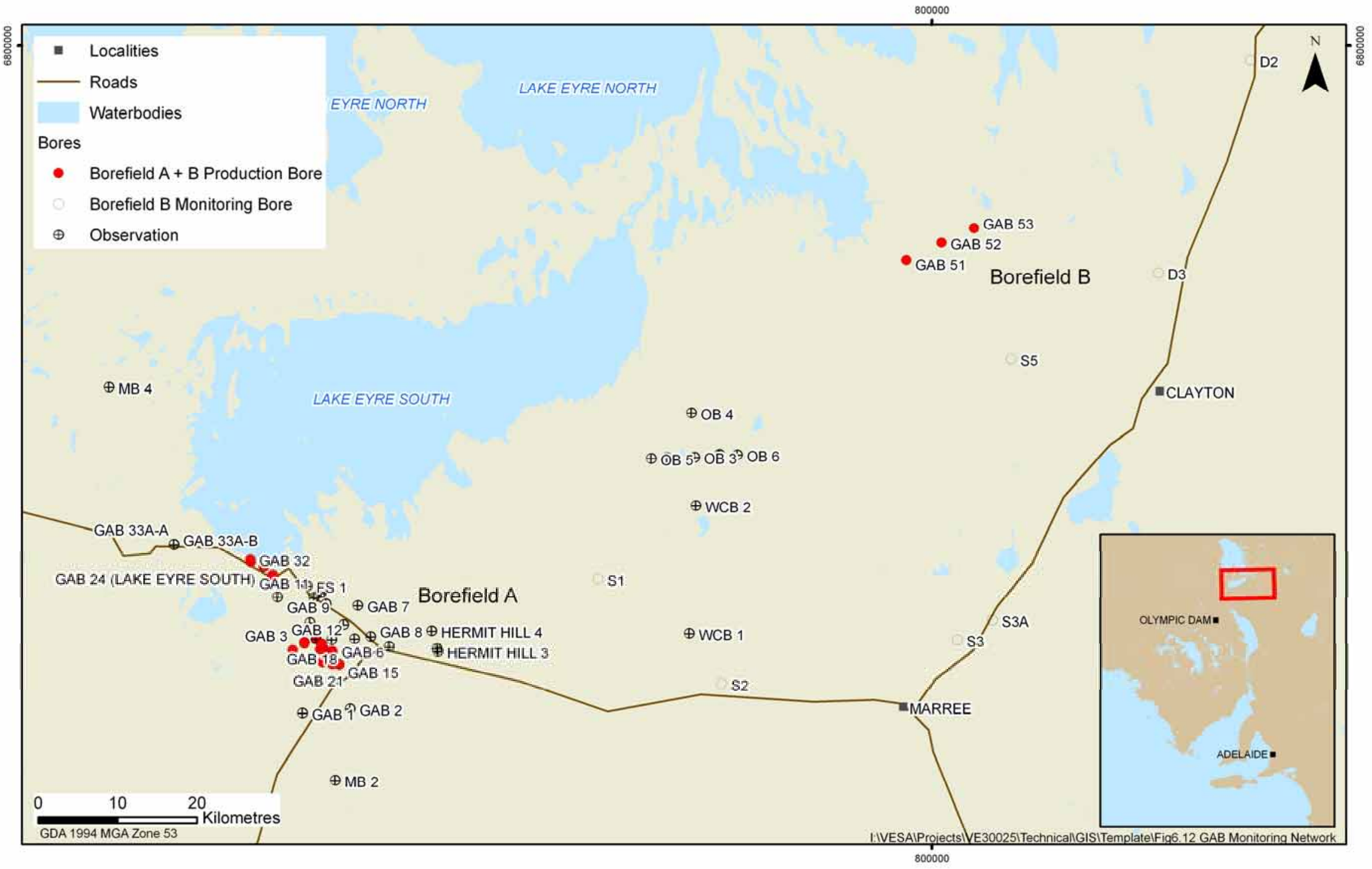


Figure 6-14
GAB monitoring network

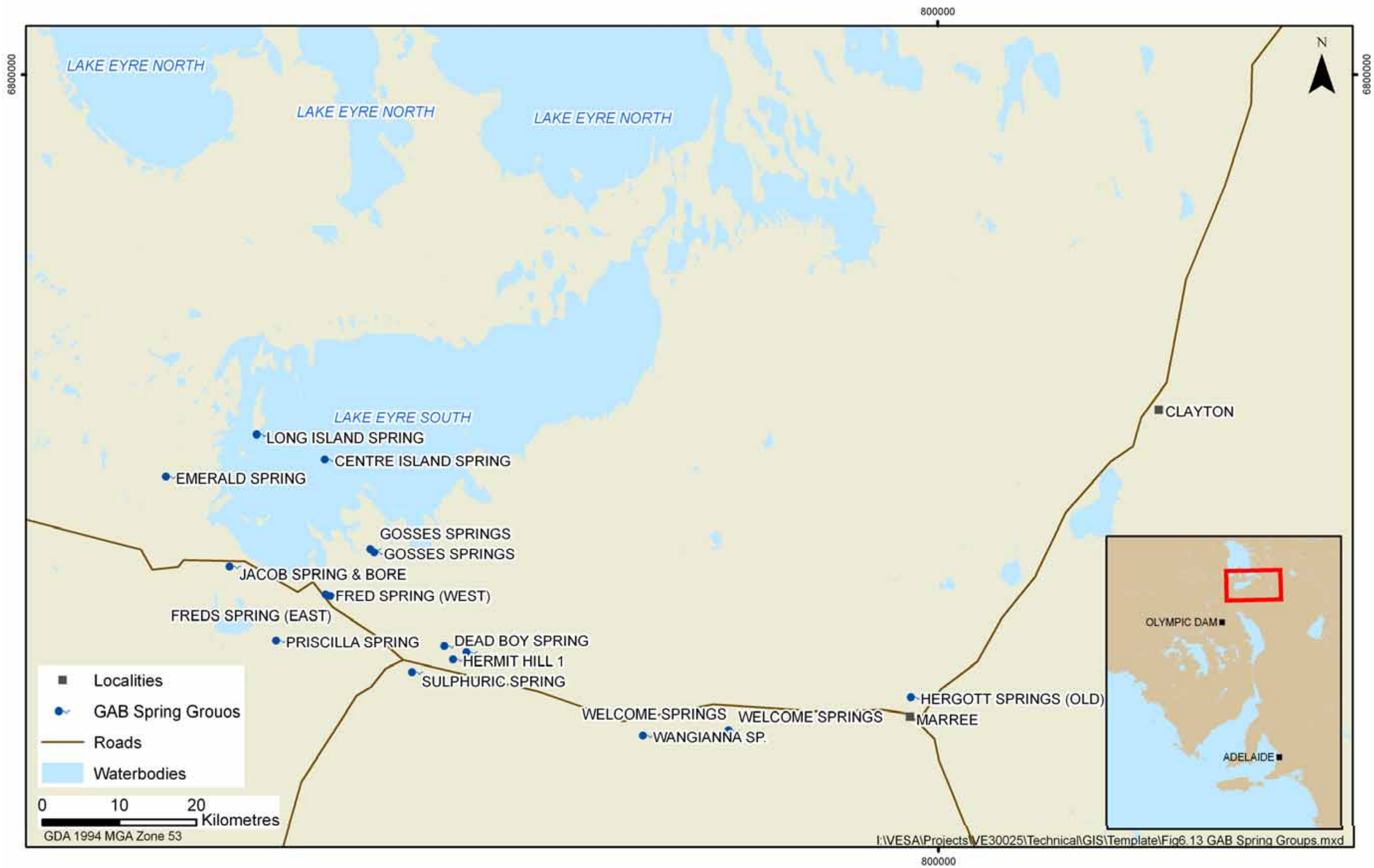


Figure 6-15 GAB spring groups

Snowden (2005) found that a statistically significant, but slight, increase in groundwater salinity is evident from 1996 across the Wellfield A area (mostly in groundwater sampled from the abstraction wells). This increase coincides with the large reduction in Wellfield A abstraction rates following the commissioning of Wellfield B. However, statistically significant rises in salinity have not been recorded at monitored GAB springs nor at the southwesterly extent of the Wellfield B designated area (Figure 5-2). This supports the observation that Wellfield A is located in an area of complex basement structure and suggests that a component of Wellfield A abstractions is sourced either from fractured basement (Adelaide Geosyncline) rocks or, more likely, underdrainage of shallower confining sediments where salt accumulation of geological time has occurred in response to evaporative processes at the ground surface.

BHP Billiton monitoring and modelling of Wellfield B operations (BHP Billiton, 2007b) show that the pattern of drawdown in response to Wellfield B abstractions generally conforms to that presented in the 1997 EIS (Kinhill, 1997). However, drawdown is greater than predicted on the southeast and northeast boundaries. To the southeast, the aquifer is known to be discontinuous and, as such, is not unexpected but the response to the northeast requires further attention to assess whether factors other than Wellfield B operation are contributing to the observed response (e.g. pastoral water supplies).

Flow rates from springs to the south of Wellfield B have been relatively stable since about 1998, although the southern Welcome Group does exhibit continued declining flow trends that have been evident since monitoring commenced in 1996. This declining trend may or may not be part of natural spring dynamics.

Mine site

Within the SML, apart from mine water, BHP Billiton also produces groundwater from dedicated production wells (Figure 6-1):

- four wells in the Saltwater Wellfield (RD809, RD811, RD813 and RD816) draw water from the THA in the area of Mashers Fault; and
- a single production well (LP02) recovers TSF seepage waters that have mounded beneath TSF cells 2 and 3 in the ALA.

Although, the Saltwater Wellfield pumps from the THA, the influence of operation of the Salt Water Wellfield on THA groundwater levels is not immediately obvious from the interpreted contours presented in Figure 6-6, most likely as a result of water level recovery in response to very low rates of pumping.

Abstraction rates from all of the on-site production wells are monitored (Figure 6-16), as are the groundwater levels in proximity to them (Figure 6-10 and Figure 6-11). The Saltwater Wellfield has operated intermittently since 1988 and LP02 has operated consistently since 1998. As shown on Figure 6-16, average total abstraction rates from operational production wells around the SML have declined between 40 to 50% since 2003 to now total around 1.25 ML/day. The major proportion of present-day abstractions is sourced from the tailing leachate recovery well LP-02.

Since commissioning in 1988, average abstractions from the Saltwater Wellfield have ranged from zero to 2 ML/day, with an operational average of around 0.2 ML/day. The hydrograph for monitoring well RD299 (Figure 6-8) shows that localised drawdowns around the Saltwater Wellfield may range up to 40 m. The reduced rates of abstraction from this wellfield since 2003 are evident in the 15 m or so recovery observed in the hydrograph of well RD299 since that time.

Production well LP02 was commissioned in 1998 for the express purpose of recovering TSF leachate from the ALA. Since that time average maximum abstractions have been similar to those reported for the Saltwater Wellfield, albeit at different times. The success of the TSF leachate recovery program is evident from the hydrograph presented for monitoring well LT02 (Figure 6-11).

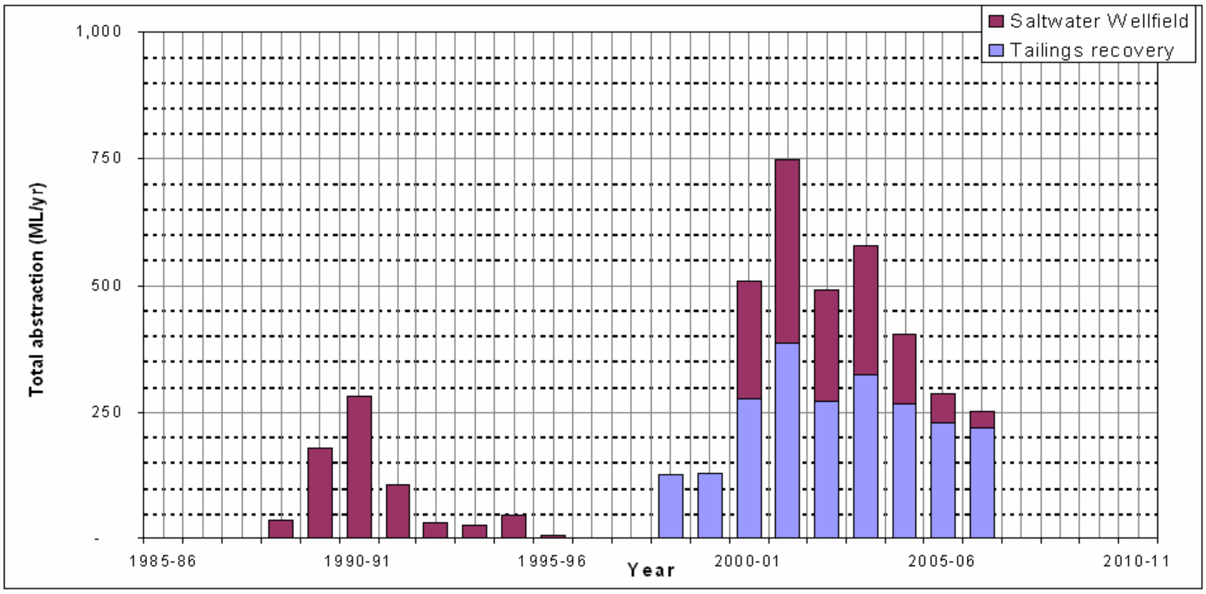


Figure 6-16 Abstraction data for SML wellfields

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STATEMENT OF LIMITATIONS

The services provided by Resource & Environmental Management Pty Ltd in preparing this report and undertaking the various studies contributing to the findings of the report have been conducted in a manner consistent with the level of quality and skill generally exercised by members of its profession and consulting practice.

This report has been prepared solely for use by BHP Limited and may not contain sufficient information for the purposes of other parties or for other uses. Any reliance on this report by third parties shall be at such party's sole risk.

The information in this report is considered to be accurate with respect to conditions encountered at the time field investigations were undertaken, and conclusions are based on the data available at the time of report preparation.

APPENDIX K2

Third-party groundwater users

K2 THIRD-PARTY GROUNDWATER USERS

Chapter 12 (Groundwater) of the Draft EIS presents the findings of a survey of pastoral stations located on the Stuart Shelf and broader Gawler Craton. The assessment was undertaken by Soil and Groundwater Pty Ltd in 2006. This appendix provides the gauging details from the third-party users' survey.

Table K2.1 Summary of Survey and Gauging Data

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
Mulgaria																	
LR 10	25-Jun-06	705533.031	6652117.003	50.250	–	12.56	37.69	0.430	40.54	24.1	14500	8.21	24.80	1.40	-147	N	Monitoring well installed by S&G
LR11	25-Jun-06	701711.707	6651123.710	55.762	–	15.44	40.33	0.520	39.88	23.5	15500	10.15	26.60	2.90	-176	N	Monitoring well installed by S&G
Sister Well	24-Aug-06	746376.939	6667481.257	64.317	–	6.86	57.46	0.000	9.06	23.1	8770	11.62*	15.37	4.50	-74	N	Disused well
Apollo Bore	24-Aug-06	755246.377	6684084.076	111.728	–	25.00	86.73	0.488	34.00	27.7	3310	11.35*	6.05	–	-31	Y	Variable SWL due to pump operation. Water sample taken from poly pipe 1 km from bore. Bore used for stock watering
Yarra Wurta Well	25-Aug-06	710294.55	6668066.12	62.172	–	21.25	40.92	2.000	22.00	19.3	24700	–	40.80	–	-171	N	Disused well. Located adjacent Yarra Wurta Creek. Very shallow water column. Inferred groundwater. Survey point approximately 20 cm above SWL measurement mark
WP1	27-Aug-06	698789.288	6650554.958	60.383	–	19.90	40.48	0.214	46.74	23.6	9080	9.29*	16.04	–	18	N	Bore installed by Tasman Drilling. Water point well for deeper drilling nearby
MS4	27-Aug-06	700009.199	6649691.763	58.972	–	20.17	38.80	0.070	759.00	26.8	25800	11.68*	42.40	10.0*	-335	N	Exploration hole by Tasman. Strong water flow at 40 m during drilling. Strong sulphide odour, high turbidity, dark grey to black – may be residual drilling polymer
MS3	27-Aug-06	699847.846	6651960.021	69.147	–	–	–	0.000	891.00	EXCESSIVE DRILLING POLYMER						N	Exploration hole drilled by Tasman. Water table at approximately 30 m

Table K2.1 Summary of Survey and Gauging Data (cont'd)

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
MS1	27-Aug-06	697819.063	6648733.940	78.605	–	–	–	0.000	–	EXCESSIVE DRILLING POLYMER						N	Exploration hole drilled by Tasman
MS2	27-Aug-06	698128.417	6648642.732	75.634	–	–	–	0.000	–	EXCESSIVE DRILLING POLYMER						N	Exploration hole drilled by Tasman. Water table at approximately 49 m
MSWB 2	27-Aug-06	699893.359	6651955.287	69.058	–	28.62	40.44	0.145	48.00	25.8	10880	12.11*	19.80	6.10	-53	N	Bore installed by Tasman Drilling. Water point well for deeper drilling nearby
MSWB	27-Aug-06	697823.988	6648561.962	79.175	–	38.74	40.44	0.240	52.80	25.3	11540	11.97*	19.98	2.90	-74	N	Bore installed by Tasman Drilling. Water point well for deeper drilling nearby
Census Dam Spring	26-Aug-06	728997.837	6659842.837	39.379	–	–	–	0.000	–	24.4	43100	11.98*	66.70	10*	-26	N	Depth varies between 0 and 45 cm. Could not find an active vent. Highly saline. Water hole 300 m long. Located in creek. Elevation measured at inferred up gradient end
Rocky Creek Spring	26-Aug-06	726670.102	6663338.031	38.54	–	–	–	0.000	–	25.9	47500	11.81*	74.40	–	6	N	Water hole 600 m to 800 m long. Located in creek. Elevation measured at inferred up gradient end
Yarra Wurta Spring	25-Jun-06	715490.901	6660890.0210	37.848	–	–	–	0.000	–	23.1	18200	8.09	30.50	0.10	312	N	Active at time of inspection
Yarra Wurta East Springs 1	26-Aug-06	716364.818	6660489.5550	37.376	–	–	–	0.000	–	23.6	24400	11.95*	40.3	–	-3	N/A	Sample taken from adjacent active vent. At least 6 active vents present – likely more. Located within a large flood plain area

Table K2.1 Summary of Survey and Gauging Data (cont'd)

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
Yarra Wurta East Springs 2	26-Aug-06	716371.756	6660504.8500	37.438	–	–	–	0.000	–	–	–	–	–	–	–	N/A	
Yarra Wurta East Springs 3	26-Aug-06	716438.507	6660514.683	37.52	–	–	–	0.000	–	–	–	–	–	–	–	N/A	
Yarra Wurta East Springs 4	26-Aug-06	716439.732	6660473.963	37.644	–	–	–	0.000	–	–	–	–	–	–	–	N/A	
Yarra Wurta East Springs 5	26-Aug-06	716395.949	6660367.034	37.485	–	–	–	0.000	–	–	–	–	–	–	–	N/A	
Yarra Wurta East Springs 6	26-Aug-06	716393.211	6660413.923	37.35	–	–	–	0.000	–	–	–	–	–	–	–	N/A	
Andamooka																	
Flowing Bore Spring	19-Jun-06	717427.217	6602732.345	53.501	6336-12	0.59	52.91	0.500	–	19.700	5960	7.40	10.64	6.10	-33	N	An active spring
Nick of Time	18-Jun-06	720304.378	6589909.401	88.483	6336-23	26.07	62.41	1.200	29.06	22.7	6050	8.22	10.84	1.40	-239	N	Poor yield based on anecdotal evidence, pungent odour. Undulating surrounds
Mulga Well	16-Jun-06	697104.389	6593669.781	88.720	6336-19	12.46	76.27	0.000	14.32	23.1	1195	7.66	2.28	3.30	1	N	Pumped – 1800 L/day approx – not pumping at time of inspection
Wirrda Well	19-Jun-06	698507.923	6604108.621	95.164	6336-5	21.29	73.87	1.600	28.41	22.3	2830	7.77	5.21	2.40	-81	N	Pumped – both for stock & homestead (Andamooka) Pump did not appear in operation at time of inspection
Pine Bore	19-Jun-06	697310.672	6594788.242	84.306	6336-40	1.73	82.58	0.465	14.91	21.5	5270	7.53	9.42	2.50	19	N	Significant root growth within well casing
Whip Well	17-Jun-06	708351.703	6595399.881	71.968	6336-16	4.78	67.19	0.000	11.24	23.8	7130	7.54	12.66	1.00	-103	N	

Table K2.1 Summary of Survey and Gauging Data (cont'd)

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
Centenary Well	18-Jun-06	720839.588	6599755.964	69.813	6336-10	10.53	59.29	0.000	16.68	23.4	2210	7.96	–	–	–	N	
Rubbish Dump Well	20-Jun-06	710017.831	6630333.159	72.614	–	6.62	65.99	0.600	11.65	23.0	1330	8.51	2.55	4.60	-205	N	
Myall Well	18-Jun-06	721611.722	6597128.216	76.327	6336-11	15.40	60.93	0.700	35.42	24.1	2260	7.85	4.20	2.10	-216	N	
Coorlay Well	15-Jun-06	687491.022	6591897.090	84.578	–	5.19	79.39	1.000	11.25	21.400	6890	8.03	12.26	1.20	-32	N	
Tod Ridge Well 6	17-Jun-06	708680.261	6594213.425	86.168	6336-17	19.95	66.22	1.300	28.05	23.4	5060	7.42	9.01	1.50	-119	N	
North Dam Bore	20-Jun-06	701765.225	6638000.977	77.690	–	22.39	55.30	1.400	27.36	23.7	813	8.52	1.58	1.60	-98	N	
Miracle Dam Bore	19-Jun-06	702888.289	6593316.981	106.937	–	6.51	100.43	0.000	15.04	22.0	1070	7.94	–	–	–	N	
Myall Bore	18-Jun-06	721740.202	6596610.362	77.800	–	18.57	59.23	0.115	36.94	23.9	1990	7.88	3.68	2.30	-219	Y	Pumped – pump in operation during inspection, but appeared to be out of water. Hence not affecting water level
WMC Bore	23-Aug-06	722665.268	6637239.365	33.567	–	1.08	32.49	0.090	6.17	23.3	92800	12.39*	131.60	0.30	-66	N	Bore likely installed by WMC on edge of Lake Torrens. Likely collapse at 6 m. Not used
Yarloo Wells	COLLAPSED	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Pine Wells	COLLAPSED	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Purple Downs																	
Purple Swamp 1	15-Jun-06	680514.841	6592137.627	81.883	6236-17	4.40	77.49	1.000	10.91	21.8	1690	7.46	3.17	2.30	49	Y	Pumped – pump in intermittent operation during inspection
Purple Swamp 2	15-Jun-06	680518.970	6592130.787	81.763	–	4.24	77.53	1.000	10.87	20.2	1736	7.78	3.19	2.00	19	N	
Purple Swamp 3	15-Jun-06	680844.643	6591395.016	83.113	–	5.11	78.00	1.000	7.35	19.9	5090	7.64	9.21	3.40	28	N	

Table K2.1 Summary of Survey and Gauging Data (cont'd)

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
Wilson Well	17-Jun-06	695214.979	6575986.214	111.733	6336-35	13.42	98.31	1.500	20.98	20.6	1008	7.64	1.94	1.00	-141	N	
WB6	16-Jun-06	682578.303	6581470.630	113.466	6236-53	20.80	92.67	0.357	210.00	23.2	6120	7.82	10.93	1.20	-120	N	Possibly a bore drilled for road construction
Horse Well	17-Jun-06	695155.778	6575031.133	114.059	6336-37	15.00	99.06	0.500	17.53	21.700	1420	6.49	2.68	1.00	204	N	Undulating surrounds
Gilles Well	COLLAPSED	–	–	–	–	–	–	–	–	–	–	–	–	–	–	N	
Roxby Downs																	
Chances Well	15-Jun-06	668814.540	6601716.899	95.947	6236-5	17.77	78.17	1.300	34.90	21.000	1133	7.91	2.17	1.20	-109	N	
Chances Well 2	15-Jun-06	668823.985	6601717.541	96.192	–	17.91	78.29	1.300	34.20	21.800	1020	7.98	1.96	3.10	5	N	
Sister Well 1	15-Jun-06	651171.184	6602566.485	88.828	6236-10	16.23	72.59	1.500	31.24	22.9	2000	7.79	1.90	5.72	-27	N	
Sister Well 2	15-Jun-06	651173.808	6602599.675	88.212	–	17.14	71.07	1.000	27.83	23.0	1290	8.01	2.44	2.90	11	Y	Pumped – pump in intermittent operation during inspection
Boundary Well	25-Jul-06	635241.124	6584243.273	135.889	–	42.30	93.58	0.600	44.07	22.4	4053	7.45	9.96	2.08	87	N	Not pumped, but well 500 m to SW was pumped via windmill (low volume)
Bambridge Well	15-Jun-06	653451.701	6604383.229	93.633	–	21.81	71.82	1.500	33.78	22.600	3080	7.95	5.64	3.40	-34	N	Pumped via windmill – windmill turning at time of inspection but did not appear to be pumping large volumes, if anything
Anna Creek																	
Lower Nth Creek Well	27-Jun-06	608700.457	6740074.041	85.868	–	24.97	60.90	0.535	27.89	21.8	1157	9.55	2.21	5.00	-238	N	Pumped by windmill and solar pump. Did not appear to be pumped at time of inspection. Slightly undulating surrounds

Table K2.1 Summary of Survey and Gauging Data (cont'd)

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
Billakalina																	
Curdlawidny Well	28-Jun-06	627888.312	6659000.277	89.909	–	36.28	53.63	1.500	37.70	21.500	12150	8.87	20.97	4.00	-226	N	
Hunts Bore	27-Jun-06	633042.498	6728951.525	56.264	–	4.05	52.21	0.354	7.85	23.900	2730	8.93	5.00	4.40	-184	Y	Pumped – variable SWL at time of inspection as pump in operation
Tuckers Bore	27-Jun-06	615810.343	6713833.374	81.933	–	25.32	56.62	0.300	27.28	17.3	1650	9.09	3.11	–	–	Y	Pumped by solar pump – pumping continuously at time of inspection
Mount Eba																	
North Homestead Bore	30-Jul-06	564878.337	6662537.365	163.040	–	56.58	106.46	0.280	82.29	23.8	3040	8.11	6.80	1.90	-163	N	Bore not used at all. Ideal for ongoing monitoring
Margaret Bore	29-Jul-06	550597.801	6663080.055	166.519	–	49.20	117.32	0.350		19.5	5060	7.70	11.19	6.52	95	Y	Pumped at time of inspection – approximately 3 to 4 l/min
Nicholls Well	28-Jul-06	561372.128	6707780.614	209.609	–	26.52	183.09	1.200	29.40	22.1	3409	8.74	0.82	3.19	92	N	Disused well
No. 1 Bore	28-Jul-06	579831.082	6698976.758	152.925	–	?	–	–	?	16.7	5407	7.74	–	–	–	Y	
Well near Central Dam	COLLAPSED	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Wirraminna																	
Pinchega Well	25-Jul-06	606977.403	6574949.243	136.338	–	18.52	117.82	1.200	19.13	21.3	4074	7.09	10.40	4.38	77	Y	Pumped via windmill – pumping at time of inspection
Old Pinchega Well	COLLAPSED	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Bon Bon																	
Mount Ernest Well	29-Jun-06	556389.103	6640074.042	146.820	–	18.63	128.19	0.600	19.71	23.5	2150.0	8	4.90	5.68	70	Y	Pumped via windmill and submersible. Pumped very low volume at time of inspection

Table K2.1 Summary of Survey and Gauging Data (cont'd)

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
Parakylia																	
Arcoona Clave Well	12-Jul-06	621477.038	6605710.620	95.627	–	4.18	91.45	0.700	6.23	20.9	394	6.56	0.97	2.63	229	N	Not pumped at all
Red Lake bore	12-Jul-06	640271.969	6632422.413	88.775	–	36.35	52.42	0.600	43.51	22.9	1290	7.11	3.06	2.44	-182	N	Not pumped
19 Mile Bore	13-Jul-06	608852.987	6644932.329	100.022	–	30.77	69.26	0.000	37.29	–	1780	7.95	4.09	–	77	N	Well 20 m away pumping a low volume
New Parakylia Bore	13-Jul-06	634733.533	6635361.091	76.214	–	23.15	53.07	0.245	38.95	21.6	1220	7.74	2.84	7.23	59	N	New bore – not used yet, but will be developed soon
Nolah Well	DRY	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Comet Well	29-Aug-06	634946.740	6635353.541	76.348	–	24.60	51.75	1.800	29.23	25.7	2270	11.41*	4.24	4.00	26	N	Pumped for stock watering. Pumped to nearby tank (pump shed tank), where water is then distributed to a number of locations. Pumped via windmill
Old Homestead Well	29-Aug-06	635432.015	6636758.207	77.769	–	26.60	51.17	1.000	35.30	24.3	2000	10.83*	3.77	5.70	-27	N	Pumped via windmill. Can be pumped dry. Pumps to same tank as Comet well and to Twin Tanks to the west
Southern Cross Well	29-Aug-06	634616.186	6635356.221	76.218	–	Could not get down well		0.800	–	28.2	2770	11.35*	5.11	6.10	-78	Y	Pumped to pump shed tank. Sample retrieved from outlet to pump shed tank
Parakylia South																	
Alex's Bore	25-Jul-06	623342.642	6597795.469	110.357	–	15.72	94.64	0.430	19.80	23.8	2190	5.98	4.97	4.75	187	N	Not pumping at time of inspection, but bore within 7 m was. Bore will pump 1,500 gal/hr and they struggle to pump it dry

Table K2.1 Summary of Survey and Gauging Data (cont'd)

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
Alex's Bore 2	30-Aug-06	623339.931	6597790.336	110.295	–	15.67	94.63	0.300	19.89	Could not retrieve sample						N	Located 7 m south of Alex's Bore 1 – pumped using a diesel pump, but cannot be pumped dry
Knoll Well	25-Jul-06	635445.788	6589966.799	123.930	–	29.63	94.30	1.200	31.95	21.7	3010	7.76	6.91	1.67	-51	N	Not pumped, but located within 70 m of well that was at time of inspection
Knoll Well 2	29-Jan-1900	635445.994	6590040.718	124.067	–	29.91	94.15	1.100	–	23.5	6880	9.38	12.20	–	-75	Y	Pumped via submersible and pump jack. Pumped to adjacent fibre glass tank
No. 1 Well	30-Aug-06	634760.103	6584259.840	137.167	–	42.67	94.50	1.320	46.67	24.7	3400	9.23	6.25	6.27	-88	N	Pumped via windmill and submersible. Pumps into adjacent tank
Homestead Bore	26-Jul-06	614014.467	6690318.699	111.862	–	44.08	67.79	0.390	50.53	23.9	999	7.49	2.34	1.91	43	N	Not used at all
Millers Creek																	
BFT 001	26-Jul-06	603024.437	6702099.331	130.396	–	62.39	68.00	0.760	Unknown	24.6	5024	7.21	11.93	0.57	-296	N	Recently installed. Still large amounts of drilling mud in bore which may affect wq data – will soon be developed and pumped
Trig Bore	26-Jul-06	593969.865	6687291.875	132.667	–	60.48	72.19	0.230	>100	23.8	4540	9.23	9.94	1.99	-97	N	Not used at all
Moodlampnie Bore	27-Jul-06	610029.535	6671361.846	113.729	–	47.27	66.46	0.105	57.13	21.5	9910	8.76	21.04	0.93	-80	N	Not used at all
No. 11 Bore	27-Jul-06	592289.264	6652806.515	138.576	–	62.72	75.86	0.100	71.80	23.8	6110	8.70	13.42	1.03	-113	N	Not used at all. Pungent odour on water
McDoual Peak																	
White Nob Bore	28-Jul-06	533326.234	6695255.918	200.804	–	77.80	123.00	0.290	79.82	19.1	5260	7.99	11.43	6.10	83	N	Pumped for stock via submersible pump, but not at time of inspection. Water sample retrieved from tank

Table K2.1 Summary of Survey and Gauging Data (cont'd)

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
CRA Bore	28-Jul-06	543020.065	6713219.622	216.605	–	98.35	118.26	0.190	▸100	–	–	–	–	–	–	N	Not pumped during inspection, but can pump 600gal/hr for 1 day, but creates drawdown. Could not retrieve water sample as bailer would not fit and no nearby tank
McDoual Peak Homestead Well	28-Jul-06	537766.509	6681747.749	184.969	–	23.73	161.24	1.150	28.20	22.6	636	8.94	1.50	5.91	64	Y	Pumped very low volume at time of inspection via windmill
Mount Vivian																	
Fishers Well	30-Jul-06	582383.998	6629782.921	147.156	–	15.07	132.08	0.600	15.79	22.5	287	8.46	711.00	4.07	30	N	Next to windmill within 5 m which are connected via a underground tunnel – windmill was pumping approx 3L/min, but was not considered to affect SWL in well. Drilling a new bore within 15m at time of inspection as small water column in well
Lively Well	30-Jul-06	577303.268	6608995.145	156.673	–	21.86	134.81	1.000	41.45	22.0	2096	8.35	4.58	8.69	94	N	Pumped very slightly at time of inspection via windmill – was not affecting SWL as can tell using dipper. Water sample collected from tank
Police Camp Well	DRY	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Deep Bore	DRY	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	

Table K2.1 Summary of Survey and Gauging Data (cont'd)

Bore/Well Name	Date	Easting (MGA 94)	Northing (MGA 94)	Reference Point Elevation (mAHD)	Unit #	SWL (m)#	RSWL (mAHD)	Stickup^	Total Depth (m)#	Temp-erature (OC)	Salinity (ppm)	pH	Conductivity (mS/cm)	DO (ppm)	Redox (mV)	Pumped During Insp-ection?	Comments
Arcoona																	
Mungapote Well	31-Jul-06	652424.294	6566031.066	110.177	–	6.45	103.73	0.000	7.32	22.4	5750	6.52	12.48	1.79	-118	N	Well not used at all. Located adjacent creek bed
MW4	31-Jul-06	675575.812	6548631.327	134.397	–	15.88	118.52	0.610	20.43	22.7	9750	6.29	20.71	2.24	-43	N	Monitoring bore installed by Volker – was pumped by Volker the previous day
WB7	31-Jul-06	681631.037	6567413.563	137.930	–	23.37	114.56	0.290	Unknown	22.0	8170	7.22	17.48	1.98	-74	N	Bore not used – likely installed as part of road construction
Engine Well	31-Jul-06	698068.213	6560786.293	130.467	–	11.02	119.45	0.600	17.87	20.5	1280	8.00	2.93	2.83	-132	N	Well not used

Notes:
* – pH probe unlikely to be working accurately.
^ – Stickup refers to height of reference point above surrounding natural ground surface.
# – Standing water level and total depth measured from reference point.

APPENDIX K3

Baseline groundwater quality assessment

K3 BASELINE GROUNDWATER QUALITY ASSESSMENT

Chapter 12 (Groundwater) of the Draft EIS presents the findings of a groundwater baseline assessments for the proposed Olympic Dam Expansion. The assessment was undertaken by Resource and Environmental Management Pty Ltd (REM). This appendix provides supplementary information in relation to the methodology undertaken and the detailed findings of the assessment.

K3.1 FIELD AND DESKTOP INVESTIGATIONS

The primary objective of undertaking the baseline survey of groundwater quality was to obtain baseline data and identify potential risks to groundwater resources associated with the construction and operation of the infrastructure corridor.

Stuart Shelf and Olympic Dam SML

Ten groundwater monitoring wells on and close to the existing Olympic Dam SML were sampled for groundwater quality parameters. These wells are monitored regularly by Olympic Dam Operations environmental team as part of an ongoing groundwater monitoring program. With the exception of QT02 and QT04, which are screened within the Tent Hill aquifer beneath the existing tailings storage facility (TSF), wells are considered to be representative of regional groundwater quality and not influenced by the existing operations.

Following an assessment of regional groundwater elevations across the Stuart Shelf (see Appendix K2 for further details), it was apparent that there was a lack of drill holes (and therefore available groundwater data) in the northeast region of the study area, between the SML and Lake Torrens. To fill this gap nine additional groundwater monitoring wells (including some nested wells) were drilled (BHP Billiton unpublished data). These wells were sampled for baseline groundwater quality and results have been provided here.

Gas pipeline corridors

A comprehensive desktop review of baseline groundwater conditions associated with both the northern and southern infrastructure corridor was undertaken. In addition to the desktop assessment, a field investigation was undertaken along the southern infrastructure corridor. Due to inaccessibility (i.e. only available by helicopter), groundwater samples could not be collected from the northern infrastructure corridor. Baseline groundwater parameters have been summarised from drillhole records located along the corridor (SAGeodatabase 2008).

Southern infrastructure corridor

Assessment of State and BHP Billiton records identified 142 potential wells available for sampling south of the Olympic Dam SML. Forty six wells were initially considered to be appropriate for sampling based on spatial coverage along the infrastructure corridor, construction parameters and depth. Of the 46 wells, 21 wells were chosen as they were accessible, less than 100 metres deep and provided a representative sample of the total wells along the corridor.

K3.2 FIELD SAMPLING METHODOLOGY

Sampling was carried out over the period 28 July though 14 August 2006 (with the exception of the new groundwater monitoring wells drilled in September 2007). Samples taken from unequipped wells were purged of at least three well volumes or until parameters of pH, redox (Eh) electrical conductivity (EC) and temperature stabilised. Readings were considered to be stable when pH was within 0.05 pH unit, EC was within 3%, Redox was within 10 mV and temperature was within 0.5 °C of the previous set of parameters.

Disposable bailers were used where the well diameter was too small for the 12 V submersible pump to fit in the well or the depth of water was too great to lift the head of water to the surface. The purging process ensured that the groundwater samples collected were representative of groundwater in the aquifer at that location. Field chemical parameters were recorded after each well volume was removed, to ensure stable geochemical conditions existed prior to the collection of the groundwater sample. The pH, redox, electrical conductivity and temperature meters were calibrated prior to the commencement of purging.

Where wells were equipped and samples could be obtained at the well head, the well was pumped and field parameters were measured at set time intervals from the pumped water until parameters had stabilised. A sample of groundwater was collected. Where wells were equipped with a windmill that did not provide access, samples were collected for subsequent laboratory testing from the nearest accessible tank.

K3.3 LABORATORY TESTING

Groundwater samples were placed in laboratory cleaned bottles containing appropriate preservatives, and then placed into a chilled esky for transport to the Australian Laboratory Services (ALS), a National Association of Testing Authorities (NATA) registered laboratory. Intra-duplicate and inter-duplicate groundwater samples were also collected and sent to ALS and Labmark Laboratories, (another NATA registered laboratory). Groundwater samples analysed for metals were filtered in the field using dedicated 0.45 micron filter for each sample and were placed into pre-acidified containers.

All samples collected were analysed for:

- major ions – sulphate, chloride, calcium, magnesium, sodium, potassium and silicon
- total alkalinity and Bicarbonate as $CaCO_3$
- electrical conductivity (EC)
- metals – arsenic, beryllium, barium, cadmium, chromium, cobalt, copper, lead, manganese, nickel, uranium, vanadium, zinc and mercury.

Analytical data for groundwater samples were compared against the following published criteria:

- SA EPA (2003) Water Quality Criteria Potable Water
- SA EPA (2003) Water Quality Criteria Livestock
- SA EPA (2003) Water Quality Criteria Irrigation
- SA EPA (2003) Water Quality Criteria Aquatic Ecosystem (Fresh)
- NHMRC (2004) Australian Drinking Water Guidelines Health.

K3.4 RESULTS

The following tables and figures provide data to supplement the information summarised within the groundwater chapter of the Draft EIS.

- Figure K4.1 – Groundwater well locations
- Table K4.1 – Summary of groundwater wells and field survey parameters
- Table K4.2 – Groundwater analytical results for the southern infrastructure corridor
- Table K4.3 – Groundwater analytical results for Olympic Dam SML
- Table K4.4 – Groundwater analytical results for new groundwater monitoring wells.

Figure K3.1 Groundwater sampling locations

Table K3.1 Summary of groundwater wells and field survey parameters

Well Name	Date	pH	Electrical Conductivity (mS/cm)	Total Dissolved Solids* (mg/L)	Redox Potential (mV)	Temperature (°C)	Depth to Groundwater (m bgl)	Well depth (m)	Target Aquifer
Southern infrastructure corridor									
LR3 (RD118)	27-Jul-06	7.4	26.5	17225	82	19.9	31.8	58	Andamooka Limestone
QR3 (RD 115)	27-Jul-06	6.7	7.62	4953	-112	19.9	49.0	169	Tent Hill Formation
LR6	29-Jul-06	7.5	40.1	26065	84	22.0	49.7	75	Unknown
WB4	28-Jul-06	6.5	120	78000	-58	23.4	11.3	155	Tent Hill Formation
PURPLE DOWNS	28-Jul-06	7.8	5.94	3861	110	13.1	4.4	11	Andamooka Limestone
WB7	30-Jul-06	7.9	20.3	13215	-187	21.3	23.2	130	Tent Hill Formation
PARADISE WELL	30-Jul-06	8.0	10.0	6507	61	15.0	–	–	Unknown
MW 4	30-Jul-06	6.1	27.2	17680	-54	19.6	15.4	21	Tent Hill Formation
GW104	31-Jul-06	6.6	66.7	43329	97	19.8	8.5	11	Unknown
WIRRAPPA DAM WELL	31-Jul-06	6.2	188	122070	-36	19.4	4.9	151	Unknown
BELLAMY WELL	01-Aug-06	6.9	44.1	28665	-232	22.5	28.0	41	Tent Hill Formation
DOG HOLLOW WELL	01-Aug-06	9.8	0.47	306	41	14.5	5.0	22	Tent Hill Formation
WARKANNA WELL	02-Aug-06	8.2	3.64	2366	9	11.9	7.1	13	Tent Hill Formation
UROS BLUFF	02-Aug-06	6.9	30.2	19630	3	20.6	20.2	108	Unknown
643300050	03-Aug-06	4.4	4.64	3016	-44	20.0	9.5	29	Tent Hill Formation
JOHN WAYNE	03-Aug-06	6.7	66.0	42900	41	21.2	8.5	12	Tent Hill Formation
643300509	04-Aug-06	6.8	41.4	26910	27	21.4	10.4	23	Tent Hill Formation
MB15	05-Aug-06	8.4	15.8	10264	41	20.5	5.3	6	Quaternary sediments
WEG ROCK	04-Aug-06	7.4	94.5	61425	77	15.9	0.5	3	Quaternary sediments
643200988	05-Aug-06	7.5	16.4	10628	-68	19.8	17.9	24	Unknown
COMET BORE	06-Aug-06	7.5	8.29	5389	88	20.8	–	–	Unknown
Stuart Shelf and Olympic Dam SML									
LR01	9-Aug-06	7.0	34.6	22490	-50	24.9	55.0	68	Andamooka Limestone
LR02	8-Aug-06	7.4	27.5	17875	-28	22.7	56.3	70	Andamooka Limestone
LR04	8-Aug-06	6.7	15.2	9848	-58	22.7	67.8	79	Andamooka Limestone
LR08	12-Aug-06	7.0	43.9	28535	-69	26.5	54.7	67	Andamooka Limestone
LR09	11-Aug-06	6.6	40.2	26130	-39	20.9	39.4	50	Andamooka Limestone
LR10	13-Aug-06	6.9	50.5	32825	-56	22.6	12.5	40	Andamooka Limestone
LR11	13-Aug-06	6.8	39.2	25480	-42	21.1	15.4	40	Andamooka Limestone

Table K3.1 Summary of groundwater wells and field survey parameters (cont'd)

Well Name	Date	pH	Electrical Conductivity (mS/cm)	Total Dissolved Solids* (mg/L)	Redox Potential (mV)	Temperature (°C)	Depth to Groundwater (m bgl)	Well depth (m)	Target Aquifer
QR01	9-Aug-06	7.0	33.5	21775	-100	24.4	–	184	Corraberra Sandstone
QR02	9-Aug-06	7.2	44.4	28860	-109	25.7	58.6	184	Corraberra Sandstone
QT02	10-Aug-06	8.1	51.2	33280	-223	23.0	–	184	Corraberra Sandstone
QT04	10-Aug-06	7.6	60.1	39065	-79	23.7	–	213	Corraberra Sandstone
RT-1	16-Sep-07	7.6	341	193000	–	–	11.5	474	Tregolana Shale
RT-2a	16-Sep-07	7.6	55.0	43400	–	–	55.1	295	Andamooka Limestone
RT-2b	16-Sep-07	7.7	328	203000	–	–	69.3	342	Arcoona Quartzite (red)
RT-3	16-Sep-07	7.5	30.0	19500	–	–	59.9	149	Andamooka Limestone
RT-4a	16-Sep-07	7.6	49.0	31700	–	–	32.1	58	Andamooka Limestone
RT-4b	16-Sep-07	7.5	327	191000	–	–	55.1	552	Yarloo Shale
RT-5a	16-Sep-07	7.6	99.6	62200	–	–	9.5	66	Andamooka Limestone
RT-5b	16-Sep-07	7.7	404	261000	–	–	21.6	200	Andamooka Limestone
RT-5c	16-Sep-07	7.6	430	257000	–	–	16.6	634	Brachina Formation
RT-7a	16-Sep-07	7.5	88.3	60200	–	–	13.0	36	Andamooka Limestone
RT-7b	16-Sep-07	7.7	90.7	62400	–	–	18.4	96	Andamooka Limestone
RT-9	16-Sep-07	7.1	54.3	31000	–	–	16.3	71	Brachina Formation
RT-16a	18-Sep-07	7.2	34.5	22100	–	–	59.1	68	Andamooka Limestone
RT-16b	18-Sep-07	7.5	84.5	56700	–	–	71.5	252	Corraberra Sandstone
RT-17a	6-Sep-07	–	29.0	18850	–	–	52.7	84	Andamooka Limestone
RT-17b	6-Sep-07	–	75.0	48750	–	–	72.2	264	Corraberra Sandstone

Note: pH and TDS results presented for wells RT-1 to RT-17b are laboratory results.
a,b,c in wells RT1-17 indicate multiple screens installed in the same drill hole (nested wells).
m bgl = metres below ground level.

Table K3.2 Groundwater analytical results for the southern infrastructure corridor

Chemical	Limit of reporting	Units	SA EPA EPP (Water Quality) 2003 POTABLE USE	SA EPA EPP (Water Quality) 2003 IRRIGATION	SA EPA EPP (Water Quality) 2003 LIVESTOCK	NHMRC Australian Drinking Water Guidelines 2004 HEALTH	QR3	LR3	LR6	WB4	PURPLE DOWNS	WB7	PARADISE WELL
						Date Sampled	27-Jul-06	27-Jul-06	29-Jul-06	28-Jul-06	28-Jul-06	30-Jul-06	30-Jul-06
MAJOR IONS AND TDS													
Total Dissolved Solids	1	mg/L				500 (1,2)	23600	17500	21100	112000	3000	11300	5150
Sulphate SO_4^{2-}	1	mg/L				500	4160	2930	4600	12700	864	1420	362
Chloride	1	mg/L					11700	8450	9260	60800	1030	5920	2900
Calcium	1	mg/L					625	566	708	1150	198	787	421
Magnesium	1	mg/L					672	453	588	2560	135	225	96
Sodium	1	mg/L					6160	4950	5760	34300	625	2840	1270
Potassium	1	mg/L					74	62	60	188	9	21	4
ALKALINITY													
Hydroxide Alkalinity as $CaCO_3$	1	mg/L					<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	1	mg/L					<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	1	mg/L					302	101	202	216	228	98	165
Total Alkalinity as $CaCO_3$	1	mg/L					302	101	202	216	228	98	165
TOTAL METALS													
Arsenic	0.001	mg/L	0.007	0.1	0.5	0.007	<0.010	<0.001	<0.010	<0.010	0.001	<0.001	0.001
Beryllium	0.001	mg/L		0.1	0.1		<0.010	<0.001	<0.010	<0.010	<0.001	<0.001	<0.001
Barium	0.001	mg/L	0.7			0.7	0.025	0.001	0.041	0.036	0.018	0.048	0.006
Cadmium	0.0001	mg/L	0.002	0.01	0.01	0.002	<0.0010	<0.0001	<0.0010	<0.0010	<0.0001	<0.0001	0.0002
Chromium	0.001	mg/L		1	1	0.05	<0.010	0.01	<0.010	<0.010	<0.001	<0.001	<0.001
Cobalt	0.001	mg/L		0.05	1		<0.010	<0.001	0.019	<0.010	<0.001	<0.001	<0.001
Copper	0.001	mg/L	2	0.2	0.5	2	0.044	0.005	<0.020	<0.020	0.007	0.002	0.002
Lead	0.001	mg/L	0.01	0.2	0.1	0.01	<0.010	<0.001	<0.010	<0.010	<0.001	<0.001	<0.001
Manganese	0.001	mg/L	0.5	2		0.5	0.763	<0.001	2.62	0.698	0.004	0.297	0.019
Mercury	0.0001	mg/L	0.001	0.002	0.002	0.001	<0.0001	0.0027	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	0.001	mg/L	0.02	0.2	1	0.02	<0.010	<0.001	0.014	<0.010	0.002	<0.001	<0.001
Uranium	0.001	mg/L	0.02	0.01	0.2	0.02	<0.010	0.023	0.016	<0.010	0.027	<0.001	0.003
Vanadium	0.01	mg/L		0.1	0.1		<0.1	<0.01	<0.1	<0.1	0.03	<0.01	0.02
Zinc	0.005	mg/L		2	20		0.179	0.01	<0.050	<0.050	0.017	<0.005	0.186

Notes:

Sample Concentration in Excess of Adopted Guideline

[1] NHMRC Australian Drinking Water Guidelines 2004 – Aesthetic.

[2] The Australian Drinking Water Guidelines (2004) states that total dissolved solid (TDS) concentrations <500 mg/L is regarded as good quality drinking water based on taste and 500-1000 mg/L is considered acceptable based on taste.

MW4	GW104	WIRRAPA DAM WELL	BELLAMY WELL	DOG HOLLOW WELL	WARK-ANNA WELL	URO'S BLUFF BORE	6433 0050	JOHN WAYNE	6443 0509	MB15	WEG ROCK	6432 00988	COMET BORE
30-Jul-06	31-Jul-06	31-Jul-06	01-Aug-06	01-Aug-06	02-Aug-06	02-Aug-06	03-Aug-06	03-Aug-06	04-Aug-06	05-Aug-06	04-Aug-06	05-Aug-06	06-Aug-06
18300	32600	212000	29700	234	2600	24100	1630	45400	13800	6870	86900	8460	4760
2230	1440	11200	2710	35	1510	1600	17	5160	908	1270	6550	1480	826
9700	19900	128000	16600	89	259	13500	1380	23400	7680	2580	49500	3880	2010
1080	2880	1400	771	12	497	582	164	1120	432	14	1100	683	142
461	713	5530	887	8	49	528	4	1160	539	62	2280	382	109
4680	7600	66000	8480	61	249	7690	57	14400	4080	2350	26800	1930	1500
65	21	409	130	3	11	58	11	31	17	131	525	38	19
<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
183	119	60	164	42	37	306	<1	138	162	771	219	104	260
183	119	60	164	44	37	306	<1	138	162	771	219	104	260
<0.010	<0.010	<0.010	<0.010	<0.001	0.005	0.016	<0.001	<0.010	<0.001	<0.001	<0.010	0.002	0.014
<0.010	<0.010	<0.010	<0.010	<0.001	<0.001	<0.001	<0.001	<0.010	<0.001	<0.001	<0.010	<0.001	<0.001
0.027	0.126	0.035	0.066	0.028	0.009	0.01	0.083	0.018	0.026	0.009	0.035	0.032	0.058
<0.0010	<0.0010	<0.0010	<0.0010	<0.0001	0.0002	<0.0001	<0.0001	<0.0010	<0.0001	<0.0001	<0.0010	0.0001	0.0006
<0.010	<0.010	<0.010	<0.010	<0.001	<0.001	<0.001	<0.001	<0.010	0.001	<0.005	<0.010	0.001	<0.001
<0.010	<0.010	<0.010	<0.010	<0.001	<0.001	<0.001	0.007	<0.010	<0.001	<0.001	<0.010	<0.001	0.004
<0.020	<0.020	<0.020	<0.020	0.001	0.003	0.001	<0.001	<0.020	0.002	<0.001	<0.020	0.002	0.108
<0.010	0.021	0.013	<0.010	<0.001	<0.001	<0.001	<0.001	<0.010	<0.001	<0.001	<0.010	<0.001	0.001
3.34	0.057	4.37	0.964	0.002	0.01	0.148	5.48	0.759	0.002	<0.001	0.062	0.015	0.185
<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
<0.010	<0.010	<0.010	<0.010	<0.001	<0.001	<0.001	0.01	<0.010	<0.001	<0.001	<0.010	<0.001	0.006
<0.010	0.178	<0.010	<0.010	<0.001									
<0.1	<0.1	<0.1	<0.1	<0.01	<0.01	<0.01	<0.01	<0.10	<0.01	<0.01	<0.10	0.01	<0.01
<0.050	<0.050	0.564	<0.050	0.009	0.02	0.022	0.012	<0.050	0.009	<0.005	<0.050	0.005	0.225

Table K3.3 Groundwater analytical results for Olympic Dam SML

Chemical	Limit of reporting	Units	SA EPA EPP (Water Quality) 2003 POTABLE USE	SA EPA EPP (Water Quality) 2003 IRRIGATION	SA EPA EPP (Water Quality) 2003 LIVESTOCK	SA EPA EPP (Water Quality) 2003 AQUATIC ECOSYTEMS (FRESH)	NHMRC Australian Drinking Water Guidelines 2004 HEALTH	QT02	QT04	LR01	LR02	LR04	LR08	QR01	QR02	LR10	LR11
							Location / Date Sampled	10-Aug-06	10-Aug-06	10-Aug-06	10-Aug-06	10-Aug-06	12-Aug-06	12-Aug-06	12-Aug-06	13-Aug-06	13-Aug-06
MAJOR IONS AND TDS																	
Total Dissolved Solids	1	mg/L					500 (1,2)	37900	46700	25400	18600	10600	31500	23500	32300	38300	28400
Sulphate SO_4^{2-}	1	mg/L					500	6520	5740	4440	3000	2000	4860	4480	4990	4630	4390
Chloride	1	mg/L						18000	25000	12200	8930	4660	15500	11000	15500	19700	14200
Calcium	1	mg/L						540	1030	952	721	451	978	590	328	988	963
Magnesium	1	mg/L						952	1270	858	482	279	820	706	572	932	831
Sodium	1	mg/L						11800	13400	6730	5370	2920	9170	6540	10800	12000	7920
Potassium	1	mg/L						74	99	52	43	38	72	63	76	74	77
Silicon	1	mg/L						4.09	5.55	8.44	6.7	10.7	3.93	3.88	1	–	–
ALKALINITY																	
Hydroxide Alkalinity as $CaCO_3$	1	mg/L						<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	1	mg/L						<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	1	mg/L						50	252	226	140	515	112	238	100	261	288
Total Alkalinity as $CaCO_3$	1	mg/L						50	252	226	140	515	112	238	100	261	288
NUTRIENTS																	
Ammonia as N	0.01	mg/L	0.5					2.52	0.138	0.029	0.056	0.622	0.028	2.15	4.7	0.233	0.185
Nitrite as N	0.01	mg/L		1		10	3	<0.010	0.023	<0.010	<0.010	<0.010	<0.010	<0.010	0.246	0.029	<0.010
Nitrate as N	0.01	mg/L		10		30	50	0.124	1.22	<0.010	0.015	<0.010	<0.010	<0.010	0.83	0.488	<0.010
Nitrite + Nitrate as N	0.01	mg/L						0.124	1.25	<0.010	0.015	<0.010	<0.010	<0.010	1.08	0.517	<0.010
Total Phosphorus as P	0.01	mg/L	0.1					<0.01	0.2	0.51	<0.01	0.18	0.02	0.15	0.13	0.05	0.04
METALS																	
Arsenic	0.001	mg/L	0.007	0.1	0.5	0.05	0.007	<0.010	<0.010	<0.001	<0.001	0.004	<0.010	0.002	<0.010	0.02	0.005

Table K3.3 Groundwater analytical results for Olympic Dam SML (cont'd)

Chemical	Limit of reporting	Units	SA EPA EPP (Water Quality) 2003 POTABLE USE	SA EPA EPP (Water Quality) 2003 IRRIGATION	SA EPA EPP (Water Quality) 2003 LIVESTOCK	SA EPA EPP (Water Quality) 2003 AQUATIC ECOSYTEMS (FRESH)	Location / Date Sampled / NHMRC Australian Drinking Water Guidelines 2004 HEALTH	QT02 10-Aug-06	QT04 10-Aug-06	LR01 10-Aug-06	LR02 10-Aug-06	LR04 10-Aug-06	LR08 12-Aug-06	QR01 12-Aug-06	QR02 12-Aug-06	LR10 13-Aug-06	LR11 13-Aug-06
Beryllium	0.001	mg/L	0.004		0.1	0.1		<0.010	<0.010	<0.001	<0.001	<0.001	<0.010	<0.001	<0.010	<0.001	<0.001
Barium	0.001	mg/L		0.7			0.7	0.02	0.033	0.015	0.014	0.049	0.022	0.086	0.038	0.027	0.03
Cadmium	0.0001	mg/L	0.002	0.01	0.01	0.002	0.002	<0.0010	<0.0010	0.0001	<0.0001	<0.0001	<0.0010	<0.0001	<0.0010	0.0002	<0.0001
Chromium	0.001	mg/L		1	1		0.05	<0.010	<0.010	0.002	0.002	0.001	<0.010	0.001	<0.010	<0.001	<0.001
Cobalt	0.001	mg/L		0.05	1			<0.010	<0.010	0.002	0.002	0.006	<0.010	0.003	<0.010	0.005	0.002
Copper	0.001	mg/L	2	0.2	0.5	0.01	2	<0.020	<0.020	0.009	0.007	0.004	<0.020	0.004	<0.020	0.014	0.012
Lead	0.001	mg/L	0.01	0.2	0.1	0.005	0.01	<0.010	<0.010	<0.001	0.001	0.014	<0.010	<0.001	<0.010	0.04	<0.001
Manganese	0.001	mg/L	0.5	2			0.5	1.16	0.773	0.426	0.655	1.06	0.2	0.917	0.185	0.592	0.714
Nickel	0.001	mg/L	0.02	0.2	1	0.15	0.02	0.026	<0.010	0.004	0.003	0.012	0.013	0.034	<0.010	0.01	<0.001
Uranium	0.001	mg/L		0.02	0.01	0.2	0.02	<0.010	<0.010	0.054	0.026	0.01	0.017	0.004	<0.010	0.021	0.017
Vanadium	0.01	mg/L			0.1	0.1		<0.10	<0.10	<0.01	<0.01	<0.01	<0.10	<0.01	<0.10	<0.01	<0.01
Zinc	0.005	mg/L		2	20	0.05		<0.050	<0.050	0.01	0.015	0.017	<0.050	0.012	<0.050	0.024	0.013
Mercury	0.0001	mg/L	0.001	0.002	0.002	0.0001	0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Bromine	0.1	mg/L												18.6	29.4	26.8	25.4
ORGANOCHLORINE PESTICIDES																	
alpha-BHC	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
Hexachlorobenzene (HCB)	2	µg/L															
beta-BHC	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
gamma-BHC	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
delta-BHC	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
Heptachlor	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
Aldrin	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
Heptachlor epoxide	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
trans-Chlordane	2	µg/L															
alpha-Endosulfan	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2

Table K3.3 Groundwater analytical results for Olympic Dam SML (cont'd)

Chemical	Limit of reporting	Units	SA EPA EPP (Water Quality) 2003 POTABLE USE	SA EPA EPP (Water Quality) 2003 IRRIGATION	SA EPA EPP (Water Quality) 2003 LIVESTOCK	SA EPA EPP (Water Quality) 2003 AQUATIC ECOSYTEMS (FRESH)	NHMRC Australian Drinking Water Guidelines 2004 HEALTH	QT02	QT04	LR01	LR02	LR04	LR08	QR01	QR02	LR10	LR11
							Date Sampled	10-Aug-06	10-Aug-06	10-Aug-06	10-Aug-06	10-Aug-06	12-Aug-06	12-Aug-06	12-Aug-06	13-Aug-06	13-Aug-06
cis-Chlordane	2	µg/L															
Dieldrin	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
4.4'-DDE	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
Endrin	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
beta-Endosulfan	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
4.4'-DDD	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
Endrin aldehyde	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
Endosulfan sulfate	2	µg/L						<2	<2	<2	<2	–	<2	<2	<2	<2	<2
4.4'-DDT	4	µg/L						<4	<4	<4	<4	–	<4	<4	<4	<4	<4
MONOCYCLIC AROMATIC HYDROCARBONS																	
Benzene	5	µg/L					10	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Toluene	5	µg/L					800	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ethylbenzene	5	µg/L					300	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
meta- & para-Xylene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Styrene	5	µg/L					30	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
ortho-Xylene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Isopropylbenzene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
n-Propylbenzene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.3.5-Trimethylbenzene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
sec-Butylbenzene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.2.4-Trimethylbenzene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
tert-Butylbenzene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
p-Isopropyltoluene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
n-Butylbenzene	5	µg/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Xylenes	10	µg/L					600	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Table K3.3 Groundwater analytical results for Olympic Dam SML (cont'd)

Chemical	Limit of reporting	Units	SA EPA EPP (Water Quality) 2003 POTABLE USE	SA EPA EPP (Water Quality) 2003 IRRIGATION	SA EPA EPP (Water Quality) 2003 LIVESTOCK	SA EPA EPP (Water Quality) 2003 AQUATIC ECOSYSTEMS (FRESH)	Location / Date Sampled / NHMRC Australian Drinking Water Guidelines 2004 HEALTH	QT02 10-Aug-06	QT04 10-Aug-06	LR01 10-Aug-06	LR02 10-Aug-06	LR04 10-Aug-06	LR08 12-Aug-06	QR01 12-Aug-06	QR02 12-Aug-06	LR10 13-Aug-06	LR11 13-Aug-06
HALOGENATED ALIPHATIC HYDROCARBONS																	
Dichlorodifluoromethane	50	ug/l						<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Chloromethane	50	ug/l						<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Vinyl chloride	50	ug/l	0.3				0.3	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Bromomethane	50	ug/l						<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Chloroethane	50	ug/l						<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Trichlorofluoromethane	50	ug/l						<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
2.2-Dichloropropane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.2-Dichloropropane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
cis-1.3-Dichloropropylene	5	ug/l						<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
trans-1.3-Dichloropropylene	5	ug/l						<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
1.2-Dibromoethane (EDB)	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.1-Dichloroethene	5	ug/l	30				300	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Iodomethane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
trans-1.2-Dichloroethene	5	ug/l	60					<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.1-Dichloroethane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
cis-1.2-Dichloroethene	5	ug/l	60					<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.2-Dichloroethene	10	ug/l					60	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
1.1.1-Trichloroethane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.1-Dichloropropylene	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Carbon Tetrachloride	5	ug/l	3				3	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.2-Dichloroethane	5	ug/l	3				3	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Trichloroethene	5	ug/l	20 (3)					<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Dibromomethane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5

Table K3.3 Groundwater analytical results for Olympic Dam SML (cont'd)

							Location	QT02	QT04	LR01	LR02	LR04	LR08	QR01	QR02	LR10	LR11
							Date Sampled	10-Aug-06	10-Aug-06	10-Aug-06	10-Aug-06	10-Aug-06	12-Aug-06	12-Aug-06	12-Aug-06	13-Aug-06	13-Aug-06
Chemical	**Limit of reporting**	**Units**	**SA EPA EPP (Water Quality) 2003 POTABLE USE**	**SA EPA EPP (Water Quality) 2003 IRRIGATION**	**SA EPA EPP (Water Quality) 2003 LIVESTOCK**	**SA EPA EPP (Water Quality) 2003 AQUATIC ECOSYTEMS (FRESH)**	**NHMRC Australian Drinking Water Guidelines 2004 HEALTH**										
1.1.2-Trichloroethane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.3-Dichloropropane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Tetrachloroethene	5	ug/l	40				50	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.1.1.2-Tetrachloroethane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
trans-1.4-Dichloro-2-butene	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
cis-1.4-Dichloro-2-butene	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.1.2.2-Tetrachloroethane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.2.3-Trichloropropane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Pentachloroethane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.2-Dibromo-3-chloropropane	5	ug/l						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Hexachlorobutadiene	5	ug/L	0.7				0.7	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
HALOGENATED AROMATIC HYDROCARBONS																	
Chlorobenzene	5	ug/L					300	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bromobenzene	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
2-Chlorotoluene	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
4-Chlorotoluene	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.3-Dichlorobenzene	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.4-Dichlorobenzene	5	ug/L					40	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.2-Dichlorobenzene	5	ug/L					1500	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.2.4-Trichlorobenzene	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1.2.3-Trichlorobenzene	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
PAH																	
Acenaphthene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2

Table K3.3 Groundwater analytical results for Olympic Dam SML (cont'd)

Chemical	Limit of reporting	Units	SA EPA EPP (Water Quality) 2003 POTABLE USE	SA EPA EPP (Water Quality) 2003 IRRIGATION	SA EPA EPP (Water Quality) 2003 LIVESTOCK	SA EPA EPP (Water Quality) 2003 AQUATIC ECOSYSTEMS (FRESH)	NHMRC Australian Drinking Water Guidelines 2004 HEALTH	QT02	QT04	LR01	LR02	LR04	LR08	QR01	QR02	LR10	LR11
							Location	QT02	QT04	LR01	LR02	LR04	LR08	QR01	QR02	LR10	LR11
							Date Sampled	10-Aug-06	10-Aug-06	10-Aug-06	10-Aug-06	10-Aug-06	12-Aug-06	12-Aug-06	12-Aug-06	13-Aug-06	13-Aug-06
Acenaphthylene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Anthracene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Benz(a)anthracene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Benzo(a)pyrene	2	ug/l					0.01	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Benzo(b)fluoranthene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Benzo(k)fluoranthene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Benzo(g.h.i)perylene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Chrysene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Dibenz(a.h)anthracene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Fluoranthene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Fluorene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Indeno(1.2.3-cd)pyrene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
N-2-Fluorenylacetamide	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Naphthalene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Phenanthrene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Pyrene	2	ug/l						<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total PAH		ug/l	0.01			3		–	–	–	–	–	–	–	–	–	–
TRIHALOMETHANES																	
Chloroform	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bromodichloromethane	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Dibromochloromethane	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bromoform	5	ug/L						<5	<5	<5	<5	<5	<5	<5	<5	<5	<5

Notes:

Sample concentration in excess of adopted guideline

[1] NHMRC Australian Drinking Water Guidelines 2004 – Aesthetic.

[2] The Australian Drinking Water Guidelines (2004) states that total dissolved solid (TDS) concentrations <500 mg/L is regarded as good quality drinking water based on taste and 500-1000 mg/L is considered acceptable based on taste.

[3] World Health Organisation (Water Quality) Guideline 2006.

Table K3.4 Groundwater analytical results for new groundwater monitoring wells

Chemical	Limit of reporting	Units	SA EPA EPP (Water Quality) 2003 POTABLE USE	SA EPA EPP (Water Quality) 2003 IRRIGATION	SA EPA EPP (Water Quality) 2003 LIVESTOCK	SA EPA EPP (Water Quality) 2003 AQUATIC ECOSYTEMS (FRESH)	NHMRC Australian Drinking Water Guidelines	RT-1	LR-10	RT-2a	RT-2a
							Date	24-Jul-07	23-Jul-07	29-Jun-07	11-Dec-06
PHYSICAL PARAMETERS											
Suspended Solids (SS)	1	mg/L						200	98	52	77
Turbidity	0.1	NTU	5			20	5	218	100	4.3	19.1
MAJOR IONS AND TDS											
Total Dissolved Solids	1	mg/L					500 (1)	193000	38000	36100	43400
Sulphate SO_4^{2-}	1	mg/L					500	10300	4430	4540	5630
Chloride	1	mg/L						114000	20400	17300	22800
Calcium	1	mg/L						835	1030	945	1000
Fluoride	0.1	mg/L	1.5	1	2		1.5	0.4	1.4	1.1	1.5
Iron	0.01	mg/L									
Magnesium	1	mg/L						3990	1030	965	1370
Sodium	1	mg/L						73500	11900	10900	14400
Potassium	1	mg/L						501	61	92	208
Silica	0.1	mg/L						105	81	114	11.9
ALKALINITY											
Total Alkalinity as $CaCO_3$	1	mg/L						85	252	213	254
NUTRIENTS											
Nitrite as N	0.01	mg/L		1		10	3	0.029	<0.010	<0.010	<0.010
Nitrate as N	0.01	mg/L		10		30	50	0.665	0.837	0.031	<0.010
Nitrite + Nitrate as N	0.01	mg/L						0.694	0.837	0.031	<0.010
METALS (DISSOLVED)											
Aluminium	0.01	mg/L		1	5	0.1		<0.10	<0.01	<0.01	–
Arsenic	0.001	mg/L	0.007	0.1	0.5	0.05	0.007	0.028	0.006	0.004	–
Barium	0.001	mg/L		0.7			0.7	–	–	–	–
Boron (Dissolved)	0.05	mg/L						4.11	5.34	5.2	–
Boron (Total)	0.05	mg/L	0.3	1	5		4	–	–	–	6.3
Cobalt	0.001	mg/L		0.05	1			0.055	0.003	0.011	–
Copper	0.001	mg/L	2	0.2	0.5	0.01	2	0.073	0.008	0.008	–
Lead	0.001	mg/L	0.01	0.2	0.1	0.005	0.01	<0.010	<0.001	<0.001	–
Manganese	0.001	mg/L	0.5	2			0.5	3.86	0.61	0.235	0.412
Strontium	0.001	mg/L						13.9	18.1	14.4	–
Uranium	0.001	mg/L		0.02	0.01	0.2	0.02	<0.010	0.026	0.051	–
Zinc	0.005	mg/L		2	20	0.05		0.172	0.011	0.009	–
IONIC BALANCE											
Total Anions	0.01	meq/L						3440	673	587	766
Total Cations	0.01	meq/L						3580	656	603	795
Ionic Balance	0.01	%						1.88	1.26	1.32	1.9

Notes:
Sample Concentration in Excess of Adopted Guideline
[1] NHMRC Australian Drinking Water Guidelines 2004 – Aesthetic.
[2] The Australian Drinking Water Guidelines (2004) states that total dissolved solid (TDS) concentrations <500 mg/L is regarded as good quality drinking water based on taste and 500-1000 mg/L is considered acceptable based on taste.

RT-2b	RT-3	RT-4a	RT-4b	RT-5a	RT-5b	RT-5c	RT-7a	RT-7b	RT-9	RT-16a	RT-16b	RT-17a	RT-17b
12-Jul-07	01-Dec-06	22-Aug-07	22-Aug-07	07-Aug-07	09-Aug-07	09-Aug-07	24-Aug-07	24-Aug-07	11-Jan-07	18-Jun-07	18-Jun-07	18-Jun-07	18-Jun-07
596	–	200	536	160	458	1150	608	296	3160	3420	84	–	–
1540	22.1	190	282	42.2	185	492	349	165	6570	2620	48.5	–	–
203000	–	31700	191000	62200	261000	257000	60200	62400	31000	22100	56700	–	–
12900	5700	3610	4880	5810	13500	12500	4420	5000	4880	4310	7440	–	–
136000	6960	15400	108000	44600	146000	143000	31900	31500	17500	9510	30800	–	–
983	554	753	1560	959	983	952	520	1930	1010	832	1040	–	–
0.4	<0.1	1	0.3	1	0.1	0.3	0.9	1.1	0.3	1.6	0.8	–	–
5170	358	615	1280	1630	5880	5510	330	1390	913	754	1620	–	–
86800	6460	8720	69400	25100	94200	94200	21400	20400	12200	6610	20200	–	–
368	63	115	83	135	347	379	136	98	225	42	104	–	–
151	14.3	48.2	120	126	214	0.4	100	93.4	10.4	104	140	–	–
84	243	233	55	248	63	56	<1	<10	216	236	203	–	–
<0.010	0.011	<0.010	<0.010	<0.010	0.015	0.573	0.349	<0.010	<0.010	<0.010	0.011	–	–
0.08	<0.010	0.152	0.188	0.139	0.101	3.11	2.11	0.096	<0.010	0.222	9.8	–	–
0.08	0.015	0.152	0.188	0.139	0.116	3.68	2.46	0.096	<0.010	0.222	9.81	–	–
<0.10	–	0.04	<0.10	<0.01	<0.10	<0.10	<0.01	0.12	–	<0.01	<0.01	0.37	0.04
0.034	–	0.002	1.06	0.011	0.017	0.021	0.004	0.004	–	0.004	0.006	0.002	0.003
–	0.085	–	–	–	–	–	–	–	0.037	–	–	–	–
2.66	5.78	4.99	114	4.31	1.22	2.06	4.47	4.36	5.61	5.29	6.47	3.47	5.94
–	7.54	–	–	–	–	–	–	–	6.86	–	–	–	–
0.014	–	0.008	<0.010	0.006	<0.010	0.032	0.007	0.007	–	0.004	0.01	0.002	0.003
0.04	–	0.013	<0.010	0.015	0.036	0.035	0.015	0.02	–	0.007	0.015	0.008	0.017
<0.010	–	<0.001	<0.010	<0.001	<0.010	<0.010	<0.001	0.002	–	<0.001	<0.001	<0.001	<0.001
0.982	0.366	0.444	<0.010	0.256	0.708	1.64	3.13	3.28	5.44	0.171	1.39	0.036	0.858
15.6	5.3	14.2	0.851	14.8	12.9	15.3	36.3	37.1	13.8	12.9	19.1	13.3	18.2
<0.010	–	0.003	<0.010	0.009	<0.010	<0.010	0.01	0.001	–	0.076	0.017	0.024	0.029
0.119	–	0.173	<0.050	0.064	0.053	1.21	0.175	1.4	–	0.049	0.023	0.009	0.005
4100	320	515	3160	1380	4410	4290	992	1000	601	362	1030	–	–
4260	340	470	3200	1280	4640	4610	988	1100	660	392	1070	–	–
1.83	2.98	4.54	0.7	4.12	2.55	3.56	0.19	4.83	4.74	3.93	1.84	–	–

APPENDIX K4

Tailings storage facility geochemistry assessment

OLYMPIC DAM EXPANSION

Olympic Dam Tailings Storage Facility Geochemical Model

Report Prepared for

ODX - Olympic Dam Expansion
BHPBilliton

Prepared by

SRK Consulting
Engineers and Scientists

Draft EIS – BHP021Rev.1

August 2008

Olympic Dam Tailings Storage Facility Geochemical Model

ODX Olympic Dam Expansion

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SRK Project Number BHP021Rev.1

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1 Introduction and Scope of Report

1.1 Terms of Reference

Tailings from the Olympic Dam Operation (ODO) currently are being deposited in a paddock-type cellular Tailings Storage Facility (TSF). Decant water is pumped to adjoining lined evaporation ponds from which a proportion of water is recycled but most is lost to evaporation. The tailings cells and evaporation ponds are periodically used to manage excess water from major rainfall events. The walls of the cells are constructed from tailings, upstream raised, with rock cover for erosion protection and the cells are unlined except for the areas under the decant pond of TSF 4.

A similar tailings storage strategy will be adopted for the proposed Olympic Dam Expansion (ODX) project.

The proposed TSF for the expansion project will be considerably larger than the existing TSF. However, unlike the existing operation, a large open pit mine will be developed. Dewatering for the establishment of the open pit would result in a drawdown of the water table in the surrounding area. Preliminary groundwater modelling has indicated that the drawdown zone would extend beyond the limits of the TSF, and, the seepage from the TSF would be captured within this drawdown zone. Furthermore, water balance modelling for the pit has indicated that, due to high evaporation rates, the pit lake would remain below the existing water table and the drawdown zone would be maintained indefinitely.

Olympic Dam Expansion retained SRK Consulting to complete a review of the available geochemical information to develop a conceptual geochemical model for the ODX TSF that would enable an assessment of the potential for acidity and contaminant release from the Olympic Dam tailings and determine the potential interactions with the soils, the Andamooka Limestone and the Arcoona Quartzite.

1.2 Approach

The geochemical properties of the ore that will be mined from the open pit are not expected to be significantly different from the ore currently being mined from the underground workings. Furthermore, the milling and processing approach that will be adopted for the expansion project will not substantially differ from that currently being used to process the ore. Consequently, the current TSF can be used as an analogue for the proposed expanded TSF with the obvious exception of the size of the TSF. It is therefore reasonable to base the development of the conceptual geochemical model on an understanding of the existing conditions within and below the TSF, supplemented with laboratory testing as available.

The general approach that was adopted for the development of the conceptual geochemical model was as follows. First, the available geochemical information pertaining to the tailings and underlying soils and substrates was reviewed and summarised. Second, geochemical speciation modelling (i.e. MINTEQ, PHREEQC) and supplemental calculations were undertaken to support the conclusions from the initial review of the tailings geochemistry. The calculations included preliminary estimates of potential overall acidity that may be released from the tailings. Third, the geotechnical drill logs were reviewed to develop an understanding of 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 the potential implications for limestone dissolution within the Andamooka Limestone Formation was estimated. For these calculations, the seepage rates that had been derived by ODX were used to establish potential short- and medium-term effects. Limited geochemical speciation modelling (i.e. MINTEQ, PHREEQC) was also undertaken to support the understanding of the interaction between the subsoils and the percolate from the tailings. Fourth, to understand the potential interaction with the bedrock strata, the groundwater quality monitoring results were reviewed in particular for changes in concentrations over time and to determine current effects.

The overall objective of the above steps were to develop estimates of solute concentrations in the percolate from the tailings, the percolate from the underlying soil strata, and the percolate from the Andamooka Limestone formation. The conceptual model addressed release and mobility of acidity, heavy metal contaminants and radionuclides to the extent that the data allowed. Where there is a paucity of data to support the conceptual geochemical model, this was identified clearly and the potential implications described.

The report is organised as follows. In Chapter 2, the background information as it applies to the development of the conceptual geochemical model has been summarised. Chapter 3 presents the conceptual geochemical model. Chapter 4 provides and assessment of the interaction of percolates with the substrates as it flows from the TSF. Chapter 5 presents a summary and conclusions.

2 Background

2.1 Ore Deposit and Mineralisation

The Olympic Dam ore deposit is considered to be a member of the Iron Oxide Copper Gold (IOCG) family of deposits. The Fe-oxide Cu-U-Au-Ag ore body formed in a 'shallow level' magmatic-hydrothermal breccia complex. Coeval felsic, mafic, and ultramafic volcanism is an integral part of the ore formation process.

The lithological units within the deposit comprise a continuum of breccias starting at the periphery with granite clasts set in a low hematite matrix progressing into the centre where the clasts are wholly hematitic in a hematite matrix.

Similar to other base metal ore deposits, the metallic minerals are not homogeneously distributed throughout the Olympic Dam ore deposit. The breccia types, economic mineralisation, and gangue minerals are spatially 'zoned' across the deposit.

The dominant sulphide minerals are chalcopyrite, bornite, chalcocite and pyrite. Carrolite, cobaltite, galena, sphalerite and molybdenite also occur to a minor extent. Other minerals of interest that are encountered in the deposit include metallic copper, electrum, (Ag-, Hg-, Pb- and Bi-)selenides and tellurides. The uranium occurs mostly as uraninite, coffinite or brannerite with trace amounts in zircon, monazite, florencite and bastinite.

The principal gangue minerals are hematite, sericite and quartz and minor gangue minerals include siderite, chlorite, fluorite and barite.

Based on the mineralogical content of the ore, the tailings are likely to contain some sulphide minerals (e.g. pyrite) and very little neutralising minerals. The carbonates present appear to be predominantly siderite ($FeCO_3$) which is neither acid consuming nor acid generating.

2.2 Mineral Processing

A schematic diagram of the process flow diagram for recovery of economic minerals from the Olympic Dam ore is shown Figure 2.1. The new circuit for the expansion will be similar to the circuit in the existing plant. The primary crushed ore from the mine passes through the grinding circuit and is then subjected to flotation to produce a copper concentrate from the ground ore. The concentrate is then processed further to recover the economic metals associated with the sulphide minerals. The tailings from this process contains mainly gangue material but also a viable percentage of uranium. Pyrite ranges up to about 1.14 % in the ore with and average content of about 0.26 %. While pyrite flotation is suppressed during the flotation step, about 50 to 60 % reports to the tailings. Based on the pyrite content of the ore, and assuming that 60 % of the pyrite reports to the tailings, the residual acid generation potential of the tailings is estimated to be about 2.5 to 11 kg H_2SO_4 eq/tonne.

The tailings stream is treated further in the hydrometallurgical facility to extract secondary copper and uranium. Sulphuric acid is added to tailings stream to solubilise the residual copper and uranium minerals. The acid leach is generally conducted at a low pH (~1.5 to 1.7) and under oxidising conditions with Eh values in the range of 380 to 425 mV. During this step all of the acid consuming minerals are generally depleted from the tailings.

It is therefore concluded that the tailings solids, when deposited in the TSF, contain no readily available or reactive acid neutralising minerals and have a low overall potential for future acid generation from further oxidation of sulphide minerals. It is noted however that minor quantities of waste solids from the mill area are also co-deposited with the tailings.

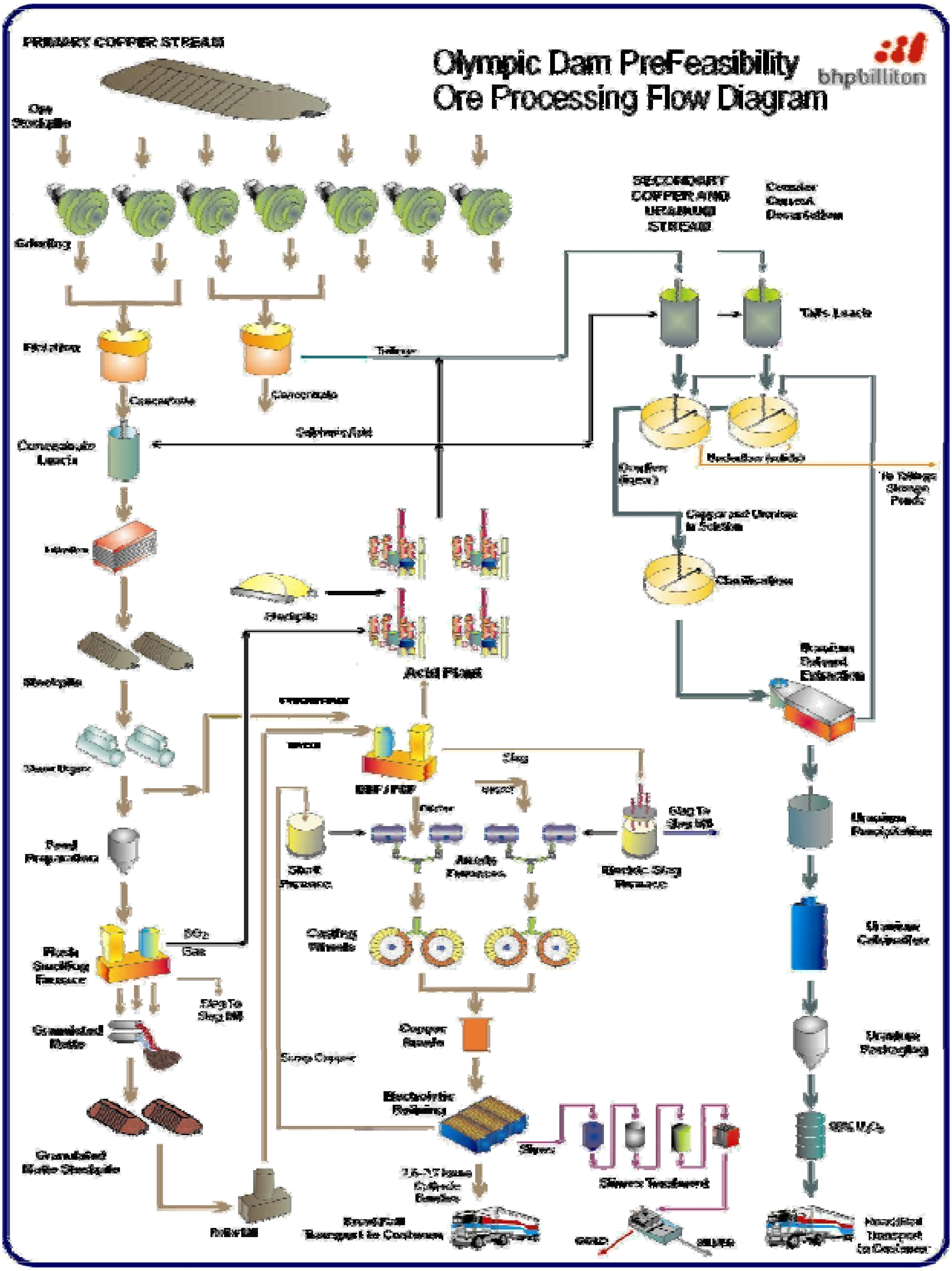

Figure 2.1 Olympic Dam Ore Processing Flow Diagram

2.3 Tailings Water Quality

As noted previously, the flotation tailings are leached with sulphuric acid at a low pH in an oxidising environment. This means that a very concentrated acidic solution is generated which is co-deposited with the tailings solids. Analyses of typical tailings pond water quality has been reported elsewhere (EGi, 1995(a), EGi 2007) and are summarised in Table 2.1. The Total acidity was analysed only for the EGi 2007 sample as shown in the last column in the table. The total acidity for the remainder of the data sets was calculated from the analytical results.

Table 2.1 Summary of Tailings Water Analyses

Parameter	Units	EGi 1995	Tailings Water (April 2007)	ARUP (2007)	EGi 2007
pH		1.7	-	-	1.5
EC	dS/m	31.5	-	-	35.2
Total Acidity	g $CaCO_3$/L	*31.0**	*72.2**	*31.0 – 95.5**	163
Free Acid	g H_2SO_4/L	-	12.0	-	-
Al	g/L	1.35	4.08	1.35 – 4.08	7.85
Ce	g/L	0.106	-	-	0.34
Co	g/L	12.5	-	-	0.105
Cu	g/L	0.13	0.15	0.150 – 2.11	2.06
Fe	g/L	7.8	13.7	7.8 – 21.4	35.75
K	g/L	0.46	1.08	0.46 – 1.25	1.88
Mg	g/L	0.28	0.8	0.280 – 0.800	2.83
SO_4	g/L	31	> 55.0	31.0 – 94.3	111.1
Th	g/L	0.0044	0.0029	0.00295	0.017
U	g/L	0.018	0.003	0.003 – 0.018	0.18

Note: * values estimated from free acid and metal concentrations

The results indicate some variability in the composition of the water associated with the tailings. It should however be noted that these results represent the analyses of incidental samples that had been obtained to support geochemical testing programs, and their sources (i.e. location of sampling) were not always well defined. The variability may be a function of the effects of evaporation and sample location.

Olympic Dam Operations has compiled a process simulation model to simulate current operations and predict future water consumption and properties (URS, 2007). The water model relies on a compilation of actual water quality data for the existing operations, as summarised in Table 2.2. The results in the table represent the averages for seven Tailings Line 1 and six Tailings Line 2 analyses. As before, total acidity was not reported and was calculated from the available analytical results.

Table 2.3 presents a summary of the Cell 4 decant water quality monitoring results for the first six months of 2007. Total acidity was again calculated as before. The results indicate that there is some short range variability in the water quality, but in general corresponds reasonably with historical results. Overall, the results indicate that the total acidity associated with the tailings water ranges from about 31 g$CaCO_3$ eq /L to about 260 g$CaCO_3$ eq /L. The average acidity for 2007 of about 153 g$CaCO_3$ eq /L is likely a reasonable estimate for estimating overall acidity loadings. The water is typically characterised by elevated concentrations of aluminium, iron, copper and elevated concentrations of sulphate.

Radionuclides in the tailings water have been monitored less frequently. A summary of the available results (provided by A. Burgess) are presented in Table 2.4.

Table 2.2 Summary of Process Simulation Tailings Water Composition (URS, 2007)

Parameter	Units	Tailings Line 1	Tailings Line 3
Major Anions			
Chloride	mg/L	2673.1	2658.5
Fluoride	mg/L	3002	3172.5
Sulphate	g/L	64.9	66.4
Sulphuric Acid	g/L	3.9	8.9
Major Cations			
Calcium	g/L	0.8	0.8
Magnesium	mg/L	745.7	697.8
Potassium	g/L	1	1.1
Sodium	g/L	2.9	3.3
Metals (Total)			
Aluminium	g/L	4.6	4.8
Copper	g/L	0.8	0.5
Ferric Iron	g/L	3.3	3.3
Ferrous Iron	g/L	20.4	16.9
Iron	g/L	23.6	20.6
Uranium Oxide	mg/L	80.9	78.8
Nitrogen Species			
Ammonia as N	mg/L	199.2	200
Other Inorganic Non-metallic Parameters			
Silica	g/L	1.5	1.2
Gross Organics			
Total Carbon	mg/L	7.9	30
Total Acidity	$gCaCO_3$ eq/L	76.3*	81.5*

Note: * values estimated from free acid and metal concentrations

Table 2.3 Summary of Cell 4 Decant Monitoring Results for 2007

Time	Al g/L	Ce mg/L	Cl mg/L	Co mg/L	Cu g/L	Fe g/L	Fe(II) g/L	Fe(III) g/L	H_2SO_4 g/L	SiO_2 g/L	SO_4 g/L	U_3O_8 mg/L	pH	Total Acidity $gCaCO_3$eq/L
8-Jan-07	15.0	487	5718	190	2.0	61.6	50.3	11.3	10.6	1.7	189.0	232	0.9	262.7
23-Jan-07	12.4	426	5588	150	1.6	52.5	42.7	9.8	12.5	0.8	170.9	185	0.9	225.1
31-Jan-07	3.0	153	1484	35	0.4	12.8	10.5	2.3	3.2	0.3	40.0	44	1.6	54.8
7-Feb-07	4.6	207	2398	45	1.5	20.1	15.9	4.2	5.3	0.6	64.2	81	1.4	87.1
15-Feb-07	5.4	238	2831	53	1.6	23.7	18.8	4.9	3.0	1.0	74.2	97	1.3	99.0
22-Feb-07	7.8	282	3357	65	1.6	28.6	22.2	6.4	13.7	1.1	88.3	109	1.3	136.7
3-Mar-07	6.5	310	3488	68	1.7	31.4	25.0	6.4	7.0	1.7	95.4	116	1.2	130.0
8-Mar-07	7.9	346	4224	77	1.6	37.3	27.6	9.7	9.8	1.6	111.0	139	1.0	156.4
14-Mar-07	10.3	325	6786	83	1.7	43.3	31.0	12.3	17.7	2.3	132.6	280	0.7	194.1
21-Mar-07	17.0	376	4737	85	1.4	51.1	29.7	21.4	12.6	2.8	188.0	145	1.2	246.8
5-Apr-07	9.3	387	4871	87	1.5	42.0	33.5	8.5	13.7	2.0	130.2	164	0.8	180.5
12-Apr-07	8.7	378	4823	90	1.5	40.0	30.9	9.1	13.7	3.0	125.0	163	0.9	171.8
18-Apr-07	8.8	376	4954	88	1.5	43.8	32.7	11.1	12.9	2.5	129.5	159	0.8	182.2
3-May-07	10.0	320	4840	120	1.3	38.2	29.2	9.0	9.6	2.2	125.0	130	0.9	170.0
18-May-07	6.4	333	4053	67	1.0	33.9	24.9	9.0	12.9	1.0	101.6	101	0.9	141.5
24-May-07	6.3	303	3895	61	0.9	28.0	23.1	4.9	10.5	1.4	95.8	91	0.9	122.2
30-May-07	7.7	375	4428	94	1.0	31.0	23.2	7.8	7.7	0.3	103.5	98	0.9	135.5
7-Jun-07	6.7	286	4073	60	0.9	29.9	21.4	8.5	12.4	1.1	96.5	94	1.0	131.5
14-Jun-07	5.9	276	3812	55	0.8	30.4	21.1	9.3	10.5	0.9	92.5	83	0.9	126.2
22-Jun-07	5.9	270	3766	57	0.8	31.5	22.7	8.8	16.0	0.8	94.0	88	0.9	134.9
28-Jun-07	6.9	296	3972	60	0.8	23.6	21.8	1.8	14.2	2.2	95.9	88	0.8	117.4
Average	**8.2**	**321**	**4195**	**81**	**1.3**	**34.9**	**26.6**	**8.4**	**10.9**	**1.5**	**111.5**	**128**	**1.0**	**152.7**

Notes: Source: Olympic Dam Operations Laboratory Database, J. Folwell
Total acidity values estimated from free acid and metal concentrations

Table 2.4 Summary of Radionuclide Activities in Tailings Water

Sample	Date	Po210 Bq/L	Pb210 Bq/L	Th230 Bq/L	Ra226 Bq/L	U238 Bq/L
New Tailings	1991	38	248	3985	3.1	1054
Old Tailings	1991	156	228	7625	3.4	1222
Tails Supernatant	1991	174	259	4531	n/d	1439
New Tailings	1992	86	318	4165	2.4	1224
Old Tailings	1992	352	423	11402	8.2	2681
New Tailings	1993	116	217	3528	1.6	1166
Old Tailings	1993	272	283	7680	3.6	2320
Cell 1	1994	109	316	2861	4.3	1206
Cell 3	1994	58	301	2363	4.5	836
Cell 2	1995	19	256	2814	3.6	1452
Tailings (ARUP)	2004	-	-	-	0.95	12.2

Source: Compilation of data from various reports provided by A. Burgess, BHPB

2.4 TSF Location

The general footprint area of the existing and planned expansion of the TSF is characterised by low relief, dominated by dune fields, low tablelands and a system of basins, small salt lakes and a few large salt lakes. The surface hydrology in the vicinity of the TSF is characterised by a mosaic of small catchments, ranging in area from 10 to 300 ha. The boundaries are generally defined by the east/west trending sand dunes.

The average annual rainfall at Olympic Dam over the period 1980 to 1995 has been approximately 160 to 180 mm. The average annual Class A Pan evaporation rate between 1980 and 1995 has been 2,788 mm.

2.5 Hydrogeology

A detailed hydrogeological model has been developed to assess the effects of the drawdown that would be created by the open pit (see Appendix K6 of the Draft EIS). That assessment has shown that a capture zone would be created by the drawdown cone that, in the very long term, would direct percolate from the TSF to the open pit. The flows from the TSF is shown initially to move away from the TSF under high flow conditions that would persist during operations, but as flows decrease after operations cease, flows would be captured and redirected to the open pit. The following sections briefly highlight the geological features within the mining area and below the TSF as they pertain to the movement of percolate.

2.5.1 Regional Stratigraphy

The Olympic Dam ore deposit is hosted in Precambrian basement rocks. The geological sequence at the site is illustrated in Figure 2.2 and key features are as follows:

Tregolona Shale comprising laminated shale is about 130 m thick at the site and directly overlies the metaphorphic basement rock. This overlain by the Arcoona Quartzite comprising the Corraberra Sandstone sequence of fine to medium sandstone and shaly sandstone with shale interbeds. The formation becomes cleaner and coarser grained with depth. The Arcoona thickness is about 140 m at Olympic Dam, and the lower Corraberra sandstone is about 25 m thick.

Andamooka Limestone, comprising massive dolomitic limestone, extends from near surface to about 60 m depth at the mine, and thickens in all directions except to the southeast. Karst features have been encountered in the near surface of the formation.

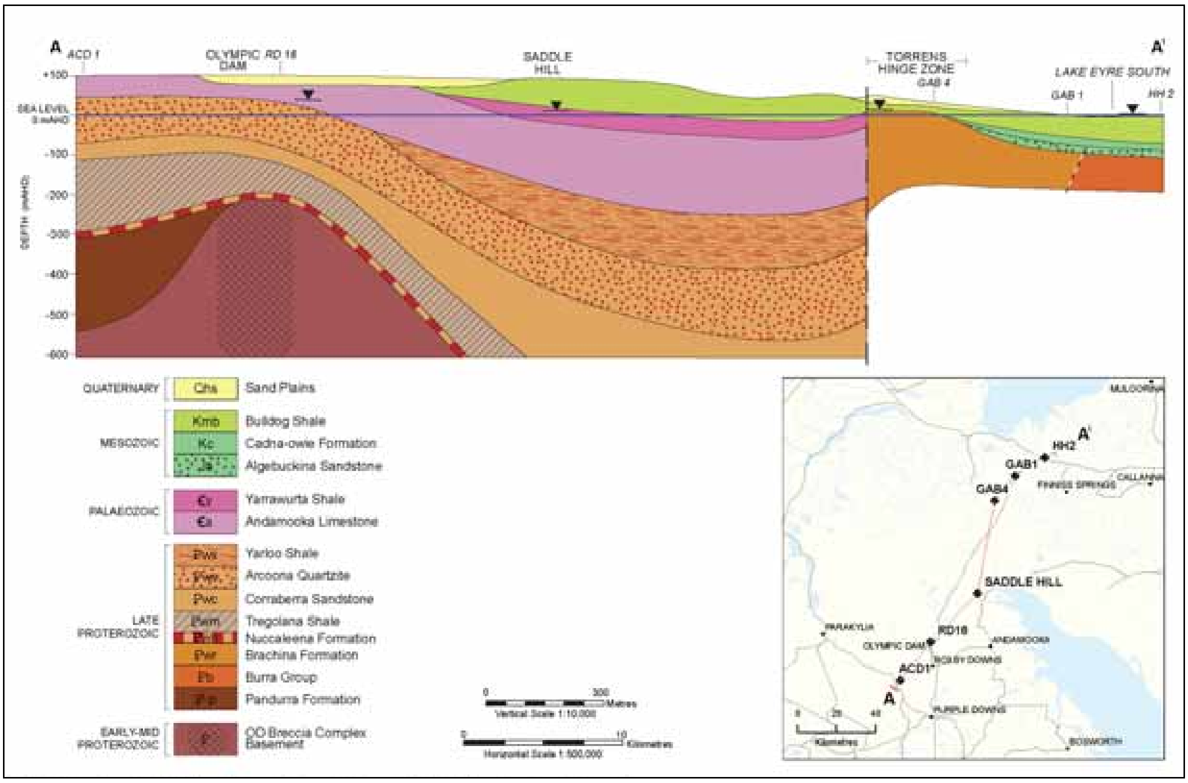

Figure 2.2 Schematic Showing Regional Stratigraphy

The ore body and its host rocks produce little or no groundwater flows into the workings. The Tregolana Shale is an essentially impermeable shale/mudstone unit. The Arcoona Quartzite, which, although lacking primary porosity, is fractured in its lower sections and yields water to ventilation shafts, decline, haulage shafts and drill holes. The Andamooka Limestone Aquifer is above the Arcoona Quartzite formation, with limited hydrogeological interconnection between the aquifers. Standing water levels differ between the aquifers from between 1 m and 15 m, with the water table being approximately 50 m below the ground surface.

2.5.2 Surface Sediments

In summary, the apparent geological history relating to the superficial deposits is one of variable weathering and erosion of the Andamooka Limestone followed by deposition of alluvial soils and aeolian soils over some of the eroded surface.

East-west sand dunes are present over the area of the TSF with average heights of 4 to 5 m. Swale areas between the dunes are generally underlain by calcareous soils and Andamooka Limestone, which outcrops or sub-crops at some locations. Gypsiferous clays can be found between the calcareous soils and limestone over parts of the area.

A number of site geotechnical investigations carried out by others indicated that there are two distinct sub-surface profiles present within the footprint of the proposed TSF. The majority of the area is generally underlain by calcareous sandy clay/clayey sand of varying depth. Beneath this, in some areas, are gypsiferous clays underlain by weathered calcrete and limestone of the Andamooka Limestone group, and occasional bands of weathered sandstone. In other areas, shallow depths of topsoil and calcareous clays underlie variably weathered Andamooka Limestone with some outcropping of the calcrete/limestone being evident.

To illustrate the variability, the logs from a geotechnical investigation (Coffey, 2007) are illustrated schematically in Figure 2.3 for selected boreholes. (The boreholes shown are roughly east-west trending within the footprint of proposed TSF expansion.) Generalised descriptions of the units encountered in the boreholes were as follows:

- Topsoil/dune sand consisting of fine to medium grained orange brown sand / silty sand
- Calcareous soils consisting of clayey sand fine to medium grained, fines of medium plasticity, and variable amounts of fine to coarse grained gravel (typically calcareous sandstone)
- Sand / silty sand, fine to medium grained weakly cemented and grading to gravely sand in places.
- Silty Clay /clayey silt, high liquid limit, with inclusions of gypsum crystals.

It is noteworthy that the clayey features are discontinuous and range considerably in thickness. The thickness of the overburden to the bedrock also is observed to vary significantly. Because of the differences in permeability amongst the different material types, it is anticipated that percolate from the TSF would follow selective flowpaths and that flows through the clays locally could be substantially lower than through the sandy / gravely materials. Furthermore, in some locations the overburden is very shallow and percolate would contact the limestone more directly with less benefit from reacting with calcareous soils and clays first. It is also apparent that there may be a potential for the development of perched water tables. The potential geochemical interactions between percolate and the sediments are discussed later in this report.

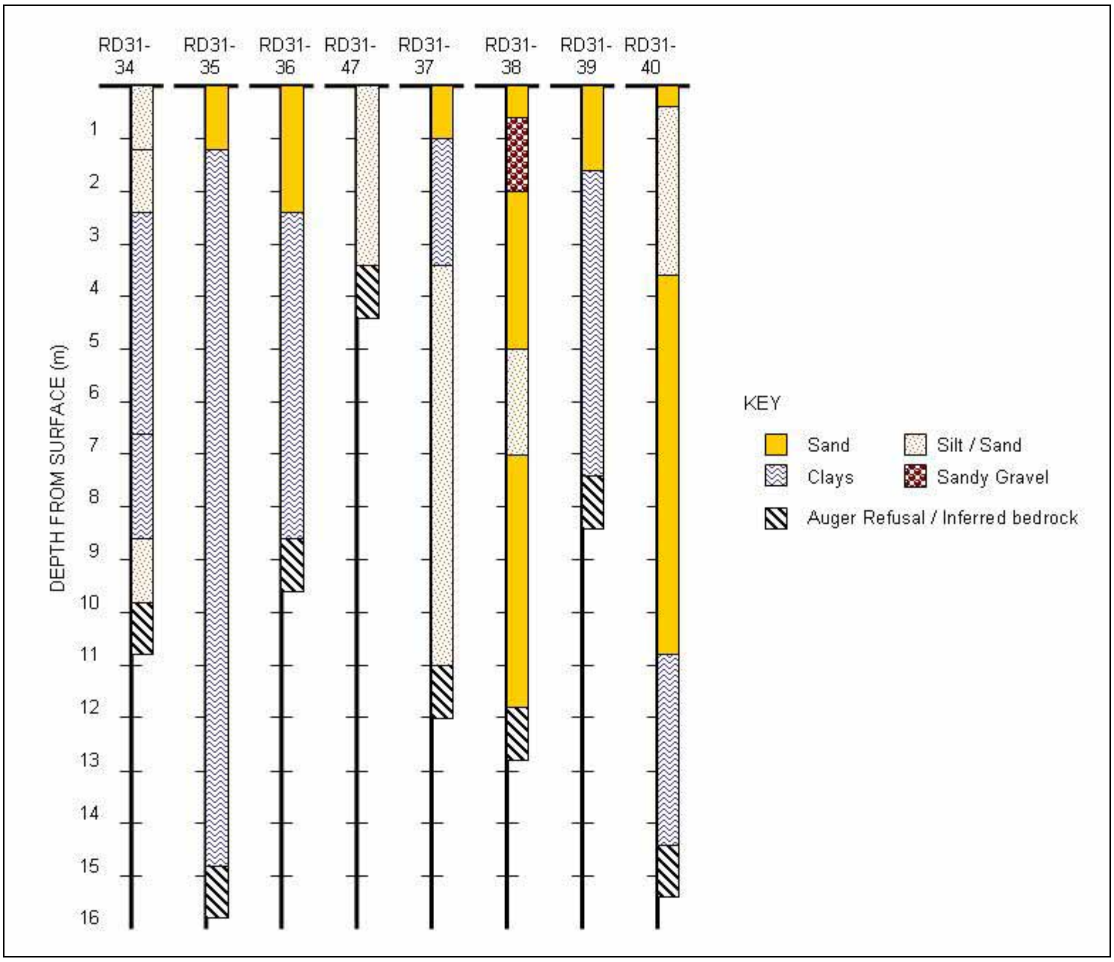

Figure 2.3 Schematic Illustrating Surface Sediment Distribution for Selected Boreholes

2.5.3 Groundwater Quality

Groundwater levels within the Andamooka Limestone have mounded below the TSF up to 20m above the natural groundwater level. In general the footprint of the seepage mound extends a distance beyond the surface footprint of the TSF. The groundwater monitoring program and results are described in the Olympic Dam annual environmental monitoring and management report (ODO, 2006). Table 2.5 provides a summary of water quality monitoring results for the Andamooka Limestone aquifer for the period 1994 to 2005.

The water quality within the Andamooka Limestone below the TSF reflects the effect of the overlying sediments and the dolomite contained in the Andamooka Limestone Formation on percolate from the TSF. When compared to the tailings liquor concentrations (see Section 2.3) it is clear that the percolate from the TSF is neutralised effectively and that most metals and trace elements are being attenuated either within the tailings or immediately below the TSF as the percolate passes through the sediments.

It is also noted that, as shown in Table 2.5, the regional groundwater and groundwater below the TSF have similar high TDS (30,000 to 40,000 mg/L) concentrations. The elevated TDS is due to naturally elevated Na and Cl concentrations, however, SO_4, Ca, Mg and HCO_3^- concentrations are also elevated within the groundwater below or near the TSF. The concentrations of metals and other trace elements generally are low and similar to regional concentrations, with the exception of bicarbonate, U and Se, which are significantly higher in the groundwater mound below the TSF.

In general, uranium concentrations tend to decrease to background values outside of the immediate influence of the TSF and evaporation ponds. We understand that the highest groundwater uranium concentrations are currently at sites near the mine water evaporation pond, which was an unlined facility. It is likely that these elevated concentrations were not a consequence of TSF seepage. It is however noted that the uranium concentrations are increasing within some of the perimeter wells that clearly are not affected by other site facilities, such as Borehole LT35. The uranium concentration in that borehole has increased from about 0.02 mg/L in 2002 to 0.096 mg/L in 2007. (Other bores that show elevated uranium concentrations with increasing trends include LT05, LT09, LT07, LT11, LT34 and LT36.)

As noted before, bicarbonate concentrations tend to be elevated within the groundwater mound below the TSF, and the elevated concentrations are coincident with higher uranium concentrations. For example, the monitoring results for boreholes LT05 and LT07 which are located in the Andamooka Limestone Formation immediately below TSF Cells 1, 2 and 3, indicated average bicarbonate concentrations of 1116 mg/L and 1362 mg/L respectively. The corresponding uranium concentrations were 0.32 mg/L and 0.44 mg/L.

The elevated bicarbonate concentrations are a result of acidity being neutralised by carbonate minerals contained within the sediments, and, the dolomite contained in the Andamooka Limestone formation. The acid neutralisation reaction generates carbon dioxide which, trapped within the environment of the mound, dissolves and forms carbonic acid and lowering the pH. (For example, the pH in borehole LT05 ranged from 5.83 to 6.91, with and average of 6.3, and that in borehole LT07 ranged from 7.4 to 6.28, with an average of 6.5.) The decrease in pH causes an increase in the solubility of some mineral phases. The combined effect of increased bicarbonate and lowering of pH also results in an increase of the solubility of the uranium as will be discussed later. The slightly depressed pH may also affect sorption and attenuation reactions.

To date no elevated concentrations have been recorded in the deeper Arcoona Quartzite formation.

The redox potential within the groundwater will dictate the speciation and thus the solubility of redox sensitive solutes (e.g. As, Fe, U etc.). While we are not aware that the redox potential has been determined within the groundwater mound beneath the TSF, it has been measured in regional bores within the Andamooka Limestone and the Arcoona Quartzite formations. The results are summarised in Table 2.6 and indicate that the groundwater is relatively reducing. The redox values also tend to decrease with depth.

Table 2.5 Summary of Groundwater Monitoring Results for the Andamooka Limestone Aquifer

Parameter	Units	Number of Samples		Median		Ratio of Median TSF to Median Regional
		Regional Bores	TSF Bores	Regional Bores	TSF Bores	
pH		43	147	7.06	6.80	
HCO_3^-	(mg/L)	29	89	188	553	2.9
EC	(S/cm)	29	90	30200	39150	1.3
TDS	(mg/L)	47	154	22000	27950	1.3
Ca	(mg/L)	47	150	893	954	1.1
Cl	(mg/L)	32	122	11202	12155	1.1
K	(mg/L)	29	90	44	55	1.2
Mg	(mg/L)	29	90	614	1010	1.6
Na	(mg/L)	29	89	5790	7660	1.3
SO_4	(mg/L)	47	151	3575	5100	1.4
U	(mg/L)	44	152	0.027	0.088	3.2
Ag	(mg/L)	29	91	0.0008	0.0008	1.0
Al	(mg/L)	29	89	0.05	0.03	0.6
As	(mg/L)	29	84	0.003	0.005	1.7
B	(mg/L)	6	41	3.8	6.8	1.8
Ba	(mg/L)	29	91	0.029	0.013	0.4
Cd	(mg/L)	8	49	1.00	1.00	1.0
Co	(mg/L)	29	91	0.004	0.007	1.8
Cr	(mg/L)	29	91	0.003	0.003	1.0
Cu	(mg/L)	47	148	0.019	0.034	1.8
Fe	(mg/L)	42	132	0.43	0.19	0.4
Hg	(mg/L)	6	45	0.2	0.1	0.5
Mn	(mg/L)	47	153	0.74	0.52	0.7
Ni	(mg/L)	29	91	0.015	0.014	0.9
Pb	(mg/L)	29	91	0.003	0.004	1.3
Se	(mg/L)	29	91	0.01	0.05	5.1
Zn	(mg/L)	29	92	0.033	0.042	1.3

Table 2.6 Summary of Regional Groundwater Redox Measurements

BOREHOLE ID BH ID	Water Depth BGL	EOH Depth BGL	pH	EC	Redox mV	Temp
QT2	n/d	n/d	8.1	51.2	-223	23.0
QT4	n/d	n/d	7.6	60.1	-79	23.7
QR1	56.74	185	7.0	33.5	-100	24.4
QR2	58.658	184	7.2	44.4	-109	25.7
QR3	49.275	169	6.7	7.6	-112	19.9
LR1	55.54	68	7.0	34.5	-58	24.9
LR2	56.3	70	7.4	27.5	-28	22.7
LR3	31.92	58.56	7.4	26.8	**82**	19.9
LR4	67.81	78.8	6.7	15.2	-58	22.7
LR5	52.62	67	6.4	29.3	**37**	19.4
LR7	53.53	67	7.2	36.1	**24**	19.9
LR8	54.62	66.8	7.0	43.9	-69	26.5
LR9	39.46	50.1	6.6	40.2	-39	20.9
LR10	12.49	40	6.9	50.5	-56	22.6
LR11	15.4	40	6.8	39.2	-42	21.1

2.6 Geochemical Investigations

2.6.1 Tailings Properties

Geochemical testing of the tailings to date (EGi, 1995, 1995a, 2007) has included:

- Leach extraction with measurement of pH and electrical conductivity (EC) (1:2 – S:L)
- Elemental analysis of tailings solids (with some radio-nuclides)
- Equilibration testing (termed "long term geochemistry")

The leach extraction tests were used to infer the porewater pH and conductivity and are useful in inferring potential changes or trends in porewater with depth. Due to diluting effects (low moisture content and high contact ratio) it is considered however that the leach extraction results underestimated the EC and over estimate the pH (i.e. the actual porewater pH is likely to be lower than the reported values). On average the tailings samples contained about 15 to 20 % (wt/wt) moisture. At the contact ratio of 2:1, the corresponding dilution is about 10 to 12 times and the pH of the pore water could be overestimated by about 1 unit. This suggests that the pH of porewater in the tailings increases from the 1.5 to 1.7 at deposition to about 2.5 rather than the 3.5 as suggested by the leach extraction testing.

Elemental analyses of the tailings solids indicated that a number of elements are elevated relative to background concentrations. These included As, Ba, Bi, Ce, Cu, Fe, Hg, Mo, Sb, Sn, and U. Unfortunately, the mineral assemblage of the secondary mineral phases in the tailings had not been determined. The mineral assemblage is required to understand how the porewater geochemistry could evolve over time.

Some understanding of the potential secondary mineral phases in the tailings can however be derived from the equilibration tests (termed "long term geochemistry"). The observed changes in these 'aging' tests indicate that while the concentrations of most elements changed little, Al, Ce, Mn, and U increased over time. These elements are therefore expected to be leached from the tailings. In contrast, SO_4, Na, Si, Th, Fe and Ca concentrations decreased over time indicating that these solutes were precipitated as secondary mineral phases. The combinations of elements, and the change in pH, suggest the changes were likely caused by the precipitation of hydronium- and sodium-jarosites, as well as gypsum. The decrease in Si also confirmed that the pH was not being modified by the dissolution of silicate minerals; rather a silicate mineral was precipitated from solution.

2.6.2 Underlying Soils and Sediments

Three investigations of the effects on the soils underlying the TSF had been undertaken to date. The first was undertaken by Davy and Green (1993). The second and third investigations were undertaken by EGi in 1995 and 2006. Combined, the testing included:

- Leach extraction tests (1:2 – S:L) with EC and pH measurements
- Elemental analyses with some radionuclide parameters
- Acid Neutralisation Capacity (ANC)
- Acid Buffering Characteristic Curves (ABCC, EGi 2007)
- Cation exchange capacity (CEC)
- Batch attenuation tests
- Column attenuation tests

These assessments indicated that the underlying soil types have varying capacities to neutralise acidity, with the dolomite, calcareous clay and, to a lesser extent, the swale materials having higher neutralising capacities, and the dune sands and clay-pan materials exhibiting a low neutralising capacity. The estimated acid neutralisation capacities are summarised in Table 2.7.

Table 2.7 Acid Neutralisation Capacity of Sediments

Soil type	ANC range (kg H_2SO_4/t)	ANC classification
Dune sand	2–4	low
Swale material	15–17	medium
Claypan material	9	low
Calcareous clay	139	high
Dolomite	975–1,041	high

Assessment of the pH and EC values for soil samples from beneath the TSF further indicated that the depth of the acidic front has increased from 40 cm in 1993 (Davy and Green, 1993), to about 2 m in 1995 (EGi, 1995), to in excess of 3 m in 2006 (EGi, 2007). This clear progression in depth suggests that the acid front may be progressing at a rate of about 0.15 m per year. However, considering the variability and discontinuity of the different sediment types, and the 'hit and miss' likelihood of intercepting the acidity front with single boreholes, it is probable that the acid front has moved faster in some areas and slower in other areas.

Batch neutralisation tests undertaken by EGi (EGi, 1995) under atmospheric conditions indicate that some of the sediments (e.g. calcareous clays, calcareous swale materials, and dolomite from the Andamooka Limestone formation) are able to effectively neutralise the tailings leachate. The neutralisation reactions result in the removal of most metals to very low concentrations, including iron, aluminium and uranium.

As shown in Section 2.3, a significant proportion of the iron is present as ferrous iron. The testwork was completed under atmospheric conditions and the observed removal of iron from solution is consistent with precipitation of ferrihydrite ($Fe(OH)_3$). As will be discussed later, underneath the TSF, the availability of oxygen for the oxidation of ferrous will be limited and it is unlikely that iron will be rapidly oxidised to ferric. Therefore under the TSF there may be less ferrihydrite precipitation and actual removals may not be as effective as indicated by the tests. Nonetheless, the tests do indicate that neutralisation to a neutral pH is a prerequisite for metal removal. Furthermore, the results do confirm that the acidic percolate is being effectively neutralised within the sediments. As noted before, the groundwater monitoring results also indicate that metals are effectively removed from solution during the neutralisation step. In the absence of supporting mineralogical data, however, it is difficult to define the exact mechanisms by which the metals are being removed from solution. Potential mechanisms are discussed further in the next chapter

EGi also completed a series of column tests under saturated conditions (EGi, 1995) with a static water head. The tests were open to atmospheric conditions, however, which likely affected the outcomes in a similar way to the batch neutralisation tests. The results did indicate that the calcareous clays were most reactive and effectively neutralised the acidic TSF percolate to a pH in excess of seven. The changes in the leachate concentrations effected by the neutralisation reactions indicate that the reason for this is likely that the carbonate minerals in the calcareous clays were predominantly calcite. The dolomite from the Andamooka Limestone formation was less successful at neutralising the acidic solution under the same test conditions.

Supplemental testing undertaken in 2007 (EGi, 2007) confirmed the outcomes of the 1995 test program, indicating that i) the dolomite from the Andamooka Limestone is less reactive than the calcareous clays (batch neutralisation tests) and that ii) the calcareous clays contain calcite (ABCC tests). EGi also concluded that the dolomite from the Andamooka Limestone will be less effective at neutralising acidity due to the formation of selective flow-paths and the potential for 'armouring' or blinding of reactive surfaces due to the formation of secondary minerals.

The test programs to date however fail to assess the potential implications of possible anoxic conditions and the build-up of carbon dioxide. These are discussed briefly in the next chapter.

As noted by EGi, the seepage from the TSF leads to the formation of gypsum within the sediments and within the Andamooka Limestone, which indicates that the water within the mound is saturated with respect to this mineral phase. As described above, the decrease in pH caused by the elevated carbon dioxide leads to the increased solubility of some mineral phases, which also means that the seepage from the Andamooka Limestone could be supersaturated with respect to several other secondary mineral phases, including calcite ($CaCO_3$), when carbon dioxide is released. As the seepage leaves the environment that sustains the supersaturated minerals (i.e. elevated carbon dioxide) it would be expected that these minerals would precipitate from solution. This could occur as the seepage exits the Andamooka Limestone and passes through the Arcoona Quartzite Formation and could lead to a reduction in the permeability of this formation.

No assessment of the potential interaction between the seepage from the mound water and the Arcoona Quartzite has been undertaken to date. The potential implications are discussed in the next chapter.

3 Conceptual Geochemical Model

3.1 Description

Based on the available information it is concluded that the geochemical reactions that may affect acidity release from the tailings include the formation of secondary minerals such as hydronium-jarosite that may or may not be stable in the long term. In addition, based on the current understanding of the conditions in and below the existing TSF, the primary mechanism that affects water quality of percolate from the TSF is neutralisation of the acidic percolate by carbonate minerals present in the sediments. Sorption and co-precipitation are secondary mechanisms that also contribute to solute removal; however, these reactions may be reversible. Furthermore, flow conditions will to a large extent dictate how and where these reactions may occur. To illustrate these conditions and potential interactions, a conceptual schematic of potential flow paths during the operation phase is shown in Figure 3.1 for operational conditions. Note that the diagram is not to scale and, since it is intended to illustrate some of potential mechanisms, the sediment layer has been exaggerated. Based on the conceptualisation, five distinct zones can be identified as follows:

Zone 1 Tailings. The tailings would be placed to a final height of about 40 m. Within the tailings zone, limited changes in the process water would be expected. First, evapo-concentration within the pond could lead to some secondary minerals becoming supersaturated (e.g. iron jarosites, gypsum, barite, anglesite etc.). As the water passes through the tailings, some of these supersaturated phases would precipitate from solution, leading to decreased concentrations of some solutes. Since the tailings water has a chemical oxygen demand, and since there are likely to be some residual sulphides present in the tailings, oxygen could be depleted at depth and anoxic conditions would be expected to prevail. This could sustain ferrous iron in solution and may preclude the formation of some phases.

Zone 2 Sediments. This zone, ranging in thickness typically from about 1 m to 6 m, but may be as deep as 15 meters, may comprise variable layers of topsoil/dune sand, calcareous soils, variable amounts of fine to coarse grained gravel (typically calcareous sandstone) and calcareous clays or clayey silt. As noted previously, the calcareous clays are the most effective at neutralising acidity and therefore the reactions in this zone would represent the interaction of percolate with primarily the calcareous sediments. The low permeability of some of the clays and some of the sediments may affect the potential for the percolate to interact with the calcareous clays as follows. First, there may be a potential for flows to migrate laterally on top of low permeability layers, which could lead to the formation of perched water tables and flows laterally outside the perimeter of the footprint of the TSF. The percolate would have limited opportunity to react with calcareous clays as it migrates over the top of the clays, but may continue to react with other more permeable calcareous soils. It is probable that this water would initially resemble percolate from the TSF, except that oxygenation may affect water quality as it relates to redox sensitive species, but would progressively be neutralised as it disperses. Furthermore, it is important to note that the clay formations are discontinuous so that opportunity for such lateral flows to disperse any significant distance would be limited and, ultimately, it would ‘decant’ or flow downward to the underlying Andmooka Limestone Formation. Second, vertical flows through the calcareous clays would lead to the effective neutralisation of the percolate and attenuation of metals for as long as excess neutralising capacity remains. Acidification, once the neutralising capacity had been depleted, may however remobilise some of the metals that were initially precipitated as hydroxide or carbonate phases. Metals sorbed to these phases could also be mobilised in time. The capacity of the sediments to neutralise the acidic percolate would depend on the total acidity loadings from the TSF and the relative abundance of these materials. These factors are discussed further in the next section. Neutralisation reactions would lead to the generation of excess carbon dioxide which could cause a decrease in the porewater pH and consequently the solubility of some contaminants may increase.

Zone 3 Unsaturated Andamooka Limestone. The Andamooka Limestone Formation varies in thickness from about 50 m to 60 m in thickness within the footprint of the TSF. The thickness of the unsaturated zone would vary depending on the elevation of the water table. Neutralised percolate from the calcareous clays would be expected to have little interaction with the unsaturated Andamooka Limestone. The reduced pH caused by excess carbon dioxide could promote dissolution of dolomite. However, some flows may bypass the calcareous clays altogether and flow directly to the Andamooka Limestone Formation. At contact any acidic flows would be expected to be completely neutralised since the Andamooka Limestone consists of dolomite,. However the reaction rates would be slower than for the calcareous clays. Flow would likely occur in fractures which could lead to selective dissolution of dolomite along these features. Depending on the percolate properties and the redox conditions, the reactions would be likely to result in a net dissolution of dolomite, i.e. the porosity of the dolomite could increase locally. Under certain circumstances (e.g. oxidising conditions), however, it may be possible that net precipitation reactions could occur so that the reactive carbonate mineral surfaces may become coated or blinded and the porosity could decrease locally. While this could cause lateral flows to occur locally, as suggested in the schematic (Figure 3.1), it should be noted that as the seepage migrates away it will contact fresh dolomitic surfaces which would continue to neutralise the percolate. The local effects of blinding and decreased porosity would diminish along these lateral flow paths. The range over which these effects (i.e. horizontal influence) could be observed would depend on the prevailing physico-chemical conditions, the percolate properties and the flow rates.

Zone 4 Saturated Andamooka Limestone. The percolate within the saturated zone is expected to be completely neutralised and anoxic because the saturated conditions would preclude oxygenation. Due to excess dissolved carbon dioxide it is also likely that the percolate would contain excess dissolved alkalinity (bicarbonate). The excess bicarbonate may complex certain solutes (e.g. uranium) causing elevated concentrations within this zone.

Zone 5 Saturated Arcoona Quartzite. The Arcoona Quartzite/sandstone formation is about 180 m thick. As the percolate passes from the Andamooka Limestone, in the absence of excess carbonate minerals, carbon dioxide may be lost from solution. This could lead to conditions that no longer support the excess dissolved carbonates and may lead to the precipitation of secondary calcite ($CaCO_3$) and/or magnesite ($MgCO_3$). Over time, the precipitation of these minerals could cause a reduction in the permeability locally within this formation.

After active tailings deposition ceases, ODX intends to place a cover on the tailings. A corresponding schematic for post closure conditions is shown in Figure 3.2. In broad terms, the same geochemical zones can be identified for the post closure conditions. After tailings deposition ceases water would no longer be ponded on the tailings. Initially, percolation rates are likely to be sustained by drain-down. Thereafter, flow rates would be much reduced and would equilibrate with natural recharge. This would mean that the groundwater mound would recede and the potential for lateral flow would decrease, provided the vertical permeability in the underlying formations had not significantly been affected. Due to the much lower flow rates, overall acidity loadings from the TSF would also decrease to low levels.

At the reduced rates of infiltration the tailings would in time become unsaturated. This could lead to increasingly oxidising conditions within the tailings. Any residual acid generation potential that may be associated with the tailings may then also contribute to acidity loadings. Potential implications are discussed below.

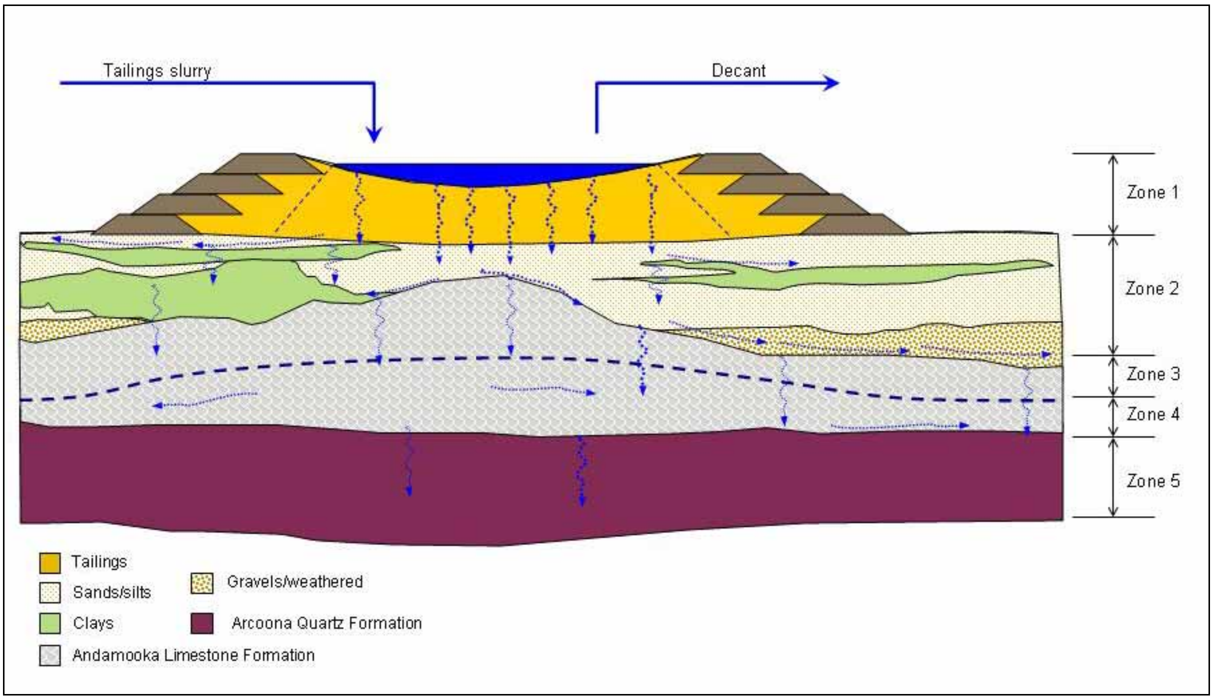

Figure 3.1 Schematic Illustrating Potential TSF Seepage Flowpaths (Not to Scale)

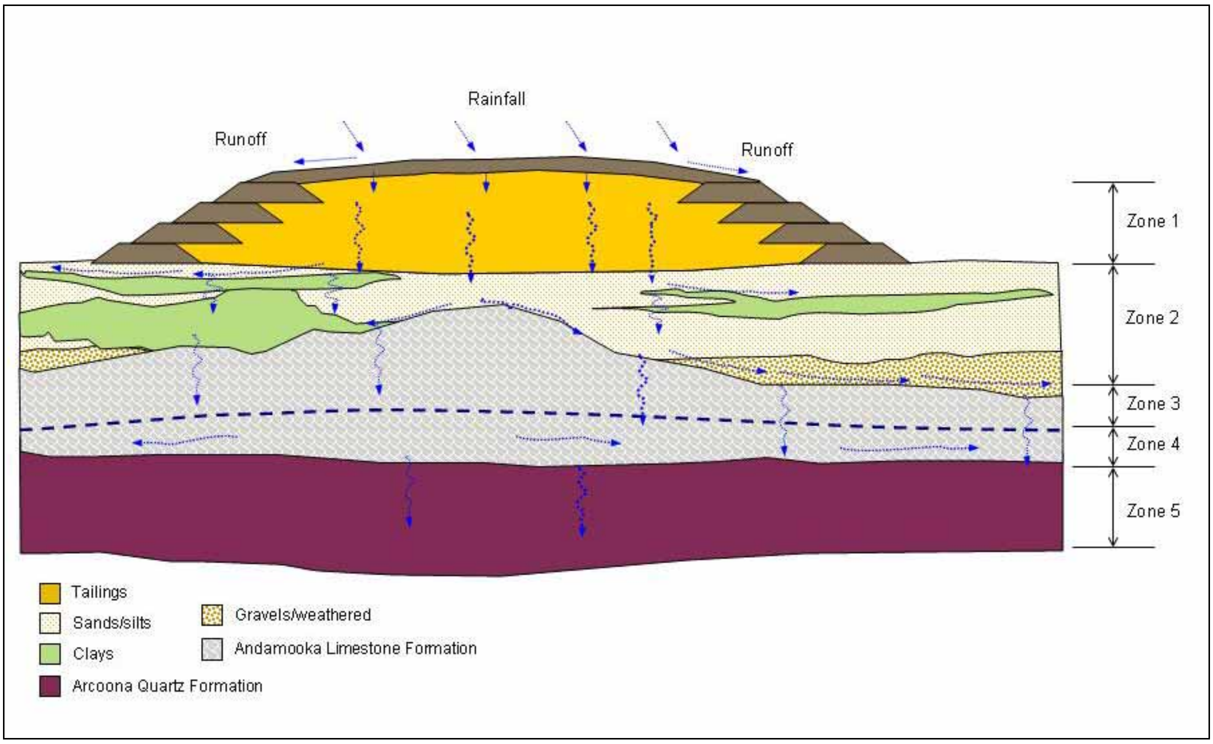

Figure 3.2 Schematic Illustrating Potential Post Closure TSF Seepage Flowpaths (Not to Scale)

3.2 Tailings Assessment

3.2.1 Acidity Balance

The water balance can be used together with the tailings water quality estimates to determine the overall acidity loading that could accumulate within the TSF over time. The water balance estimate indicates that the net process water inflow to the TSF would be expected to be about 112,384 m^3/day. On average about 7,370 m^3/day of pond water would be decanted to the surge ponds for recycling, and about 4,705 m^3/day would be pumped to the evaporation ponds. The TSF will be developed as a series of 9 cells (Cell 5 to 13, and an optional Cell 14) which will be commissioned as required throughout the operational period and raised to a height of about 65 m. Seepage from each cell will vary as more tailings are deposited and is expected to decrease from about 1600 m^3/day for the first two years after the cell is commissioned, to about 352 m^3/day thereafter. Because multiple cells could be operational at any one time, the total seepage from the TSF will vary over time and will be equal to the sum of the seepage from each cell.

Using a total acidity concentration in the order of 80 g/L, the total acidity loading to the TSF (9 cells, 3,600 ha) is estimated to be about 3,646 kgH_2SO_4/m^2. Depending on the secondary mineralisation that may occur within the tailings, most of the acidity would be expected to be mobile and could be released in the very long term. The residual sulphide minerals may contribute up to an additional 1,287 kgH_2SO_4/m^2.

The acidity loading associated with the seepage loss during the operational life of the TSF would amount to about 76.3 kgH_2SO_4/m^2, or about 2.1 % of the estimated potentially mobile acidity accumulated in the TSF. This means that the majority of the acidity would still be present in the tailings deposit at the end of operations. The implications with respect to the acid neutralisation capacity of the sediments are discussed later.

3.2.2 Major Ion Percolate Water Quality

The available data upon which to base estimates of tailings seepage quality are the data that have been summarised in Section 2.3. Based on the variability in the results and the uncertainty of the origin of the samples (i.e. affected by evaporation) the porewater in the tailings may differ somewhat from the process water. Furthermore, an important assumption implicit in using the EGi data is that the experimental conditions were representative of those that might be expected in-situ within the tailings column.

With ageing (i.e. as the porewater equilibrates with the tailings), it is expected that gypsum and K-jarosite will precipitate in the tailings. Saturation indices calculated using the PHREEQC model (Parkhurst and Appelo, 1999) verified this conclusion indicating saturation indices well above zero. The saturation index (S.I.) of a mineral is a useful indicator of the thermodynamic stability of mineral phases with respect to the solution chemistry in question:

- S.I. > 0 - the mineral is oversaturated. Unless kinetically inhibited, it might be expected that the mineral would precipitate.
- S.I. < 0 - the mineral is under-saturated. If the mineral is present within solid material contacting this solution, then it might be expected to dissolve from the solid in order to attain equilibrium.
- S.I. ≈ 0 - the solid is close to equilibrium with the solution.

(It should however be noted that the ionic strength of these solutions are very high, and ideally PITZER simulations should be undertaken to estimate equilibrium conditions. The available

PITZER thermodynamic database however is very limited and precludes a detailed assessment of the equilibrated solution.)

It is possible that some contaminant metals and radionuclides might co-precipitate along with such minerals. Such a possibility is borne out by the observed reductions in the concentrations of several elements (e.g. As, Mo, Pb, Sn, Se) in the later extracted solutions during the EGi testwork, when compared to the fresh tailings liquor. It is also possible that the higher pH of the 'aged' solutions (in the EGi equilibration tests) is associated with increased precipitation of iron oxy-hydroxide phases, thus increasing the sorptive capacity of the tailings solids. Increased sorption will also lead to lower solution concentrations. It is unlikely that complete equilibration of the solutions will have been achieved in the short term tests undertaken by EGi. Depending on the reaction kinetics it may take many years to achieve equilibrium conditions. However, with further ageing and possible increases in porewater pH, it might be expected that solution concentrations of these elements would be further reduced.

The concentrations of some elements increase in the EGi 'aged' test solutions (e.g. U, Co, Mn, Zn). Until a satisfactory understanding of the secondary mineral assemblage has been developed, it is difficult to estimate how further ageing (i.e. complete equilibration) might affect the solution concentrations of these elements.

Recognising that the short term 'aging tests' as conducted by EGi may not adequately represent pore water conditions within the tailings, the water quality of the aged samples is likely the most reasonable representation of percolate from the tailings.

3.2.3 Fate of Radionuclides in Tailings Porewater

When deposited, the tailings will contain uranium not removed during processing, and significant quantities of daughter products within the uranium decay series. Significant concentrations of the following radionuclides have been identified in tailings liquors and supernatant (EGi, 1995; ARUP 2007):

^{210}Pb, ^{210}Po, ^{226}Ra, ^{230}Th, ^{238}U

Within the tailings, during ageing and compaction, water-solid interactions are expected to take place. It is likely that the distribution of radionuclides between the liquid and solid phase will change during such interactions.

Possible controls on radionuclide distribution are:

- Solubility of radionuclide-bearing minerals present within the tailings;
- Sorption of radionuclides to mineral surfaces.

No mineralogical data were available for the tailings. To assess the likelihood of solubility controls, the water chemistries measured during the EGi test program were examined. The geochemical modelling code, PHREEQC (Parkhurst and Appelo, 1999) was used, combined with the HATCHES thermodynamic database (Bond et al, 1997). The HATCHES database is released annually through the Nuclear Energy Agency (NEA) and contains a wide range of thermodynamic data for a range of radionuclide-bearing minerals.

Calculations based on the tailings liquor and solution extracted after 7 months (EGi, 1995; Table 5) showed that most radionuclide-bearing minerals were under-saturated (S.I. values < 0). There were some exceptions, mainly sulphate and fluoride salts. Table 3.1 lists some of the minerals with S.I. values close to or greater than zero.

There is a possibility that the solubility of sulphate and fluoride-bearing salts could influence radionuclide concentrations at the very acidic pH values of early tailings porewater. However, it should be borne in mind that the thermodynamic database contains data for pure mineral phases. In the tailings environment it is possible that radio-nuclides may be incorporated as impurities within major element minerals. Data for impure phases and solid solutions are very limited and so the current modelling did not include such a possibility.

Table 3.1 Saturation Indices for Selected Radionuclide-bearing Minerals in the Tailings Liquor and the Solution Extracted After 7 Months Ageing

Mineral	Tailings Liquor	7 month Solution
ThF_4	-0.83	-2.29
ThF_4: $2.5H_2O$	+0.96	-0.5
$Th(SO_4)_2$	+5.51	+4.68
$PbSO_4$	-0.18	-1.79
UO_2SO_4:$3H_2O$	-0.11	+0.62
UO_2SO_4:H_2O	-1.66	-0.93

Notes:
- Consistent with the test conditions, aerobic conditions were assumed (pe + pH = 14). For the pH values, pH 1.7 and 3.3, the corresponding Eh values are 725 and 630mV, respectively.
- The ionic strength of the solutions was of order 0.8 to 0.9M. Such high ionic strengths are outside the limits of confidence in the thermodynamic data being used, and ideally a more sophisticated ionic strength correction approach is required. Such an approach was not adopted here as the calculations described are illustrative only.
- Radium and polonium were not included in the calculations as these elements were not included in the analytes in the EGi study. Also, in the case of polonium, no data are included in HATCHES database.

In the very long term, it is expected that the pH in the tailings porewater will increase as contained acidity is flushed from the tailings. As the pH increases, hydroxide minerals may become potential solubility controls.

The other likely control on radionuclide behaviour is sorption. Sorption is often represented by using a distribution coefficient, K_D:

$$K_D = C_{ads}/C_{aq}$$

Where C_{ads} is the concentration of element adsorbed to the solid phase and C_{aq} is the concentration remaining in solution.

Data were available regarding the concentration of U and Pb in the tailings solids. Using the solution concentrations measured in the EGi geochemistry testwork (Table 5) it was possible to calculate K_D values as shown in Table 3.2.

Table 3.2 Calculated K_D values

Radioelement	C_{ads}, wt%	C_{aq}, mg/L	K_D, ml/g
Uranium	0.027	18 (tailings liquor) 110 (solution extracted at 7 months)	15 2
Lead	0.007	2.3 (tailings liquor) 0.06 (solution extracted at 7 months)	30 1200

These values fall towards the low end of what might be expected given the anticipated high surface area of the tailings materials, and the likelihood that strong adsorbents such as iron oxy-hydroxides are present in significant quantities. However, the very acidic pH values are probably inhibiting sorption to some degree. Many elements sorb most strongly at near-neutral and alkaline pH values.

A more rigorous examination of the role of sorption in the tailings requires an understanding of which minerals are controlling sorption, which sorption mechanism is involved (e.g. ion exchange and/or surface complexation) and how solution chemistry might affect sorption. K_D values may range over orders of magnitude depending on factors such as the available surface area of an adsorbent, the solution pH and the presence or absence of competing ions for sorption sites.

For the radionuclides of interest in the Olympic Dam tailings, the following comments can be made about likely controls on their behaviour in the tailings:

- Lead – Possibly controlled by the solubility of $PbSO_4$ or by incorporation in major element sulphate or hydroxyl-sulphate minerals. Alternatively, lead is known to sorb strongly to oxy-hydroxide minerals (via a pH dependent surface complexation mechanism) or to clay minerals (by occupying interlayer exchange sites).
- Polonium - There is very little information available for polonium. A literature review would be necessary to establish if any data are available describing its solubility or sorption behaviour.
- Radium – Like lead, may be controlled by the solubility of sulphate salts. Additionally, radium is strongly sorbed to minerals that are associated with a high exchange capacity (clays and zeolites).
- Thorium – Most likely to be controlled by sorption onto oxy-hydroxide minerals (via a pH dependent surface complexation mechanism).
- Uranium – Exists in more than one oxidation state and so will be sensitive to redox conditions in the tailings. The reduced form, uranium(IV) is less soluble and more strongly sorbing than the oxidised form. Most likely to be controlled by sorption onto oxy-hydroxide minerals (via a pH dependent surface complexation mechanism). The oxidised form, uranium(VI), is most likely in the tailings unless it is anticipated that conditions in the tailings become reducing. In addition to pH, sorption of uranium(VI) is affected by the presence of dissolved carbonate. Uranium(VI) forms strong aqueous complexes with carbonates and so high dissolved carbonate concentrations are associated with reduced sorption.

3.3 Soils and Sediments

3.3.1 Acidity Balance

Of the sediments, the calcareous clays have been shown to be most reactive and most effective at neutralising the acidity from the TSF. On average the calcareous clays have a neutralisation capacity of about 139 kgH_2SO_4 eq/tonne, primarily as calcite. The acidity that may be released over the life of active operations of the TSF would result in the consumption of the ANC of a continuous calcareous clay layer to a depth of about 0.3 m. To neutralise all of the acidity stored in the TSF would require a continuous clay layer of about 19.7 m thick.

The consumption of the carbonate minerals within the clays would result in an increase in porosity. However, concurrently with the consumption of carbonates, other secondary mineral phases would be formed. The secondary minerals that may be formed would depend on the composition of the percolate from the TSF and on the prevailing conditions at the reaction sites.

The percolate from the TSF will contain an abundance of sulphate and various metals, as well as free acid. Neutralisation of the free acid will lead to the formation of gypsum. The dissolved metals may lead to the formation of metal hydroxides and additional gypsum. Speciation of some metals however depends on the redox conditions. For example, under oxidising conditions, the rate of oxidation of ferrous iron to ferric iron increases rapidly as the pH increases, and ferrihydrite

($Fe(OH)_3$) is readily precipitated from solution. However, for anoxic conditions ferrous iron will not be oxidised and will remain in solution so that the net mass of precipitate formed will be substantially less than for oxidising conditions. Since there is an abundance of ferrous iron in the percolate it is anticipated that oxygen will be rapidly consumed and conditions will tend toward anoxic conditions beneath the TSF. Towards the perimeter of the TSF oxidising conditions may prevail which could lead to slightly different reactions and consequences.

Based on the average water quality presented in Table 2.3, the total mass ANC consumed considering both calcite and dolomite as neutralising minerals, and the resultant mass of solids that could be generated, were calculated. Estimates were prepared for both oxidising and anoxic conditions. For oxidising conditions it was assumed that all of the iron would precipitate as ferrihydrite, whereas for anoxic conditions only the iron already in the ferric state would precipitate. The results are shown in Table 3.3.

Table 3.3 Summary of Estimated ANC Consumption and Solids Precipitation

Description		Solids Consumed / Generated	
ANC Source		**Calcite**	**Dolomite**
Consumed (g/m^2)		153	141
Generated (g/m^2)	Oxidising Conditions	272	182
	Anoxic Conditions	221	131

The ANC contained in the calcareous clays appears to be predominantly calcite. As shown in the Table 3.3, with calcite as the ANC source more solids would be generated (precipitated) than would be consumed (dissolved), irrespective of oxidising or anoxic conditions. A significant proportion of the solids that would be precipitated would be gypsum which has a lower density than calcite, whereas the densities of the other secondary minerals are likely to similar to that of calcite. This means that the neutralisation reactions would result in a net reduction of porosity, i.e. the clays are likely to become less permeable. The potential consequences could be as follows. First, a reduction in the permeability would lead to increased lateral flows over the top of the clay layer. Second, the net accumulation of solids at the reaction sites could lead to the ‘blinding’ of reactive ANC. And third, since the flow through the clays would decrease, physically less ANC would be available for reaction with the acidity.

3.3.2 Water Quality

Apart from the neutralisation testing that has been undertaken by EGi (EGi 1995) for oxidising conditions, no direct measurements of actual pore water quality within the clays and other sediments underlying the TSF are available.

As shown in Section 2.6, redox measurements from regional groundwater boreholes showed that the groundwater tends to be reducing, although the exact conditions beneath the TSF are not known. The oxidation of ferrous to ferric as the percolate is neutralised will consume oxygen so that anoxic conditions would be expected to develop over time.

Another factor that has not been accounted for within the testing is the effect of elevated carbon dioxide. The results presented in Table 9 of the EGi report (EGi 1995) indicate that the calcareous clays would buffer the tailings percolate to a pH of about 7.7. Preliminary equilibration calculations were performed with the PHREEQC model to equilibrate the Cell 4 tailings water (See Table 2.3) with calcite, a carbon dioxide overpressure of about 0.001 atmospheres, and a redox of about 70 mV. The results suggest that the neutralised porewater should equilibrate at a pH of about 6.7, which is lower than the test results indicated. The lower pH however is more consistent with the pH values measured within the TSF boreholes. At the lower pH, a number of solutes are likely to have a higher concentration than indicated by the test results. With the exception of iron, uranium and possibly a few other elements, the concentrations indicated by the neutralisation tests nonetheless would reasonably represent solute concentrations in percolate from the calcareous clays.

Apart from the clays, a proportion of the percolate that would flow to the Andamooka Limestone would comprise neutralised solution from the calcareous clays, partially neutralised solution from the calcareous swale materials, and, unaffected percolate that passes through the dune and other none-reactive sands.

The seepage quality from the sediments, and hence the acidity loading that would first contact the Andamooka Limestone, would therefore vary from completely neutralised to un-reacted tailings percolate. Clearly the loadings over time would depend on the flowpaths that develop and how they might change over time. This would be a function of the spatial distribution and layering of primarily of the calcareous clays beneath the TSF.

3.4 Andamooka Limestone

As discussed above, the seepage that would contact the Andamooka Limestone would, depending on the thickness and distribution of the calcareous clays, vary from completely neutralised to percolate that resemble the tailings pore water quality. It is further likely that the percolate quality would locally vary with time as ANC is increasingly depleted from thin layers of calcareous clays. As noted previously, for the period that the TSF is operated only about 4 % of the total acidity is likely to be released, and, neutralisation of this amount of acidity would require about 1.4 m of available reactive calcareous clays. While additional refining of the estimate will be required, the plot provided in Figure 2.3 suggests that in about 75 % of the bores there are clay layers of 1 m or more in thickness. This suggests that it may be possible for most of the acidic percolate to be neutralised within the sediments during the operational period. (An assessment of the sorption capacity would need to be undertaken to assess the mobility of trace elements, however, results to date suggest that neutralisation would limit the mobility of most parameters.) The remaining 25 % or so of the seepage that may percolate directly to the Andamooka Limestone Formation would react with the dolomite contained in this formation and would be neutralised.

As shown by the ground water monitoring results, and supported by the fact that the percolate will have a significant chemical oxygen demand, the unsaturated zone of the Andamooka Limestone would be anoxic. Hence, as shown in Table 3.3 for dolomite under anoxic conditions, more solids would be consumed than would be deposited. An increase in porosity of about 1 to 2 % is indicated (assuming densities of 2.4 for gypsum, 3.8 for ferrihydrite, and 2.74 for alunite) within the affected zone. This means that it is likely that karst features would be enhanced (i.e. enlarged) within the affected zones.

In the longer term, as the calcareous clays are depleted, the acidity loading to the Andamooka Limestone will increase. It is important to note that after closure, i.e. after draindown has occurred, seepage rates from the TSF will decrease considerably so that acidity loadings will be much lower than during the operational period. The net loadings would depend on the rate of infiltration and would need to be determined for the actual configuration of the closed TSF system. It is however important to note that, in theory, there is sufficient dolomite contained in about a 2 to 4 m thick layer of Andamooka Limestone to neutralise all of the acidity contained in the tailings. Clearly there is a large abundance of neutralisation capacity and it is unlikely that acidic percolate will migrate very far from the TSF before it is neutralised. Therefore, assuming that infiltration rates revert to near regional recharge rates, other factors such as alkalinity in the regional water as well as dilution would become more significant in determining solute concentrations in groundwater. Once infiltration rates have been established for the final closure infiltration rates together with percolate water quality estimates, potential local and regional effects may be determined.

3.5 Arcoona Quartzite

Infiltration to the carbonate Andamooka Limestone system will be affected by elevated carbon dioxide overpressure. As the percolate enters the Arcoona Quartzite system and moves away from the carbonate controlled system it is likely that carbon dioxide losses would occur which could cause an increase in the pH. The lower pH values observed in the groundwater monitoring data in the mound within the Andamooka Limestone Formation below the TSF (compared to the regional values within the Andamooka Limestone Formation and in particular within the Arcoona Quartzite) are indicative of such conditions. This change in pH may cause some phases to precipitate from solution. To determine the amount of solids that could be formed would require a good understanding of the build-up of carbon dioxide concentrations above and within the Andamooka Limestone as well as an accurate measure of the dissolved species that form as a result of the carbonic acid.

Based on initial speciation modelling, a 10 fold increase in carbon dioxide concentration above atmospheric conditions (i.e. from 0.03 % to 0.3 %) would decrease the equilibrium pH from 8.3 to 7.6 and could lead to a 2 fold increase in dissolved dolomite concentration. A 100 fold increase (to around 3%) would decrease the pH to 7.0 and increase the dissolved dolomite by a factor of 5. To reach the pH observed in the groundwater mound of about 6.5 would require a carbon dioxide concentration increase of about 500 times the atmospheric partial pressure to about 15 %. At those conditions the dissolved dolomite would increase by a factor of 9.5 times that at atmospheric conditions. As the water moves away from the influence of the carbon dioxide, the pH would be expected to increase. Assuming it increases to the regional pH of about 7.5, and assuming that only calcite would be precipitated from solution, it is estimated that between 85 and 220 mg of $CaCO_3$ could be deposited from each litre of solution that passes through the Arcoona Quartzite formation. To assess the potential effects on the permeability of the formation, these rates of deposition would need to be factored into the estimated flow rates that are expected to pass through the Arcoona Formation.

3.6 Potential Temporal Effects

As noted above only about 2.1 % of the total potential acidity accumulated within the TSF would be released during the period of active operations. To neutralise this acidity loading would require about 1 m of calcareous clays. The drill logs suggest that most of the TSF footprint is likely to be underlain by calcareous clay to a depth of 1 m or more. This means that during the operational period most of the acidity would be neutralised within the sediment layer. This is consistent with the observations for the existing TSF system. During this period there would be a net accumulation of carbon dioxide beneath the TSF. Based on the potential chemical oxygen demand of the percolate, it would be expected that oxygen would be depleted from the porespace and anoxic conditions would develop and be sustained. Furthermore, since most of the neutralisation reactions are likely to occur within the sediment layer, local effects on the porosity and permeability of the Andamooka Limestone Formation would be insignificant.

After operations cease, percolation rates are expected to decrease somewhat but would remain comparatively elevated due to drain-down of porewater from the tailings. The rate of drain-down is expected to slow as time progresses. However, assuming that percolation rates remain constant at levels slightly below predicted operational seepage rates, elevated percolation rates could be sustained for many tens of years (estimated to be on the order of 150 to 250 years). During that time it is estimated that as much as 30 % additional acidity could be mobilised from the TSF. About 7 m or more of underlying calcareous clays would be required to neutralise the potential acidity loading that could be released during that period. Clearly not many areas of the TSF would be underlain by corresponding thicknesses of calcareous clay layers and neutralisation reactions would occur within the unsaturated zone of the Andamooka Limestone. Reactions are however expected to be limited to the upper few meters of the formation. Carbon dioxide release rates would be sustained during this period and anoxic conditions would continue to prevail. Acidification of minor areas of clays could be expected and the associate release of some solutes. These however would be captured within the neutralisation reaction zones lower down. During this period dissolution of dolomite will become more pronounced and, locally, porosity may increase. In the latter stages of this phase, it may be conceivable that the effects of carbon dioxide could locally be carried through to the Arcoona Quartzite Formation.

After draindown is complete, percolation rates will enter a third phase. The rate of percolation would then be expected to decrease to a rate equal to the rate of net infiltration from rainfall (i.e. natural recharge for the final surface). The rate of acidity release would correspondingly decrease to low levels. At that time, most neutralisation reactions would be expected to occur within the upper zones the Andamooka Limestone formation. Carbon dioxide would continue to be generated, however, at a reduced rate and it is possible that partial pressures may decrease during this phase. Depending on the total availability of the acidity, this phase could continue for several thousands of years.

3.7 Limitations and Uncertainties

There are a number of uncertainties and limitations that preclude verification of the conceptual geochemical model at present and also preclude the development of concise source terms for the TSF. These can be summarised as follows.

- Within the tailings the uncertainty primarily relates to the secondary minerals that actually form within the tailings and how stable they would remain in the long term. This leads to uncertainty with respect to the total acidity release from the tailings as well as the actual pore water quality that will develop over time. In part this deficiency is a result of testing procedures that did not fully recognise the physico-chemical conditions that may prevail within the tailings at depth.
- The current assessment assumed that most of the acidity would remain mobile and could be released in the long term. While this is a conservative approach, it may lead to an overstatement of the potential consequences that may be associated with acidic percolate from the TSF. Nonetheless, it is concluded that sufficient acid neutralisation capacity is available within the sediments and the Andamooka Limestone Formation to neutralise all of the acidity within the immediate vicinity of the TSF footprint.
- The availability of radionuclide monitoring results for tailings water and for porewater within the tailings as well as below the TSF lead to uncertainty in identifying the attenuation mechanisms. This also leads to uncertainty in determining the future behaviour of the radionuclides for various conditions that may develop below the TSF.
- Within the soils and sediments the distribution and continuity of the calcareous clays in particular but also other calcareous materials is not fully understood. Furthermore, the secondary minerals that would accumulate within the sediments and soils, as well as the effects of carbon dioxide accumulation on the stability of these phases are poorly understood. This leads to uncertainty in the potential effects on porosity and the likelihood that the availability of some calcareous clays may be limited due to physical effects.
- The extent to which carbon dioxide has accumulated to date and the extent to which it may increase in the future is also uncertain. This may have significant implications on the potential effects that may occur locally within the Andamooka Limestone Formation and the Arcoona Quartzite Formation. There is also uncertainty with respect to how rapidly the effects of carbon dioxide may dissipate as percolate exits the Andamooka Limestone formation. Other sources of uncertainty include the rate of percolate release during drain-down and the rate of infiltration that would prevail in the longer term after closure.

4 Summary and Conclusions

The ore properties and processing for the Olympic Dam Expansion project are not expected to change significantly from the current operating conditions. It was therefore concluded that the current tailings properties and geochemical observations at the existing TSF can be used to project potential future conditions. It was further concluded from sulphide recovery data that the tailings may have an acid generation potential in the order of about 2.5 to 11 kg H_2SO_4 eq/tonne.

The water quality of the leachate associated with the current tailings indicates that all acid neutralisation capacity has been depleted from the tailings prior to deposition. There are however equilibration reactions that are occurring within the tailings which suggest that hydronium and other jarosites are being formed within the tailings. These reactions may sequester some of the acidity with the tailings, however, no mineralogical data were available to confirm the occurrence of the secondary mineral phases. The results nonetheless suggest that the percolate from the TSF will remain acidic and will be characterised by elevated solute concentrations similar to the leachate properties (i.e. decant water quality).

Drill logs that were recorded as part of the geotechnical investigation within the footprint of the planned future TSF cells indicated that the sediments underlying the TSF generally comprise topsoil/dune sand, calcareous soils, sand / silty sand, fine to medium grained weakly cemented and grading to gravely sand in places, and, silty clay /clayey silt, high liquid limit, with inclusions of gypsum crystals. The clayey features are discontinuous and range considerably in thickness, as does the thickness of the overburden to bedrock. Because of the differences in permeability amongst the different material types, it is anticipated that percolate from the TSF could follow selective flowpaths and that flows through the clays locally could be substantially lower than through the sandy / gravely materials. The clay features may also lead to the development of perched water tables. The geotechnical investigation showed that in some locations the overburden is very shallow and percolate could contact the limestone more directly without the benefits of reacting with calcareous soils and clays first.

The geochemical testing indicated that, of the sediments, the calcareous clays have the highest ANC values, are the most reactive and are most effective at neutralising the percolate from the tailings. The test results also suggest that the ANC occurs predominantly as calcite within these calcareous materials. The geochemical testing indicated that the Andamooka Limestone Formation in this location is dolomitic. The testing further showed that the dolomitic material tends to be less reactive than the calcareous clays, and under oxidising laboratory test conditions likely is ‘blinded’ by secondary minerals that precipitate from solution.

Geochemical assessments of the conditions within the sediments underlying the tailings have indicated that an acid front has developed in the sediments below the TSF and that it is progressing downwards with time as ANC in the sediments are being depleted.

Groundwater quality monitoring results indicate that water within the mound in the Andamooka Limestone Formation below the TSF remains near neutral in pH. The groundwater quality monitoring results however indicate that bicarbonate in particular, as well as selenium and uranium concentrations are elevated above regional concentrations. Localised below the TSF pH values are also shown to be slightly depressed below neutral conditions. The elevated bicarbonate concentrations together with the depressed pH values are indicative of the build-up of carbon dioxide below the TSF which would affect equilibrium reactions. The carbon dioxide is generated from the neutralisation reactions that occur when acidic percolate from the tailings contacts the carbonate minerals present in the underlying sediments and bedrock.

It is concluded that neutralisation of the acidic seepage by carbonate minerals is the primary mechanism for modifying the water quality of the percolate and that most contaminants are removed by this mechanism. It is also concluded that sorption and possibly co-precipitation are secondary mechanisms that contribute to the attenuation of contaminants within the neutralised zone.

Based on the above observations a conceptual geochemical model was developed. It is concluded that the TSF system, and in particular the movement of water from the tailings to the underlying aquifers, represents a very complex system. Due to the complexity of the system, it means that a range of possible flow and reaction paths would need to be considered, leading to a range of possible outcomes rather than a 'single-value' prediction.

The geochemical model identifies five distinct zones, each of which would have a different effect on water that flows downward from the tailings.

Within the tailings some of the acidity may be sequestered as secondary mineral phases. However, until these mineral phases can be identified it is assumed that the percolate from the tailings would resemble the decant water quality. This seepage water quality would persist during the operational period, during the drain-down period after tailings deposition ceases and for many years beyond. In the longer term, as the tailings become dewatered, the rate of percolation will slow down and will become equal to the natural recharge rate. (The recharge rate would depend on the closure measures that would be implemented.) At that time, oxygen ingress to the tailings could lead to the oxidation of the residual sulphides and may add to the acidity levels. In the long term however, acidity loadings are expected to decrease proportionally to the reduction in percolation rates.

Overall acidity balances indicate that during the period of active tailings deposition, only about 2.1 % of the total acidity contained in the TSF would have been released. For this period it is estimated that excess acid neutralisation capacity is available within the underlying calcareous soils and sediments. In the longer term the Andamooka Limestone formation would offer adequate capacity to neutralise all of the acidity contained in the TSF.

There is however a possibility that the clays may over time become less permeable due to the accumulation of secondary mineral phases which may change flow directions and decrease the overall availability of the calcareous clays to neutralise the acidity immediately below the TSF. Lateral flow would however bring the percolate into contact with additional calcareous clays which would promote neutralisation. Solute concentrations in neutralised percolate from the sediments may be inferred from some of the laboratory test results (e.g. neutralisation test results presented by EGi, 1995). It is important however to recognise that these tests do not necessarily reflect the controlling physico-chemical conditions that would prevail beneath the TSF and that actual concentrations may be significantly different.

In the longer term existing karsts and features within the unsaturated zone of the Andamooka Limestone are likely to be enhanced locally by neutralisation reactions under anoxic conditions. This could lead to marginal increases in horizontal permeability, however, such effects will also lead to the exposure of fresh reaction surfaces laterally which would promote further neutralisation and solute removal from the percolate as it migrates away from the TSF and ultimately towards the open pit. The water quality monitoring results for the groundwater mound may be used to infer the water quality in the interim. However, it is important to note transient conditions are still being observed in some of the boreholes.

Due to the effects of excess carbon dioxide, percolate from the Andamooka Limestone may carry with it excess dissolved solids that may precipitate as the percolate moves outside the influence of the carbon dioxide generated within the acid neutralisation zone. These precipitates could affect the permeability of the Arcoona Quartzite in the longer term and may affect the movement of percolate locally in the very long term.

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APPENDIX K5

Rock storage facility geochemistry assessment

Olympic Dam Expansion

Assessment
Olympic Dam Mine Rock Geochemistry

Report Prepared for

Olympic Dam Expansion Project

Prepared by

SRK Consulting
Engineers and Scientists

Draft EIS – BHP030

August 2008

Assessment
Olympic Dam Mine Rock Geochemistry

Olympic Dam Expansion

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Disclaimer

The opinions expressed in this Report have been based on the information supplied to SRK Consulting (Australasia) Pty Ltd (SRK) by Olympic Dam Expansion Project (ODX). The opinions in this Report are provided in response to a specific request from ODX to do so. SRK has exercised all due care in reviewing the supplied information. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions form the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information and does not accept any consequential liability arising from commercial decisions or actions resulting from them.

1 Introduction

1.1 Terms of Reference

Mining at the Olympic Dam Operation is currently by underground methods only. Very little mine rock is being produced from development workings and is mostly being placed in mined out areas underground resulting in no storage of mine rock above ground.

BHP Billiton is assessing the feasibility of expanding the Olympic Dam project to include development of a large open cut mine and extend the life of mine to beyond 40 years of operation. Open cut mining generates large quantities of mine rock which is stored on the surface adjacent the open pit. Consequently, as part of the proposed Olympic Dam Expansion (ODX) project a large rock storage facility (RSF) would be developed.

Based on current estimates about 4 255 million m^3 (in situ) of rock would be placed in the RSF over a period of forty years. The RSF would receive different rock types or lithological units that would be encountered as the mine is developed, including overburden, and sedimentary and basement rocks. Because the open pit would be developed in a series of fifteen “push-back” stages, all types of mine rock would be produced throughout the life of mine.

Mine rock brought to surface would be exposed to oxidizing conditions that may alter the chemical stability of some of the contained mineral phases. For example, sulphidic minerals would oxidise and may release heavy metals to porewater and, when insufficient neutralising minerals are present, could also lead to acidic pH conditions. In the very long term, the potential for metals to leach from the mine rock could alter the underlying groundwater quality. To assess to what extent the water quality may be altered, it is necessary to establish:

- how the mine rock would weather over time (overall potential for metal acid generation and contaminant release);
- the rate at which contaminants may be released to the porewater over time (i.e. porewater concentrations that may be developed over time); and,
- the rate at which percolate would be released at the base of the RSF (i.e. net loadings to the underlying aquifer).

Previously Western Mining Corporation (WMC) and more recently BHP Billiton Olympic Dam Operations compiled from exploration data a database of geochemical properties of the mine rock at the Olympic Dam Project. ODX commissioned ENSR/AECOM to assess the geochemical properties of the mine rock using supplemental testing procedures and, from these properties, estimate the potential for contaminant release from the RSF.

Olympic Dam Expansion Project retained SRK Consulting to review the available geochemical information for the ODX RSF and to identify any information gaps that should be addressed within the timeframe of commissioning and operating the RSF.

1.2 Approach

The approach that was adopted for the preparation of this report comprised five steps. First, the geological background and geochemical findings from previous studies as they relate to the mine rock were summarised. Second, the use of these data to generate water quality predictions for RSF was reviewed and assessed. Third, supplemental calculations and evaluations were completed to the extent possible to either highlight the significance of, or address, the potential issues that were identified in the previous step. Fourth, supplemental investigations and assessments that may be considered during the planning and/or early production phases were identified. Finally, recommendations for source term descriptions are provided.

1.3 Report Structure

The remainder of the report is laid out as follows. Chapter 2 contains a summary of pertinent background information, and summarises the findings of the geochemical investigations to date. Chapter 3 briefly assesses the plausibility and applicability of the proposed source terms. The conclusions and recommendations are contained in Chapter 4.

2 Background

2.1 Project Setting

The Olympic Dam Project is located near the township of Roxby Downs in a semi-arid region of South Australia about 570 km north-north-west of Adelaide by road.

Average annual rainfall at Roxby Downs is about 164 mm and is sporadic and unpredictable with no seasonal pattern. Intense rainfall events that are generally of short duration may occur at any time of the year. The site on average receives rain 49 days per year.

Temperatures range from - 6 to + 48^{o} C and evaporation is high throughout the year, with an annual average of about 3,100 mm.

2.2 Olympic Dam Expansion Project

BHP Billiton is assessing the feasibility of developing a large scale open pit operation at the Olympic Dam underground mine. Under the proposed revised mining proposal, the operation of the Olympic Dam Expansion project is expected to be in excess of 40 years. Unlike for underground operations, the introduction of open pit mining will result in the production of a large mass of mine rock (about $11.253x10^{9}$ tonnes over a 40 year period) that will need to be placed in an RSF.

The mine rock will comprise a mixture of overburden, sedimentary rock and basement rock which will originate from both above and below the water table. Upon exposure to atmospheric conditions, some minerals contained in the mine rock will react with the oxygen and may potentially cause the release to porewater of soluble metals. In time, as infiltration enters the mine rock, these metals may be transported to the base of the RSF and could enter the groundwater system.

As part of the feasibility assessment, BHP Billiton ODX has developed a conceptual design for the RSF. The design has been based on the production schedule and cost optimization for haulage distance and elevation from the pit. Other design considerations included infrastructure corridors, proximity of low grade ore stockpile to the run-of-mine pile, geotechnical stability, the arid recovery area location and dust generation. The lay-out of the RSF is illustrated in Figure 2-1. The RSF will be developed to a maximum height of about 150 m in lifts nominally about 25 m high.

2.3 Surficial and Bedrock Geology

Olympic Dam is located within the Stuart Shelf geological province, which comprises a relatively thin sequence of sedimentary rocks overlying the metamorphic basement rocks of the Gawler Craton, which hosts the Olympic Dam orebody. The basements rocks comprise a variably brecciated and altered granite complex. The sedimentary cover comprises a sequence of sandstones, limestone and unconsolidated sands and clays. The main attributes of the geological units identified at the site are summarised in Table 2-1.

The Quaternary dune sands, clay-sandy soils and weathered rock that constitute the overburden that will be stripped from the open cut mine area as well as the substrate underlying the proposed RSF comprise natural soils containing topsoil, dune sand, calcareous soils, and silty clay to clayey silt. Some inclusions of gypsum crystals are also encountered. The sedimentary rocks comprise distinctly weathered calcareous sandstone, with some interbedded siltstone layers. Small karstic features typically are present as small voids.

The sedimentary rocks of most significance on the Stuart Shelf include the Andamooka Limestone and the Tent Hill Formation, which comprises the Arcoona Quartzite, Corraberra Sandstone and Tregolana Shale.

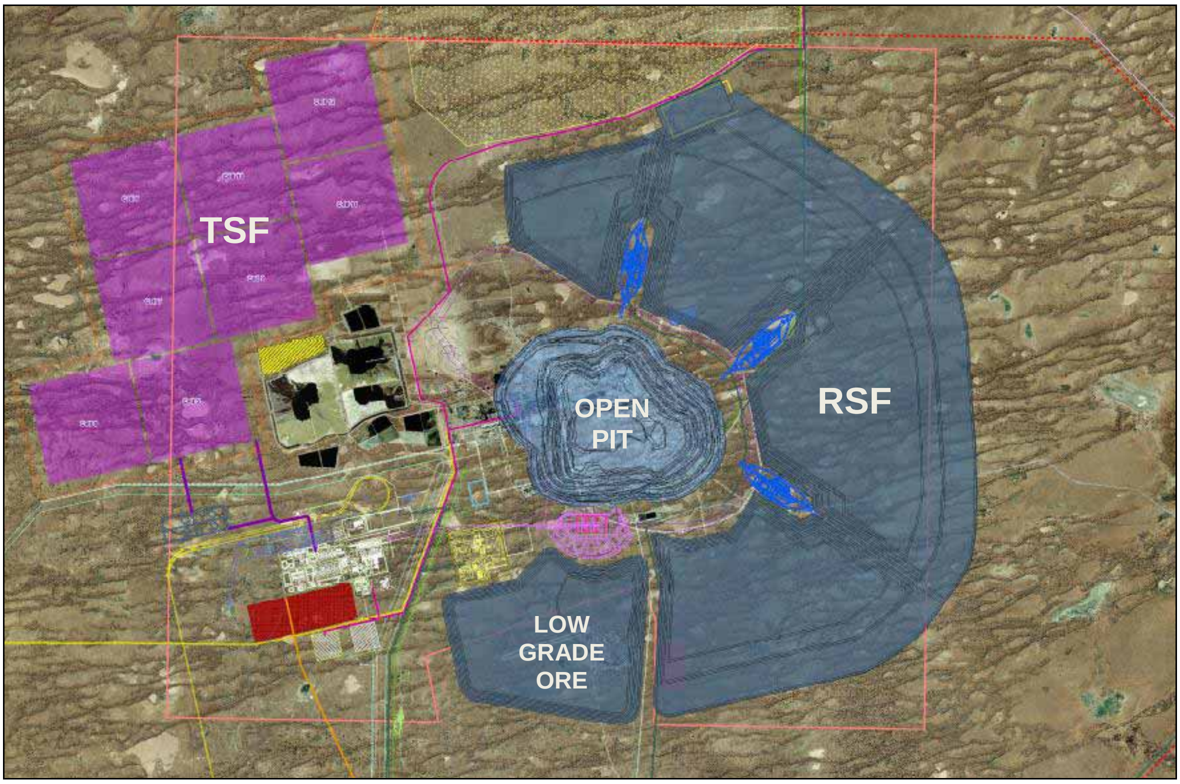

Figure 2-1 Aerial View of RSF Layout

Table 2-1 Geological Setting

Category	Geological Unit	Description
Overburden	Cainozoic sands and clays	Unconsolidated material - dominantly sandy, but contains discontinuous clay lens of varying thicknesses. (Typ. ~ 10 m)
	Andamooka Limestone	Dolomitic limestone, locally siliceous. (Typ. ~ 32 m)
	Arcoona Quartzite	Massive, cross-bedded quartzite (Typ. ~111 m). Muddy laminations and red coloration observed towards the top of the sequence (Typ. ~ 5 m). White Arcoona quartzite at depth (Typ. ~ 30 m).
	Corraberra Sandstone	Red, massive, cross-bedded sandstone (Typ. 20 m).
	Tregolana Shale	Thinly laminated red and green shales (Typ. 125 m).
	Pebble Conglomerate	Conglomerate separating the cover sequence from the underlying basement (Typ. 9 m).
Basement	Olympic Dam Breccia Complex (ODBC)	Wide variety of breccias types showing a complete gradation from granite breccias to haematite-rich breccias. Iron oxide mineralization is widespread; early magnetite is overprinted by haematite (occasionally accompanied by sulphides). Hydrothermal alteration of silicates has produced secondary sericite, chlorite and siderite. Minor but significant additional lithologies present within the ODBC are: • volcanoclastic rocks (lapilli and ash-fall tuffs) • mono and polymineralic veins • ultramafic, mafic and felsic dykes

The Roxby Downs Granite, underlying the sedimentary rocks, contains the Olympic Dam orebody and forms the basement rocks in the immediate area of Olympic Dam.

Surficial volcanoclastic rocks such as lapilli tuffs and laminated ash-fall tuffs are preserved in the upper parts of phreatomagmatic diatreme structures in the OBDC (Reeve et al., 1990). Fine-grained and finely laminated haematite–quartz ± sericite siltstone and sandstone showing graded bedding and soft sediment deformation are common features of these rocks.

Some porphyritic felsic volcanic clasts within the ODBC may be derived from coherent extrusive lava flows correlated with the Gawler Range Volcanics. These rocks were either overlying the Roxby Downs Granite and subsequently incorporated into the breccia complex as the hydrothermal system developed or, alternatively, may have been intruded into the ODBC.

Narrow (generally <10mm thick) mono or polymineralic veins, veinlets and vein fragments occur throughout the ODBC and in the surrounding granite. Vein assemblages typically consist of minerals that are dominant alteration and mineralisation phases within the breccia complex (Reeve et al., 1990) and comprise haematite, sericite, chlorite, siderite, barite, fluorite, quartz, sulphides or pitchblende in various combinations.

2.4 Mine Rock Descriptions

The lithological descriptions evolved through the Olympic Dam exploration and development phases and were retained in subsequent geochemical investigation programs. Summary descriptions of the different rock types are provided in Table 2-2. It is important to note that the hematite abundances in the “Granite – Hematite” categories in the major basement complex units are based on the analytically determined iron content of the rock rather than by visual or other means. Visually it would be difficult to distinguish amongst these different rock types to this accuracy.

2.5 Mine Rock Production

The production schedule was derived from the resource blockmodel and pit optimization prepared by ODX. The mine rock production schedule by rock type is shown in Figure 2-2. As shown, during the earlier years predominantly overburden will be placed in the RSF. In later years the proportion or rock from the basement complex increases. However, overall, the basement complex rock comprises only about 33% of the total mine rock that will be placed in the RSF.

Table 2-2 Rock Unit Descriptions

ROCK UNIT	Code
Overburden	
Cainozoic Sands and Clays	ZWS
Andamooka Limestone	ZAL
Arcoona Quartzite – Transition	ZWA
Arcoona Quartzite Red	ZWAR
Arcoona Quartzite White	ZWAW
Corraberra Sandstone	ZWC
Tregolana Shale	ZWT
Pebble Conglomerate	ZWP
Basement Complex - Major units	
Granite	GRN
Granite > 90%, Hematite < 10%	GRNB
Granite 70-90%, Hematite 10-30%	GRNH
Granite 40-70%, Hematite 30-60%	GRNL
Granite 10-40%, Hematite 60-90%	HEMH
Granite < 10%, Hematite > 90%	HEM
Hematite > 90% + quartz +or- Barite? no sulphide present	HEMQ
Basement Complex - Minor Units	
Hematite greater than volcanic components	HEMV
Dolerite	DOL
Mixed ash epiclastics	KASH
Laminated hematite-quartz sandstone / siltstone (volcanic conglomerate + tephra)	KHEMQ
Volcanic ash	VASH
Igneous Dyke	EVD
Volcanic components greater than hematite	VHEM
Brecciated / fragmented igneous dyke (unclassified)	EVB

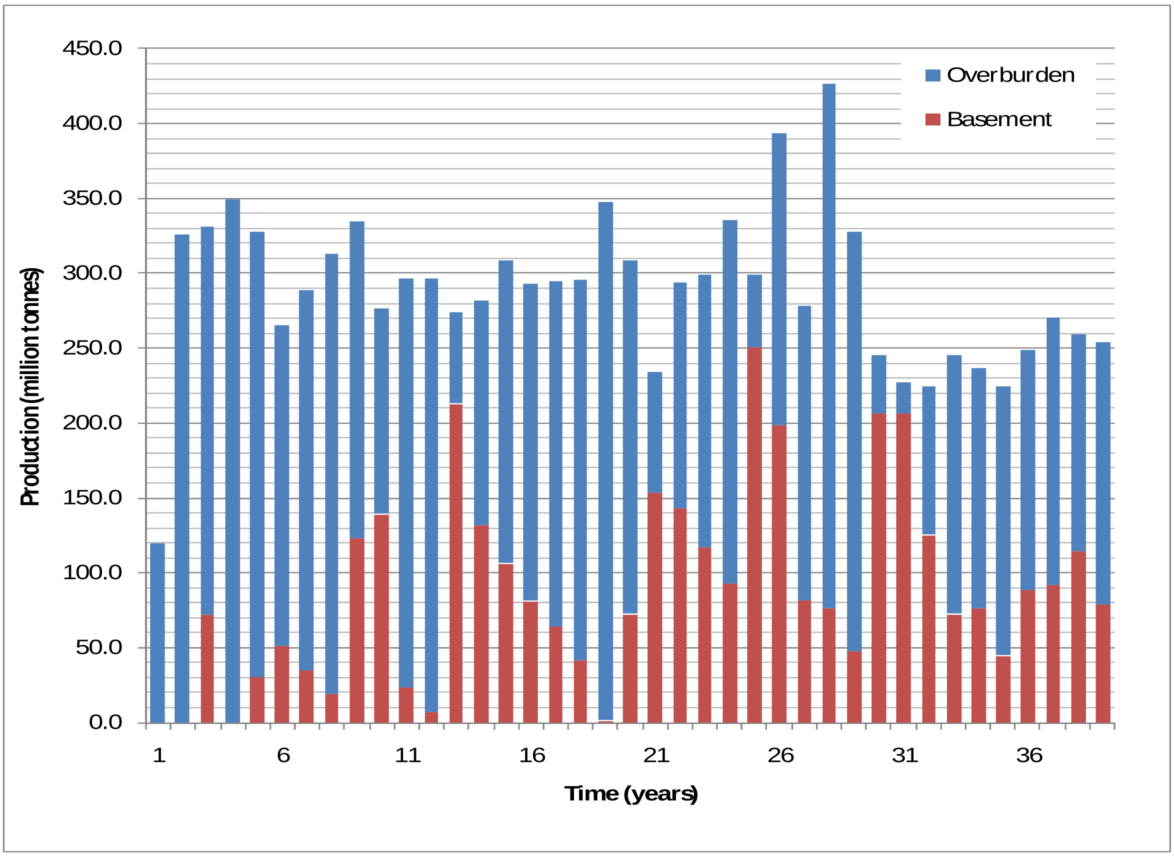

Figure 2-2 Mine Rock Production Schedule and Source

2.6 Hydrogeology

A detailed description of the regional and local hydrogeology is beyond the scope of this report but can be summarised as follows. The two primary aquifer systems are hosted by fractures in the Arcoona Quartzite and the Corraberra Sandstone to the south and the Andamooka Limestone which dominates to the north. This regional aquifer is hydraulically continuous across the Stuart Shelf. A shallower local aquifer at Olympic Dam is hosted by vugs and cavities within the Andamooka Limestone. Small perched water tables may exist above clay lenses within the near-surface unconsolidated Cainozoic material beneath the TSF and unlined water storage facilities.

The hydrogeological assessment has shown that a capture zone would be created by the drawdown cone that would form as a result of the dewatering of the pit. In the very long term, the water balance for the pit show that evaporative losses would exceed combined inflows so that the capture zone would be maintained after mining ceases. Depending on the recharge to the RSF, percolate from the RSF would be expected to flow to the open pit.

2.7 Geochemical Studies

ENSR/AECOM completed a geochemical investigation on the basis of the rock classification and production schedule to assess the potential for contaminant release from the mine rock (ENSR/AECOM, 2008). That investigation comprised:

- Compilation and summary of geochemical data collected throughout Olympic Dam exploration and development phases.
- A series of static tests to determine the acid base account properties and elemental compositions of the mine rock by rock type.
- Mineralogical examination of selected samples.
- A series of small scale weathering tests to determine solute release rates from each rock type.
- Contact tests to determine potential solute attenuation reactions that may occur with the underlying the footprint of the RSF.

The following sections summarise the outcomes of the geochemical investigations.

2.7.1 Sampling Method and Frequency

A sampling and analytical program was established by mining operations commencing with exploration and mining. Supplemental drilling sampling investigations have also been completed in support of the expansion project. In summary, samples sourced from four different programs have been characterized. The programs were as follows:

- Routine exploration and grade control sampling commenced in 1975 and is ongoing. The samples represent predominantly basement complex rock, with diamond drill core assayed at variable intervals, ranging from 1 m to 2.5 m splits through mineralised rock and 5 m to 6 m chip sampling through un-mineralised rock.
- Geochemical study of the overburden (Ehrig, 2001) comprising 2 m-composite samples, subject to lithological boundaries, extending from surface to the top of the breccia complex in two drill holes.
- Geochemical characterisation of mine rock outside the ore envelope targeting basement complex minor units) comprising composite chip samples at 1 m, 3 m and 5 m intervals bound by lithological contacts from five drill holes in areas located outside the ore envelope.
- Geochemical study of the overburden in support of the WMC Prefeasibility Study (WMC, 2005) with drillholes spread across the proposed pit area and comprising 5 m-composite chip samples to the top of the breccia complex.

The distribution of the total number of samples that have been included in the analytical program is summarised in Table 2-3. The analytical programs associated with the samples consisted of three levels:

i) Indicator (limited to Ba, U, Fe, Cu, Ag, Au, Si, S, total inorganic carbon - 2,207,295 samples)

ii) Comprehensive (included an expanded elemental list – 163,437 samples - and ANC analyses - 1168 samples)

iii) Specific (included ABA and NAG/NAG solution analyses – 19 samples).

Table 2-3 summarises the estimated total mass of each lithological unit that will be placed in the RSF. In the next column over, the table shows the distribution of the total number of indictor samples, which includes samples for ore rock, low grade ore and mine rock samples that were analysed. The total numbers of samples specific to the mine rock program are shown in subsequent columns, and include the sample frequency for the comprehensively analysed samples.

As shown in the table, the sample distribution is somewhat skewed toward the granite and granite-low hematite units, with about 62% of the samples associated with these two units while they represent only about 13% of the rock mass.

Based on the exploration drilling programs, the sample locations of the mine rock relative to the ore class materials within the shell of the open pit are illustrated in Figure 2-3. The blue sections of the drill holes indicate the mine rock and the red sections indicate ore grade materials. The green zones were not sampled and are mostly within the overburden materials which were not sampled as exploration drilling programs. Although not all drillholes are shown, it is apparent that the sample density and frequency of the exploration and grade control programs provide good coverage of the mine rock near the ore zones, and mostly within the pit shell. Note that the drill program specifically for sampling the overburden comprised 21 drillholes spaced at a regular grid over the entire footprint of the open pit area.

Table 2-3 Summary of Total Samples Analysed

ROCK UNIT	Code	Mass (Mt)	Total Indicator* (#)	Mine Rock		Mine-ralogy (#)	Detailed Kinetic (#)
				Comp.. (#)	Frequency (#/Mt)		
Overburden							
Cainozoic Sands and Clays	ZRS	427	-	-	-	-	-
Andamooka Limestone	ZAL	1068	-	95	0.09	1	1
Arcoona Quartzite – Transition	ZWA	877	-	42	0.05	-	1
Arcoona Quartzite Red	ZWAR	2913	-	391	0.13	1	1
Arcoona Quartzite White	ZWAW	675	-	81	0.12	1	1
Corraberra Sandstone	ZWC	289	-	77	0.27	1	1
Tregolana Shale	ZWT	1501	-	469	0.31	1	1
Pebble Conglomerate	ZWP	21	-	13	0.63	1	1
Basement Complex - Major units							
Granite	GRN	62	962,371	32,376	521	142	-
Granite > 90%, Hematite < 10%	GRNB	1410	612,178	39,313	28	323	1
Granite 70-90%, Hematite 10-30%	GRNH	393	217,148	8,643	22	129	1
Granite 40-70%, Hematite 30-60%	GRNL	100	167,840	7,513	75	86	2
Granite 10-40%, Hematite 60-90%	HEMH	103	86,027	3,620	35	53	2
Granite < 10%, Hematite > 90%	HEM	58	53,660	1,526	26	1	1
Hematite > 90% + quartz	HEMQ	859	270,154	20,741	24	85	1
Basement Complex - Minor Units							
Hematite greater than volcanics	HEMV	152	-	13	0.09	1	-
Dolerite	DOL	7	-	-	-	-	-
Mixed ash epiclastics	KASH	-	-	63	-	-	2
Laminated hematite-quartz sand-/ siltstone	KHEMQ	280	-	53	0.19	3	1
Volcanic ash	VASH	-	-	30	-	-	-
Igneous Dyke	EVD	14	-	-	-	-	-
Volcanics greater than hematite	VHEM	-	-	3	-	-	1
Brecciated / fragmented igneous dyke	EVB	45	-	5	0.11	-	-
TOTALS		11,254	2,369,378	115,067	733	829	19

Notes: * includes ore, low grade ore and mine rock samples

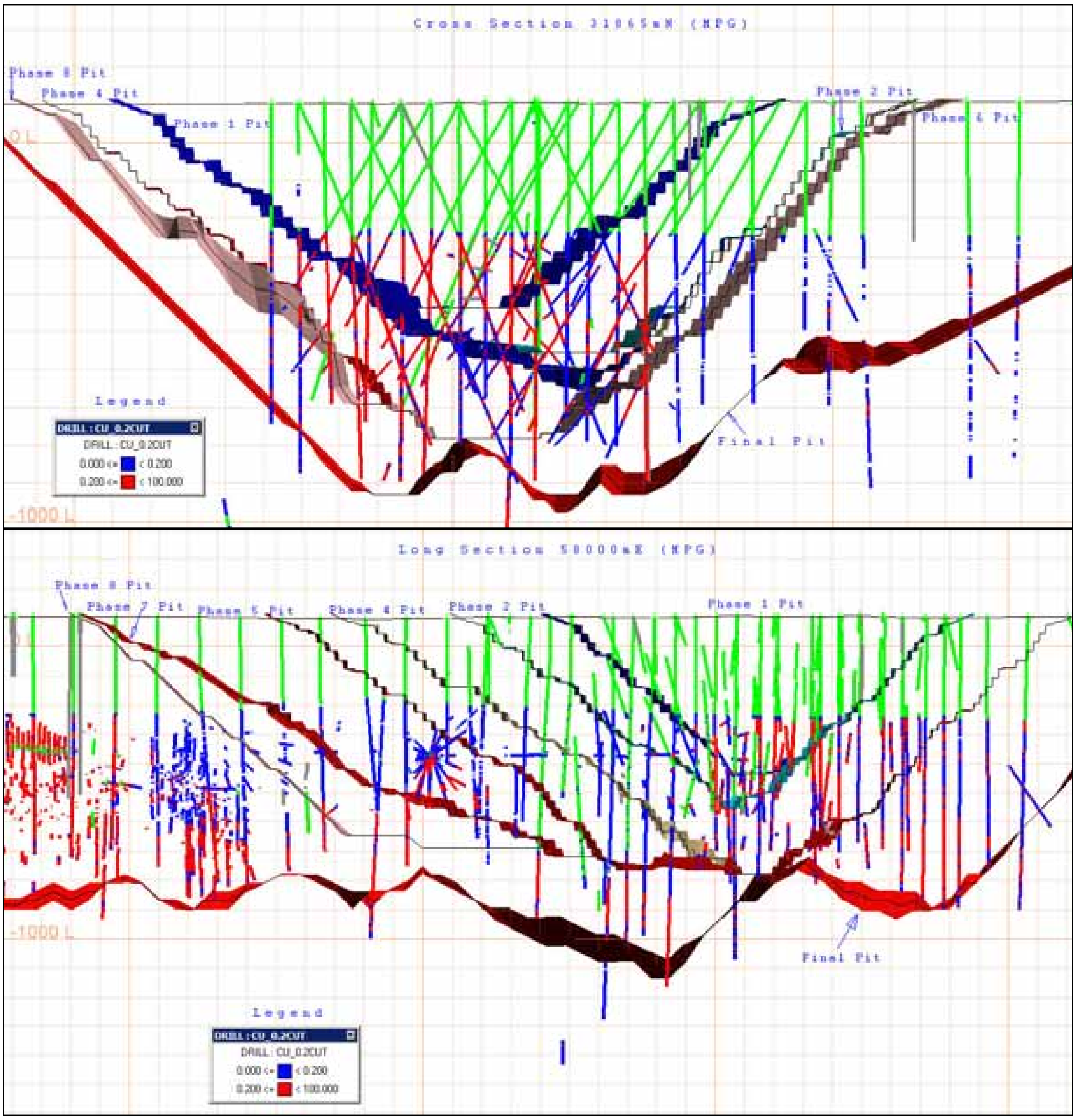

Figure 2-3 Cross (top) and Long (bottom) Sections Illustrating Exploration Sample Locations and Density (Blue) Relative to Ore Samples (Red).

(Notes: Zones in Green have not been sampled and generally represent the overburden. The overburden materials were sampled in drill programs that specifically targeted this zone.)

2.7.2 Geochemical Composition

Complete results for the lithological units, together with estimates of geochemical abundance indices for major and minor elements, are reported in ENSR/AECOM (2008).

The mean contents of the overburden units are compared to the mean crustal abundance for key elements in Table 2-4. In general, most trace elements occur at low concentrations in the overburden units, with the exception of the deeper strata near the contact with the basement complex. Based on the geochemical abundance indices, the Tregalona Shale (about 13% of the mine rock) is enriched in antimony (Sb) and elevated in arsenic. The Pebble Conglomerate (about 0.2% of the rock) is enriched in antimony (Sb), arsenic (As) and molybdenum (Mo), and elevated in copper (Cu) and uranium (U_3O_8).

Table 2-4 Summary of Mean Elemental Content of Overburden Units

Parameter	Units	Crustal Abundance	ZAL N=95	ZWA N=42	ZWAR N=391	ZWAW N=81	ZWC N=77	ZWT N=469	ZWP N=13
Al	%	8.2	0.42	3.32	2.37	0.70	1.06	7.48	2.92
As	ppm	1.5	3.8	3.7	2.1	1.8	2.1	11.9	111.8
Ba	%	0.05	-	0.03	0.02	-	-	0.08	0.72
Bi	ppm	0.048	5.1	-	-	-	-	-	-
Co	ppm	20	3.3	12.9	4.7	4.2	4.9	22.0	25.4
Cr	ppm	100	21.1	36.7	33.1	22.8	23.1	79.9	42.3
Cu	ppm	50	10.7	42.0	5.7	39.4	12.8	97.2	368.2
Fe	%	4.1	0.67	1.52	1.76	1.02	1.93	5.26	16.89
Mn	ppm	950	910	348	71	85	102	388	1973
Mo	ppm	1.5	1.2	2.0	1.8	2.1	1.6	1.4	30.3
Ni	ppm	80	2.0	15.6	12.2	4.4	5.3	36.3	12.3
Pb	ppm	14	11.3	7.0	3.9	8.1	8.0	12.7	41.2
Sb	ppm	0.2	-	-	-	-	-	5.0	12.1
Si	%	27.7	3.07	34.3	40.9	44.2	42.4	29.9	26.0
U3O8	ppm	8.5	4.0	4.4	4.2	4.1	5.0	4.8	16.0
V	ppm	160	7.3	17.9	18.0	10.2	20.4	61.9	23.4
Zn	ppm	75	13.6	27.8	11.2	28.7	24.5	52.1	59.8
CO_2	%	0.176	43.0	5.0	0.1	0.4	0.5	0.8	4.2
S	%	0.026	0.04	0.18	0.02	0.04	0.04	0.06	0.22

(Source of mean crustal abundances: Bowen, 1979)

The corresponding mean elemental contents of the major basement rock units are compared to the mean crustal abundance for key elements in Table 2-5. The geochemical abundance indices for the major basement units (27% of the mine rock) indicate enrichments in barium (Ba), copper (Cu), and uranium (U). In the ENSR/AECOM report, uranium enrichments appear to have been overestimated because the average crustal abundance value had not been converted from U to U_3O_8. Uranium enrichment is confined to the Pebble Conglomerate (ZWP) only. Other elements that are enriched include cerium (Ce), lanthum (La), iron (Fe), gold (Au) and silver (Ag). Elements present at elevated concentrations include cobalt (Co) and lead (Pb) and sulphur (S).

Mean elemental contents of the minor basement rock units are compared to the mean crustal abundance for key elements in Table 2-6. The geochemical abundance indices for the minor basement units (4.4% of the mine rock) indicate enrichments in barium (Ba), copper (Cu) and uranium (U). Other elements that are enriched include cerium (Ce), lanthum (La), iron (Fe), gold (Au) and silver (Ag), whereas cobalt (Co) and lead (Pb) and sulphur (S) at present at elevated levels.

Table 2-5 Summary of Mean Elemental Content of Major Basement Units

Parameter	Units	Crustal Abundance	GRN	GRNB	GRNH	GRNL	HEMH	HEM	HEMQ
Al	%	8.2	7.14	6.80	4.44	2.88	1.88	1.54	0.68
As	ppm	1.5	-	-	-	-	-	-	-
Ba	%	0.05	0.28	0.39	1.04	1.75	2.54	1.71	2.78
Bi	ppm	0.048	-	-	-	-	-	-	-
Co	ppm	20	163.1	145.8	192.9	213.3	220.4	187.1	286.7
Cr	ppm	100	-	-	-	-	-	-	-
Cu	%	0.0050	0.07	0.06	0.07	0.07	0.07	0.14	0.04
Fe	%	4.1	4.68	7.71	17.6	29.6	42.2	56.3	46.8
Mn	%	0.095	0.06	0.04	0.03	0.02	0.02	0.02	0.03
Mo	ppm	1.5	-	-	-	-	-	-	-
Ni	ppm	80	-	-	-	-	-	-	-
Pb	ppm	14	294	189	116	84.3	73.7	94.5	74.6
Sb	ppm	0.2	-	-	-	-	-	-	-
Si	%	28.2	32.2	30.5	26.6	20.2	12.4	4.4	10.4
U_3O_8	ppm	8.5	53	65	78	92	114	236	83
V	ppm	160	-	-	-	-	-	-	-
Zn	ppm	75	80.6	86.2	90.6	94.3	69.9	64.3	60.6
CO_2	%	0.176	0.84	0.49	0.41	0.39	0.38	0.38	0.42
S	%	0.026	0.13	0.22	0.31	0.45	0.66	0.51	0.73

Table 2-6 Summary of Mean Elemental Content of Minor Basement Units

Parameter	Units	Crustal Abundance	EVB	HEMV	KASH	KHEMQ	VASH	VHEM
Ag	ppm	0.07	-	1.00	-	2.38	1.71	-
Au	ppm	0.004	0.07	0.11	0.13	0.39	0.11	0.03
Ba	%	0.05	0.90	2.84	0.51	3.63	2.26	1.92
Cu	%	0.005	0.25	0.02	0.13	0.47	0.13	0.03
Fe	%	4.1	11.7	51.3	9.9	29.8	38.4	43.4
Si	%	28.2	29.1	9.5	24.5	17.8	12.5	15.2
U	ppm	2.4	35	35	35	80	39	27
CO_2	%	0.176	0.1	0.1	1.4	0.2	0.1	0.2
S (T)	%	0.026	0.26	0.68	0.46	1.21	0.55	0.46
Sulphide S	%	-	0.26	0.0	0.12	0.35	0.05	0.0

2.7.3 Mineralogy

The mineralogical investigations included X-ray diffraction (XRD) to determine the semi-quantitative mineralogical abundances and scanning electron microscopy (SEM) to examine mineral composition, grain morphologies and textures.

Findings with regard to the overburden units were as follows:

- Andamooka Limestone – predominantly dolomite, CaMg(CO3)2 (98 wt%) with minor quartz, SiO2. Within the dolomite grains, there is some evidence of minor substitution by Fe and Mn.
- Arcoona Quartzite – dominated by quartz (70-90 wt%). Other minerals present are feldspars, muscovite (probably sericite), chlorite and minor to trace kaolinite, haematite and ilmenite. Dolomite is present towards the top of the unit, close to the contact with Andamooka Limestone. SEM indicated the presence of trace salt (NaCl).
- Corraberra Sandstone – dominated by quartz (40-80 wt%) and feldspars (7-29 wt%). Minor constituents were chlorite, haematite, ilmenite and siderite. No clays were detected, suggesting that this unit had not undergone significant weathering.

- Tregolana Shale – this unit had a more silica-rich composition than would be expected for this rock type. The mineralogy is dominated by quartz and feldspar, with minor haematite and ilmenite.

The basement units range from granite comprising quartz (40-50 wt%), feldspar (20-40 wt%) and muscovite (14-18 wt%) to a haematite-rich mineralogy comprising up to 90 wt% haematite. Minor minerals are siderite, chlorite, fluorite and barite (barite can be present in quantities up to 10 wt%). SEM investigation of a haematised granite sample showed the presence of poorly crystalline clays and salts as coatings on larger mineral grains.

Ore mineralogy within the basement lithologies include:

- sulphides - mainly copper and iron sulphides (chalcopyrite, bornite, chalcocite and pyrite). Minor sulphides of Co, Ni, Pb, Zn and Mo are also present;
- uranium minerals included uraninite, coffinite and brannerite;
- lanthanoid minerals such as Florencite and Bastnäsite.

2.7.4 Acid Generation

2.7.4.1 Base Accounting

Acid base accounting (ABA) evaluates the balance between acid generation (oxidation of sulphide minerals) and acid neutralisation (dissolution of neutralizing carbonates minerals, and to a lesser extent, silicate minerals). The maximum potential acidity (MPA) is determined from the sulphide mineral content and acid neutralising capacity (ANC) is determined by reaction with a strong acid and determining the amount of acid that was consumed by neutralizing reactions.

The total sulphur content is most often to calculate MPA; however, if there is evidence that a significant proportion of the total sulphur is present as sulphate sulphur, then the MPA is determined only from the sulphide sulphur component. The reason for this is that some minerals that contain oxidized sulphur species such as gypsum ($CaSO_4.2H_2O$) and barite ($BaSO_4$) do not contribute to acid generation processes. Therefore, the use of total sulphur is a conservative when determining the MPA.

As with MPA, ANC determinations are not precise and may not represent the ANC that is actually available to maintain neutral pH conditions. For example, the very low pH values generated during the tests may lead to the reaction of minerals that may not otherwise react to neutralise acidity. Nonetheless by adopting conservative interpretation criteria these uncertainties generally are addressed. The net acid production potential (NAPP) is determined by subtracting the ANC from the MPA. A positive value indicates a potential for acid generation; a negative value indicates a potential for acid neutralization.

A summary of the acid base account test results is provided in Table 2-7.

The average corrected total sulphur concentrations in the overburden rock ranged from 0.05 to 0.26%, with the highest concentration occurring in the Pebble Conglomerate unit (ZWP). Corresponding MPA values ranged from 1.5 to 8 kg H_2SO_4/t of overburden mine rock. The ANC values in the overburden ranged from 1 to 930 kg H_2SO_4/t (equivalent).

Because of the high ANC values throughout, there is excess acid consuming capacity in the overburden material. The high ANC / MPA ratio further indicates that there is a considerable margin of safety between the MPA and the ANC so that acid generation is not likely to occur within these units. All of the overburden units are classified as Non-Acid Forming (NAF).

ANC was not routinely determined for basement rocks. The mineralogy suggests that the acid neutralization capacity of the basement mine rock is limited due to the absence of common neutralising minerals such as calcium and magnesium carbonates and the dominance of siderite ($FeCO_3$). Therefore, in the assessment of the acid base account properties the acid neutralising capacity in the basement rock units was disregarded which, by convention, leads to overestimating the net potential for acid generation.

Based on their interpretation of the results, ENSR/AECOM classified six of the major basement units (GRNH, GRNL, HEMH, HEM, and HEMQ) as potential acid forming (PAF). These units together with the minor unit (KHEMQ) that was classified as PAF make up about 16% of the total rock mass. The remainder of the basement units were classified as non-acid forming but containing some potentially acid generating materials on the basis of the low average sulphur content.

The mass weighted average net acid producing potential of the RSF as a whole, based on total sulphur corrected for barite sulphur is approximately -59kg H_2SO_4/t with an ANC to MPA ratio in excess of 10:1, i.e. the combined the mine rock in the RSF will be net acid consuming. The calculation was repeated for total sulphur not corrected for barite sulphur which resulted in an MPA increase from about 5.to about 9 kg H_2SO_4/t, however, the revised net acid generation potential of -54.7 kg H_2SO_4/t (ANC:MPA ratio of about 7) indicates that the RSF would remain net acid consuming even for this conservative assumption. Consequently, while it may be possible that acid generation could occur in very localised pockets of rock, the overwhelming acid neutralization potential and the RSF configuration (see Sections 2.2 and 2.5) makes it unlikely that acid could be generated from the RSF as a whole.

2.7.4.2 Net Acid Generation (NAG)

Net acid generation tests, during which sulphide minerals are oxidized with hydrogen peroxide (a strong oxidant), are used to assess the acidity that may be generated by a samples. The NAG tests were completed on the 19 samples that were also tested in the kinetic tests (see next Section 2.7.5).

All samples tested returned NAG pH values in excess of 5.5, even though some of the samples had positive NAPP values (based on a barite corrected sulphur content), as shown in Table 2-8. It is noteworthy that the lowest pH was not associated with the sample with highest NAPP value, nor did the sample with the highest NAPP value return an acidic NAG-pH. This may reflect on the reactivity of the sulphide minerals.

The NAG leachates were analysed and the results for key parameters are summarised in Table 2-9. As shown, barium was released from all of the rock units, however the concentrations in the solutions did not show any correlation with the sample barium content.

The overburden materials may have a potential to release manganese, and possibly molybdenum at low concentrations. Manganese concentrations do not correlate to solids content but rather appears to be subject to dissolution rather than an oxidation release mechanism. The molybdenum contents of the samples were low and the potential for release is considered small. It should be noted that the sample for ZWAW had an arsenic content of 1 mg/kg and a zinc content of 7 mg/kg, which suggests that solution analyses for these elements may be anomalous.

The samples representing the major basement units have a propensity to release copper and molybdenum likely due to sulphide mineral oxidation (e.g. GRNH sample, which the lowest NAG pH value of 5.5). Manganese, and to a lesser extent arsenic, cobalt, uranium and zinc may be released under oxidising conditions.

The minor basement units have a propensity to release arsenic under oxidising conditions.

Table 2-7 Summary of Average Acid Base Account Results

Lithological Unit	Code	Distribution (wt%)	Samples (N)	S* (%)	MPA	ANC	NAPP	ANC / MPA	Classification	Comment
Overburden										
Cainozoic Sands and Clays	ZRS	3.8%								
Andamooka Limestone	ZAL	9.5%	95	0.12	3.7	481	-477.3	130	**NAF**	
Arcoona Quartzite - Transition	ZWA	7.8%	42	0.19	5.8	112.7	-106.9	19	**NAF**	
Arcoona Quartzite Red	ZWAR	25.9%	391	0.04	1.2	12.7	-11.5	11	**NAF**	
Arcoona Quartzite White	ZWAW	6.0%	81	0.05	1.5	19.5	-18	13	**NAF**	
Corraberra Sandstone	ZWC	2.6%	77	0.05	1.5	23.7	-22.2	16	**NAF**	
Tregolana Shale	ZWT	13.3%	469	0.08	2.4	38	-35.5	16	**NAF**	
Pebble Conglomerate	ZWP	0.2%	13	0.26	8	89.7	-81.7	11	**NAF**	
Basement Complex - Major units										
Granite	GRN	0.6%	30000	0.13	4	-	-	-	**NAF**	contains some PAF
Granite > 90%, Hematite < 10%	GRNB	12.5%	11921	0.22	7	-	-	-	**NAF**	contains some PAF
Granite 70-90%, Hematite 10-30%	GRNH	3.5%	5926	0.31	9	-	-	-	**PAF**	contains some NAF
Granite 40-70%, Hematite 30-60%	GRNL	0.9%	5389	0.45	14	-	-	-	**PAF**	contains some NAF
Granite 10-40%, Hematite 60-90%	HEMH	0.9%	2992	0.66	20	-	-	-	**PAF**	contains some NAF
Granite < 10%, Hematite > 90%	HEM	0.5%	1345	0.51	16	-	-	-	**PAF**	contains some NAF
Hematite > 90% + quartz	HEMQ	7.6%	10920	0.73	22	-	-	-	**PAF**	contains some NAF
Basement Complex - Minor Units										
Hematite > volcanic components	HEMV	1.4%	5	0.06	8	-	-	-	**NAF**	
Dolerite	DOL	0.1%	63	0.11	3.4	-	-	-	**NAF**	contains some PAF
Mixed ash epiclastics	KASH	-	-	-	-	-	-	-	-	
Laminated hematite-qtz sand-/silt-stone	KHEMQ	2.5%	53	0.37	11.2	-	-	-	**PAF**	
Volcanic ash	VASH	-	30	0.06	1.8	-	-	-	**NAF**	
Igneous Dyke	EVD	0.1%	-	-	-	-	-	-	-	
Volcanic > hematite	VHEM	-	3	0.02	0.5	-	-	-	**NAF**	
Brecciated / fragmented igneous dyke	EVB	0.4%	-	-	-	-	-	-	-	

Notes: * total sulphur corrected for barite content
Units of MPA, ANC and NAPP are kg H_2SO_4/t mine rock

Table 2-8 Summary of NAG Test Results

Unit Code	ANC kgH_2SO_4/t	S-tot (%)	Sulphide S (%)	AP kgH_2SO_4/t	NAPP kgH_2SO_4/t	NAG-pH
Overburden						
ZAL	993	<0.01	0	0	-993	10.9
ZWAW	1.3	0.02	0.017	1	-0.3	6.8
ZWA	11	0.06	0.04	1	-10	8.6
ZWC	8.4	0.02	0.017	1	-7.4	8.8
ZWT	9.6	0.02	0.012	1	-8.6	8.5
ZWAR	2.4	0.02	0.014	0	-2.4	6.7
ZWP	81.7	1.03	0.95	29	-52.7	8.5
Basement Complex - Major Units						
HEMH 148187	1.3	1.2	1.14	35	33.7	6.1
GRNL 148207	2.1	0.17	0.036	1	-1.1	7.0
HEM 148194	1.1	0.72	0.64	20	**18.9**	6.2
HEMQ	1.8	0.59	0.53	16	**14.2**	8.7
HEMH	9.1	0.04	0.034	1	-8.1	7.2
GRNH	4.5	0.38	0.28	9	**4.5**	5.5
GRNB	5.4	0.35	0.20	6	**0.6**	7.5
GRNL	2.4	0.16	0.15	5	**2.6**	6.7
Basement Complex - Minor Units						
KASH	65.1	0.01	0	0	-65.1	9.0
KASH LAM	7.8	0.04	0	0	-7.8	7.2
KEMQ VASH	8.9	0.52	0.43	13	**4.1**	6.3
VHEM	4.9	0.86	0.80	24	**19.1**	9.2

Table 2-9 Summary of NAG Solution Analyses

	Concentrations in NAG solutions								
Unit	As mg/L	Ba mg/L	Co mg/L	Cu mg/L	Mn mg/L	Mo mg/L	Ni mg/L	U mg/L	Zn mg/L
Overburden									
ZAL	<0.001	**0.081**	<0.001	<0.001	**0.003**	<0.001	<0.001	<0.001	<0.005
ZWAW	**0.006**	**1.25**	<0.005	<0.005	**0.12**	**0.007**	<0.005	<0.005	**0.041**
ZWA	<0.005	**0.037**	<0.005	<0.005	**0.048**	**0.006**	<0.005	<0.005	<0.025
ZWC	<0.001	**0.027**	<0.001	<0.001	<0.001	**0.007**	<0.001	<0.001	<0.005
ZWT	<0.001	**0.098**	<0.001	**0.003**	**0.008**	<0.001	<0.001	<0.001	<0.005
ZWAR	<0.005	**0.129**	<0.005	<0.005	**0.015**	**0.005**	<0.005	<0.005	<0.025
ZWP	<0.020	**0.037**	<0.020	<0.020	**0.02**	**0.063**	<0.020	<0.020	<0.005
Basement Complex - Major Units									
HEMH 148187	**0.061**	**0.33**	**0.022**	**0.582**	**0.243**	**0.171**	<0.020	<0.020	0.125
GRNL 148207	<0.005	**0.192**	<0.005	**0.065**	**0.082**	**0.012**	<0.005	<0.005	<0.025
HEM 148194	<0.010	**0.754**	<0.010	<0.010	**0.053**	**0.078**	<0.010	<0.010	**0.069**
HEMQ	**0.046**	**0.856**	<0.020	<0.020	<0.020	**0.058**	<0.020	<0.020	<0.100
HEMH	<0.005	**0.649**	<0.005	<0.005	**0.012**	**0.016**	<0.005	<0.005	<0.025
GRNH	<0.001	**0.094**	**0.053**	**13.8**	**1.77**	**0.002**	**0.009**	**0.095**	**0.054**
GRNB	<0.005	**0.122**	<0.005	**0.023**	**0.25**	**0.209**	<0.005	<0.005	<0.025
GRNL	<0.020	**0.088**	<0.020	**0.087**	**0.62**	<0.020	<0.020	<0.020	<0.100
Basement Complex - Minor Units									
KASH	**0.023**	**0.021**	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.100
KASH LAM	**0.074**	**0.447**	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.250
KEMQ VASH	**0.03**	**0.506**	<0.005	<0.005	**0.029**	**0.091**	<0.005	**0.014**	<0.025
VHEM	**0.036**	**0.568**	<0.005	<0.005	<0.005	**0.068**	<0.005	<0.005	<0.025

2.7.5 Weathering Tests

2.7.5.1 Procedure

Twelve small scale weathering tests were completed on 19 samples to represent the lithological units, with duplicate samples for the HEMH and HEM categories. These tests were performed on 1.5 to 2 kg rock samples obtained from underground and drill core and crushed to less than 25 mm. The tests, based on the procedures described in the AMIRA P387A ARD Test Handbook (AMIRA, 2002), were completed in 170 mm diameter Buchner filters with a free draining bed height of about 75 mm or less (ENSR/AECOM 2008). The leaching procedure included weekly wet-dry cycle and a flushing cycle between 1 and 4 weeks, with about 600 ml of deionised water to produce about 425 ml of leachate per flush that was analysed for dissolved constituents. Heat lamps were used to promote evaporation between cycles. The volume of leachate and constituent concentrations can then be used to calculate solute release rates over time, estimate oxidation rates and determine the lag to net acid generation for potentially acid generating samples.

2.7.5.2 Sample Representation

As noted, the intent of the sample selection was to represent each of the lithological units. Five samples were selected from the overburden, six from the major basement host rocks, and five from the minor basement lithologies. Table 2-10, Table 2-11 and Table 2-12compare the elemental compositions of the samples with the mean elemental contents of each unit respectively for the overburden, major basement rock units. Note that a test was also completed on a sample (KASH LAM) which was not identified in the geochemical database. In general the trace element contents of the samples tested reasonably reflect the mean composition of the lithological units, with the possible exception of the sulphur content of the ZWP sample. With respect to the major basement rock units there appears to be some variability in the copper content both above and below the mean values within each unit, whereas the cobalt content generally is below the mean content. A similar comparison of the minor units is more difficult due to limited data. Nonetheless the samples appear to reasonably represent each of the units.

Table 2-10 Comparison Between Overburden and Kinetic Sample Composition

Element	Units		ZAL	ZWA	ZWAR	ZWAW	ZWC	ZWT	ZWP
As	ppm	Mean	3.8	3.7	2.1	1.8	2.1	11.9	111
		Sample	<0.2	5.5	1.8	1.0	1.1	9.4	146
Ba	%	Mean	-	0.03	0.02	-	-	0.08	0.72
		Sample	0.001	0.084	0.026	0.012	0.011	0.032	0.36
Co	ppm	Mean	3.3	12.9	4.7	4.2	4.9	22	25.4
		Sample	2.8	2.8	8.6	2.6	5.8	19	16.6
Cu	ppm	Mean	10.7	42.0	5.7	39.4	12.8	97.2	368
		Sample	2.9	7.8	2.3	2.6	1.9	55.3	158
Fe	%	Mean	0.67	1.52	1.76	1.02	1.93	5.26	16.9
		Sample	0.35	1.34	1.99	0.63	3.36	4.69	23.8
Mn	ppm	Mean	910	348	71	85	102	388	1973
		Sample	984	200	56	22	98	246	3030
Mo	ppm	Mean	1.2	2.0	1.8	2.1	1.6	1.4	30.3
		Sample	0.84	9.9	3.2	4.3	2.6	2.2	62.5
Ni	ppm	Mean	2.0	15.6	12.2	4.4	5.3	36.3	12.3
		Sample	1	6.1	18.2	6	4.6	34.6	9.6
Pb	ppm	Mean	11.3	7.0	3.9	8.1	8.0	12.7	41.2
		Sample	11.2	10.9	9.1	2.5	9.5	12.4	50.3
U3O8	ppm	Mean	4.0	4.4	4.2	4.1	5.0	4.8	16.0
		Sample	4.3	7.1	6.4	2.1	5.0	12.1	55.3
Zn	ppm	Mean	13.6	27.8	11.2	28.7	24.5	52.1	59.8
		Sample	10	15	19	7	15	61	110
S	%	Mean	0.04	0.18	0.02	0.04	0.04	0.06	0.22
		Sample	<0.01	0.06	0.02	0.02	0.02	0.02	1.03
CO_2	%	Mean	43.0	5.0	0.1	0.4	0.5	0.8	4.2
		Sample	-	-	-	-	-	-	-
AP	kgH_2SO_4/t	Mean	3.7	5.8	1.2	1.5	1.5	2.5	8
		Sample	0.0	1.0	0.0	1.0	1.0	0.0	29
ANC	kgH_2SO_4/t	Mean	480.9	112.7	12.6	19.5	23.7	37.9	89.7
		Sample	993	11	2.4	1.3	8.4	9.6	81.7
NAPP	kgH_2SO_4/t	Mean	-477	-106	-11.4	-18	-22.2	-35.4	-81.7
		Sample	-993	-10.0	-2.4	-0.3	-7.4	-9.6	-52.7

Table 2-11 Comparison Between Major Basement and Kinetic Sample Composition

Element	Unit		GRN	GRNB	GRNH	GRNL	HEMH	HEM	HEMQ
As	ppm	Mean	-	-	-	-	-	-	-
		Sample	34.7	31.3	25.6	39.3	106/204	299	252
Ba	%	Mean	0.28	0.39	1.04	1.75	2.54	1.71	2.78
		Sample	0.58	0.62	0.42	**0.04**	**0.028/0.027**	**0.35**	**0.26**
Co	ppm	Mean	163	145	192	213	220	187	286
		Sample	**11.6**	**23.3**	**21.4**	**10.6**	**31.5/13.5**	**4.9**	**3.9**
Cu	ppm	Mean	700	600	700	700	700	1400	400
		Sample	**422**	2130	3160	**143**	**271**/882	**166**	423
Fe	%	Mean	4.68	7.71	17.62	29.59	42.19	56.29	46.84
		Sample	16.6	4.03	4.03	5.37	16.1/33.1	45.4	36.3
Mn	ppm	Mean	600	400	300	200	200	200	300
		Sample	**49**	1755	518	153	132/**45**	**52**	**17**
Mo	ppm	Mean	-	-	-	-	-	-	-
		Sample	15.1	43.8	41.6	4.53	35.4/157	164	168
Ni	ppm	Mean	-	-	-	-	-	-	-
		Sample	5.2	3.1	4.4	3.2	2.9/3.3	3.7	1.8
Pb	ppm	Mean	294	188	115	84	73	94	74
		Sample	**8.8**	**7.1**	**7.6**	**6.1**	18.2/19.7	151	36.2
U3O8	ppm	Mean	53	65	78	92	114	236	83
		Sample	153	123	191	141	117/557	118	138
Zn	ppm	Mean	80	86	90	94	69	64	60
		Sample	40	75	34	19	115/43	25	19
S	%	Mean	0.13	0.22	0.31	0.45	0.66	0.51	0.73
		Sample	0.17	0.35	0.38	0.16	**0.04**/1.1	0.72	0.59
CO_2	%	Mean	0.84	0.49	0.41	0.39	0.38	0.38	0.42
		Sample	-	-	-	-	-	-	-
AP	kgH_2SO_4/t	Mean	4	7	9	14	20	16	22
		Sample	1	6	9	5	**1**/35	20	16
ANC	kgH_2SO_4/t	Mean	-	-	-	-	-	-	-
		Sample	2.1	5.4	4.5	2.4	9.1/1.3	1.1	1.8
NAPP	kgH_2SO_4/t	Mean	-4	-7	-9	-14	-20	-16	-22
		Sample	1.1	-0.6	-4.5	-2.6	8.1/-33.7	-18.9	-14.2

Table 2-12 Comparison Between Minor Basement and Kinetic Sample Composition

Element	Unit		EVB	HEMV	KASH	KHEMQ	VASH	VHEM
As	ppm	Mean	-	-	-	-	-	-
		Sample	-	-	27.4	246	-	351
Ba	%	Mean	0.90	2.84	0.51	3.63	2.26	1.92
		Sample	-	-	0.059	0.40	-	0.28
Co	ppm	Mean	-	-	-	-	-	-
		Sample	-	-	37.9	8.1	-	11.8
Cu	ppm	Mean	2500	200	1300	470	1300	300
		Sample	-	-	329	404	-	138
Fe	%	Mean	11.7	51.3	9.9	29.8	38.4	43.4
		Sample	-	-	7.31	26.3	-	24.4
Mn	ppm	Mean	-	-	-	-	-	-
		Sample	-	-	1330	312	-	53
Mo	ppm	Mean	-	-	-	-	-	-
		Sample	-	-	1.54	115	-	113
Ni	ppm	Mean	-	-	-	-	-	-
		Sample	-	-	200	3.9	-	12.6
Pb	ppm	Mean	-	-	-	-	-	-
		Sample	-	-	11.2	78.6	-	199
U3O8	ppm	Mean	35	35	35	80	39	27
		Sample	-	-	35	106	-	154
Zn	ppm	Mean	-	-	-	-	-	-
		Sample	-	-	243	116	-	73
S	%	Mean	0.26	0.68	0.46	1.21	0.55	0.46
		Sample	-	-	0.01	0.52	-	0.86
CO2	%	Mean	0.1	0.1	1.4	0.2	0.1	0.2
		Sample	-	--	-	-	-	-
AP	kgH_2SO_4/t	Mean	1.9	0.0	6.7	10.8	1.6	0.0
		Sample	-	-	0	13	-	24
ANC	kgH_2SO_4/t	Mean	-	-	-	-	-	-
		Sample	-	-	65.1	8.9	-	4.9
NAPP	kgH_2SO_4/t	Mean	1.9	0.0	6.7	10.8	1.6	0.0
		Sample	-	-	65.1	-4.1	-	-19.1

2.7.5.3 Results

The kinetic tests for the overburden samples were operated for about 16 weeks (with the exception of the ZWP sample), whereas in the tests for the basement rock complex samples continued for in excess of 60 weeks. The results can be summarised as follows:

- The pH values of leachates from all tests remained within a near neutral range. The leachate pH values for the major basement rock complex units ranged from about 5.0 (HEMH) to 8 (GRNL), those for the minor basement complex units ranged from about 7.5 (VHEM) to 9.3 (KASH), and those for the overburden units ranged from about 7.5 (ZWP) to 9.0 (ZAL).
- All tests indicated an initial flush of sodium chloride for the first few cycles (up to about between 8 to 12 weeks) with initial sodium concentrations ranging from more than a hundred to more than a thousand mg/L. After this initial flush, the sodium concentrations typically decreased to moderately low concentrations ranging from a few mg/L to in excess of 20 mg/L. Similar trends existed for chloride.

- Sulphate concentrations similarly typically showed elevated concentrations associated with the initial few cycles, after which it then decreased to lower steady state levels. Initial concentrations ranged from tens to hundreds of mg/L, with some of the higher concentrations associated with the overburden materials. The overburden units contain naturally occurring gypsum and it is possible that gypsum dissolution explains the elevated concentrations of sulphate. (It should however be noted that the tests on the overburden samples were terminated before the steady state conditions were observed, and as a result solute release rates for these units are likely to be overestimated.) After the initial flush, the sulphate concentrations decreased to less than 5 mg/L after about after about 30 weeks of testing. Generally higher concentrations were associated with the volcanic and epiclastic materials (KASH, VHEM and KEMQI-VASH).
- Consistent with the geochemical properties, metal concentrations in leachate from the overburden material were negligible compared to basement complex units. Observed metal release from the basement breccia complex units were as follows:
  - granitic material (GRNH, GRNB and GRNL) leachates contained detectable concentrations of copper, molybdenum and uranium.
  - haematitic material (HEMQ and HEMH) leachates contained detectable concentrations of arsenic and molybdenum.
  - volcanic and epiclastic material (KASH, VHEM and KEMQI-VASH) leachates generally contained higher, aluminium, arsenic, copper, iron, manganese and zinc relative to other materials tested.

As noted above, over time the rate of solute release rates decreased to reach pseudo steady state conditions. The mineralogical assessment indicated that a number of soluble and less soluble mineral phases are associated with the samples. Some of the minerals are inherently associated with the samples as they occur in their natural state (i.e. prior to being extracted by drilling). Some of the minerals may have been introduced artificially with the drilling fluids that were used during the sampling process. Finally, some mineral phases will have formed after the samples had been exposed to oxidizing conditions, for example from the oxidation of sulphide minerals. These pre-existing minerals all contribute to the initial high solute release rates. Once all of the more readily soluble minerals have been flushed, the solute release rates start to reflect the reaction rates that would be associated with fresh rock. These pseudo state release rates calculated by ENSR/AECOM are summarised in Table 2-13 and Table 2-14. Where concentrations were below detection limits, 50% of the detection limit was adopted. Additional calculations were also completed by ENSR/AECOM to assess the effects of using 80% and 100% of the detection limits. The rates were used to predict overall solute release rates from the RSF as described in Section 2.8.

Table 2-13 Summary of Kinetic Test Production Rates for Overburden Units

Parameter	Units	ZWAW	ZWA	ZWC	ZWT	ZWAR	ZAL	ZWP
pH	pH units	7.8	7.7	7.8	9.7	8.3	9.0	7.6
Alkalinity	gCaCO3/t/wk	0.47	0.39	1.00	2.46	1.93	1.19	2.10
F	g/t/wk	0.0106	0.0106	0.0096	0.0116	0.0286	0.0134	0.0097
SO4	g/t/wk	1.6	6.9	4.2	2.0	3.8	1.1	5.6
Metals								
Al	g/t/wk	0.0404	0.0212	0.0094	0.1396	0.0953	0.0049	0.0147
As	g/t/wk	0.0001	0.00005	0.00005	0.0015	0.0001	0.00005	0.0004
Ba	g/t/wk	0.0203	0.007	0.0059	0.0178	0.015	0.0028	0.0223
Ca	g/t/wk	0.05	0.94	0.56	0.40	0.18	0.19	1.84
Cl	g/t/wk	1.62	2.01	12.4	12.2	2.70	3.07	0.98
Cu	g/t/wk	0.0006	0.0002	0.0001	0.0011	0.0005	0.00005	0.0004
Fe	g/t/wk	0.022	0.0074	0.0126	0.141	0.0884	0.0011	0.0023
K	g/t/wk	0.05	0.21	0.13	0.17	0.25	0.05	0.19
Mg	g/t/wk	0.03	0.42	0.51	0.40	0.07	0.11	0.37
Mn	g/t/wk	0.0045	0.0036	0.0009	0.0067	0.006	0.0002	0.0021
Mo	g/t/wk	0.00018	0.000094	0.000033	0.000096	0.000061	0.000237	0.005
Na	g/t/wk	1.62	2.38	10.5	3.96	2.99	2.39	1.07
Ni	g/t/wk	0.00005	0.00005	0.00005	0.0001	0.0002	0.00005	0.0001
P	g/t/wk	0.0003	0.0003	0.0003	0.0004	0.0003	0.0003	0.0024
Pb	g/t/wk	0.0001	0.00005	0.0002	0.0004	0.0004	0.00005	0.0001
Si	g/t/wk	0.070	0.030	0.018	0.11	0.092	0.012	0.016
Sr	g/t/wk	0.001	0.0039	0.0099	0.0051	0.0026	0.0018	0.0106
U	g/t/wk	0.00005	0.00005	0.00005	0.0001	0.0004	0.00005	0.0001
Zn	g/t/wk	0.0014	0.0008	0.0005	0.0014	0.0023	0.0002	0.0005

Notes: pH represents the average pH value;
where concentrations below detection limit 50% of the detection limit was adopted in the calculation

Table 2-14 Summary of Kinetic Test Production Rates for Basement Complex Units

		Major Units								Minor Units			
Parameter	**Units**	**HEMH 148187**	**GRNL 148207**	**HEM 148194**	**HEMQ**	**HEMH**	**GRNH**	**GRNB**	**GRNL**	**KAS H**	**KASH Lam.**	**VHEM**	**KHEMQ-VASH**
pH	pH units	6.1	6.8	6.4	6.7	7.0	6.5	7.1	8.0	9.3	8.9	7.6	8.0
Alkalinity	gCaCO3/t/wk	0.87	1.75	0.86	0.90	1.10	1.15	1.86	2.46	8.95	2.68	1.20	1.00
F	g/t/wk	0.0382	0.0655	0.0227	0.0535	0.0456	0.2297	0.1708	0.1411	0.0579	0.1117	0.0294	0.2151
SO4	g/t/wk	1.0	0.5	0.6	0.5	0.9	3.4	1.0	1.2	0.5	1.3	3.2	1.5
Metals													
Al	g/t/wk	0.0016	0.0147	0.0065	0.0044	0.0306	0.0049	0.0144	0.044	0.1096	0.1073	0.0196	0.0228
As	g/t/wk	0.0002	0.0006	0.0034	0.0086	0.0008	0.0001	0.0002	0.003	0.0042	0.0024	0.0045	0.0058
Ba	g/t/wk	0.0691	0.0197	0.0597	0.0625	0.0049	0.0074	0.0251	0.0017	0.0042	0.0175	0.013	0.0217
Ca	g/t/wk	0.63	0.13	0.35	0.22	0.10	0.79	0.11	0.12	0.12	0.11	0.32	0.09
Cl	g/t/wk	2.34	0.45	2.44	1.47	0.73	0.34	0.21	1.24	1.53	0.59	0.29	0.19
Cu	g/t/wk	0.048	0.0019	0.0003	0.0007	0.0008	0.0223	0.0014	0.0014	0.0067	0.0012	0.001	0.0005
Fe	g/t/wk	0.0048	0.0039	0.0015	0.0009	0.0277	0.0011	0.0023	0.0545	0.1675	0.1377	0.0039	0.0217
K	g/t/wk	0.28	0.19	0.20	0.08	0.10	0.60	0.40	0.14	0.25	0.12	0.38	0.10
Mg	g/t/wk	0.11	0.08	0.07	0.08	0.10	0.14	0.11	0.12	0.12	0.11	0.09	0.09
Mn	g/t/wk	0.0083	0.0005	0.0003	0.0004	0.0004	0.0174	0.0025	0.0005	0.0058	0.0022	0.0004	0.0002
Mo	g/t/wk	0.0019	0.0057	0.00316	0.0043	0.0007	0.0096	0.011	0.0028	0.0019	0.0010	0.011	0.017
Na	g/t/wk	1.40	0.98	1.64	1.06	1.41	0.74	0.84	2.43	5.04	2.27	1.55	1.42
Ni	g/t/wk	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0004	0.0007	0.0001	0.0001
P	g/t/wk	0.004	0.0033	0.0037	0.0016	0.0018	0.002	0.0034	0.0027	0.0056	0.0035	0.0071	0.0026
Pb	g/t/wk	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001
Si	g/t/wk	0.0069	0.039	0.011	0.008	0.066	0.015	0.035	0.091	0.350	0.303	0.029	0.083
Sr	g/t/wk	0.0333	0.0019	0.0123	0.0038	0.0004	0.0054	0.0017	0.0003	0.0008	0.0006	0.0025	0.0006
U	g/t/wk	0.0001	0.0021	0.0001	0.0001	0.0001	0.0005	0.0011	0.003	0.0002	0.0002	0.0001	0.0005
Zn	g/t/wk	0.0017	0.0008	0.0008	0.0007	0.0015	0.0015	0.0013	0.0008	0.0012	0.0017	0.0005	0.0007

Notes: pH represents the average pH value;
where concentrations below detection limit 50% of the detection limit was adopted in the calculation

2.8 Water Quality Predictions

2.8.1 Approach

The water quality of the percolate from the RSF will depend on the net infiltration. Based on their assessment (and supported by literature data) ENSR/AECOM concluded that the majority of infiltration would be stored within the pore space in the near surface layer of the rock storage facility and would largely be lost to evaporation under the arid climatic conditions that prevail at the mine site and that only a small proportion (typically 1-3% of annual rainfall) would report to the base of the RSF as rapid preferential flow. Their geochemical model is based on preferential flow which would be expected to dominate for the prediction horizon.

The assumed infiltration rate for the Base Case scenario was estimated to be 1% of annual rainfall (or about 1.64 mm/annum, or equal to a flux of about 1.64 $L/m^2/year$), which nominally is one order of magnitude above the estimated natural regional recharge rate of about 0.1 mm/annum.

The approach adopted by ENSR/AECOM to predict the water quality in percolate comprised the following steps for each element considered:

i) The solute release rates calculated in the previous steps were corrected for surface area exposure differences between the test samples and that which will be deposited in the RSF. The difference in particles size distribution between the test samples and that inferred for the blast rock were used to derive the correction. The correction was applied as follows:

*Production Rate SA = Laboratory Rate * (Mine Rock SA) / (Test Sample SA)*

Where mine rock surface area (SA) and test sample surface areas are in equivalent units (m^2/kg) and the *Laboratory Rate* and *Production Rate SA* are in units of g/t/wk.

Surface area correction factors ranged from 0.028 to 0.84.

ii) Selective flow paths are assumed to occur within only 1% of the total mine rock, so that the surface area corrected production rate is corrected as follows:

*Production Rate FP = Production Rate SA * 0.01*

iii) Since the predictions are based only on the flow within selective flow paths, which are assumed to occur through the coarse particles, an additional surface area correction is applied of 0.1 to account for a lower proportion of reactive surfaces within the coarser particles (Note: the flow may not necessary occur within the coarse particles for low moisture conditions). The correction is as follows:

*Production Rate RA = Production Rate FP * 0.1*

iv) Completely mixed conditions were assumed to allow calculation of a mass weighted average production rate that could be applied to any part of the RSF. The weighted average was calculated as follows:

$$\text{Avg. Production Rate} = \sum_i [\text{Production Rate RA }(i) * \text{mass }(i) * \sigma_i / (\text{Total Mass})]$$

Where i is summed for all the rock units, σ_i is the bulk density of rock unit i ($tonne/m^3$) and the *Avg. Production Rate* is in $g/m^3/year$.

Because completely mixed conditions were assumed, these production rates apply to any volume of rock irrespective of its location within the RSF. To estimate the percolate quality, ENSR/AECOM completed a one dimensional assessment of the release of solutes for the entire height of the RSF, for a 1 m^2 one-dimensional column of rock to the height of the each of the three plateaus of the RSF (i.e. 50 m, 100 m and 150 m). This was done by calculating the solute concentrations that would result if the annual solute production from 1 m^3 of rock is dissolved in the annual infiltration of 1.64 L as follows:

*Concentration = Avg. Production Rate / 1.64 * 1000*

Where the *Avg. Production Rate* is in g/m^3/a, the *Concentration* in mg/L and 1000 is a conversion factor from g to mg.

The equivalent concentration of any height of the RSF column can then be determined by multiplying the corresponding concentrations with the height of the RSF in meters. This step was undertaken within PHREEQC. The PHREEQC runs were set up to stepwise increase the solute concentration for each 1 m cell of the rock column height, calculate the equilibrium concentrations after applicable secondary mineral phases were allowed to form, and then 'pass' the resultant concentrations to the next 1 m step before the solutes generated in that part of the column is added to the flow. This was repeated until the full height of the rock column had been simulated. The secondary mineral phases that were assumed to limit solute concentrations are summarised in Table 2-15.

Table 2-15 Possible Mineral Phases Adopted in PHREEQC Model Runs

Mineral	Formula
Amorphorus structure of Al silicate (surrogate: adularia)	$KAlSi_3O_8$
Alunite-like phase	$KAl_3(SO_4)_2(OH)_6$
Barite	$BaSO_4$
Bixbyite	Mn_2O_3
Calcite	$CaCO_3$
Celesite	$SrSO_4$
Cerrusite	$PbCO_3$
Cristobalite	SiO_2
Aluminium oxy-hydroxides (surrogate: diaspore)	AlOOH
Fluorocarbo-apatite*	$Ca_{9.316}Na_{0.36}Mg_{0.144}(PO_4)_{4.8}(CO_3)_{1.2}F_{2.48}$
Ferrihydrite	Fe(OH)3
Fluorite	CaF_2
Gypsum	$CaSO_4$:$2H_2O$
Jarosite-Na*	$NaFe_3(SO_4)_2(OH)_6$
Zeolites (surrogate: leonhardite)	$Ca_2Al_4Si_8O_{24}$:$7H_2O$
Magnesite	$MgCO_3$
Malachite	$Cu_2(OH)_2CO_3$
Smectite-like phase (surrogate: Montmorillonite)	$(HNaK)_{0.09}Mg_{0.29}Fe_{0.24}Al_{1.57}Si_{3.93}O_{10}(OH)_2$
Na-Autunite	$Na_2(UO_2)_2(PO_4)_2$
Rhodochrosite	$MnCO_3$
Strontianite	$SrCO_3$
Uraninite with non-stoichiometric U-oxide	U_4O_9
Plumbogummite	$PbAl_3(PO_4)_2(OH)_5$:H2O
Kaolinite	$Al_2Si_2O_5(OH)_4$
Azurite	$Cu_3(OH)_2(CO_3)$2
Covellite	CuS
Fluorapatite	$Ca_5(PO_4)$3F
Clpyromorphite	$Pb_5(PO_4)_3Cl$
Manganite	MnOOH
Rutherfordine	UO_2CO_3
Uraninite	UO_2
Schoepite	$UO_2(OH)_2$:H_2O
Smithsonite	$ZnCO_3$
Scorodite	$FeAsO_4$:$2H_2O$
Huntite	$CaMg_3(CO_3)_4$
Goethite	FeOOH
Halite	NaCl

2.8.2 Input and Sensitivity Constraints

In the base case simulations, the initial pH was estimated based on the mass weighted average pH calculated from the kinetic test results, but was allowed to be calculated for the chemical reactions simulated in the PHREEQC model. It was further assumed that the RSF would be fully oxygenated and that the pE is fixed at +8 (or about 475 mV). Carbon dioxide concentration was assumed to be about ten times atmospheric levels (i.e. 0.3%).

Twenty two sensitivity runs were also completed for the range of conditions shown in Table 2-16.

Table 2-16 Summary of Conditions Assessed in the Sensitivity Analysis

Range	Infiltration (% of annual rainfall)	Flushing	Reactive Surfaces	Redox (mV)	Initial pH	CO_2
Minimum	1%	1%	10%	-118	5.5	0.03%
Maximum	3%	10%	50%	615	8.3	0.30%

Because of the uncertainty associated with the source of the ongoing salt release observed for the kinetic tests, a series of corrections were also applied to the production rates to account for potential residual saline groundwater / porewater that may have affected the test results. These corrections however are speculative.

2.8.3 Results

As noted before, the RSF will have three plateaus at 50, 100 and 150 m heights. The percolate water quality predictions were therefore prepared to reflect each of these areas based on overall column height so that solute concentrations can be applied to each of the respective footprint areas. The results are summarised in Table 2-17.

Table 2-17 Summary of Water Quality Predictions

		Area: 50 m Height			Area: 100 m Height			Area: 150 m Height		
		Base	Sensitivity Range		Base	Sensitivity Range		Base	Sensitivity Range	
Parameter	Units	Case	Min.	Max.	Case	Min.	Max.	Case	Min.	Max.
pH	s.u.	7.7	4.6	9.2	7.6	4.2	9.3	7.6	3.9	9.4
pE	-	6.7	-2.6	9.8	6.8	-2.5	10.2	6.8	-2.5	10.4
Eh	mV	395	-118	580	400	-150	600	400	-115	615
SO_4	mg/L	7800	1266	175695	15624	2538	123165	23466	3816	183396
Cl	mg/L	2640	654	97045	5289	1310	84538	7946	1969	126986
Salinity	mg/L	8436	2034	250505	16591	3818	148885	24776	5560	222745
Al	mg/L	0.0	0.0	25.8	0.0	0.0	46.7	0.0	0.0	70.1
As	mg/L	3.2	1.1	157	6.4	2.1	64.2	9.6	3.2	96.6
Ba	mg/L	0.014	0.0030	0.047	0.012	0.0050	0.040	0.011	0.0030	0.035
Ca	mg/L	106	0.40	1003	193	0.10	1727	283	0.00	2201
Cu	mg/L	0.1	0.1	26.1	0.1	0.1	52.3	0.1	0.1	78.7
F	mg/L	19.8	7.4	660.1	18.2	6.9	1477.3	17.0	7.3	2297.3
Fe	mg/L	0.0	0.0	203.8	0.0	0.0	339.5	0.0	0.0	309.9
K	mg/L	234	72	10617	468	144	4664	704	216	7006
Mg	mg/L	185	0.50	1438	334	0.40	2270	485	0.30	3416
Mn	mg/L	0.40	0.03	40.4	0.69	0.024	81.0	1.0	0.020	122
Na	mg/L	2428	451	82729	4865	903	48692	7310	1357	73151
Ni	mg/L	0.12	0.04	5.73	0.24	0.08	2.39	0.36	0.12	3.60
P	mg/L	0.00	0.00	7.71	0.00	0.00	27.48	0.00	0.00	45.17
Pb	mg/L	0.17	0.07	3.94	0.34	0.12	4.00	0.38	0.18	6.10
Si	mg/L	15.1	4.8	17.3	14.5	7.3	17.1	13.9	5.0	17.4
Sr	mg/L	4.4	0.10	33.2	8.8	0.08	33.7	10.3	0.07	44.1
U	mg/L	0.30	0.001	2.98	0.60	0.001	5.98	0.91	0.001	9.00
Zn	mg/L	1.25	0.16	24.4	2.52	0.33	25.4	3.79	0.49	38.1

Note: Predictions were not completed for Cr, Co or Mo.

The table shows the base-case results together with the range of concentrations estimated for each parameter. Note that while the column reported for the base-case for each area represents a single prediction, the ranges presented are not for single predictions but rather the maximum and minimum from all the results. That is to say that the predicted minimum concentration for one solute is not necessarily from the same sensitivity run as that for another parameter. For example the minimum concentration of iron does not necessarily come from the same run that the minimum zinc concentration originates from. The same is true for the maximum concentrations.

The sensitivity runs indicated the following general correlations:

- Solute concentrations not affected by secondary mineral phases generally vary:
  - Directly with fraction of rock flushed (a tenfold increase from 1% to 10% causes approximately a tenfold increase in solute concentrations)
  - Inversely with net infiltration (a threefold increase in infiltration from 1% to 3% of annual precipitations causes approximately a threefold decrease in solute concentrations)
  - Directly with reactive surface area (a fivefold increase from 10% to 50% causes approximately a fivefold increase in solute concentrations)
- Increasing carbon dioxide causes a decrease in pH which in turn affects solubility limited solutes.
- Uranium, iron and to a lesser extent manganese and arsenic concentrations, are dependent on both redox and pH conditions.
- Nickel and copper concentrations generally are correlated to pH conditions.
- Barium and lead concentrations generally are independent of either pH or redox conditions.

The predicted solute concentrations shown in Table 2-17 represent the percolate from the RSF. Once the percolate leaves the base of the RSF the solutes will interact with the underlying soils and sediments as has been demonstrated for the TSF. ENSR / AECOM completed a series of contact tests to assess the potential for metal attenuation in the substrate. The results are discussed in the next section.

Note that since no testing of rock representative of low grade ore had been completed, percolate water quality predictions were not prepared specifically for the low grade ore stockpile. Assuming that the stockpile will be removed and processed toward the end of mining the period, it will not represent a long-term source. Depending on the net infiltration rate, it may not even represent a short term source.

2.9 Assessment of Solute Fate

The soils and subsoils underlying the proposed RSF footprint comprise variable thicknesses of dune sand grading to clay and weathered rock materials, including topsoil and dune sand, calcareous soils, sand to silty sand, clayey silt to silty clay (with inclusions of gypsum crystals) and weathered calcareous sandstone with some inter-bedded siltstone layers. The residual soil layer ranges between 2 and 15 m, with an average of about 6 m.

Three investigations of soils and sediments preceded the ENSR/AECOM assessment. These studies (Davey and Green, 1993; EGi, 1995; EGi, 2006) were completed primarily to assess attenuation effects beneath the TSF and addressed the interaction between the acidic tailings liquor and the calcareous clay, swale and dolomitic materials. These investigations showed that the calcareous soils and overburden have a potential to neutralise acidity and to attenuate metals including uranium. Test results reported in these studies indicated that neutralisation to a neutral pH is a prerequisite for metal removal. Monitoring results also confirmed that the acidic percolate from the tailings is being effectively neutralised within the sediments, and that metals are effectively removed from solution as the percolate pass through the soils and sediments.

The ENSR/AECOM evaluation included geochemical characterization (elemental compositions), mineralogy and contact tests to assess attenuation capacities.

The results indicated that the dominant phases throughout all soil profiles are quartz (up to 90%), illite (up to 86%) and kaolinite (up to 75%). Halite is ubiquitous albeit in small quantities (< 2%). The XRD analysis also suggested the possible presence of smectite and formation of an illite-rich smectite mixed layer. The clay minerals (illite and smectite) tend to weather to kaolinite, hence its abundance. Calcite is occasionally present at a few percent but sometimes may be present up to 29%. Gypsum too occurs at a similar heterogeneous distribution. Goethite, occasionally up to 26%, and hematite were present in one of the deeper samples at a depth of almost 15 m.

To assess sorption reactions, ENSR/AECOM calculated partition coefficients (K_d) from results for contact tests following the USEPA batch method. Four samples of sandy clays were selected from the upper 2 m of the soil profile. The contact tests were completed at various liquid to solid ratios and only uranium sorption was assessed. The calculated K_d values reported by ENSR/AECOM are illustrated in Figure 2-4 and ranged between 12 and 141 mL/g (mean ± standard deviation = 51 ± 36), depending on the soil composition and the solid to liquid ratio.

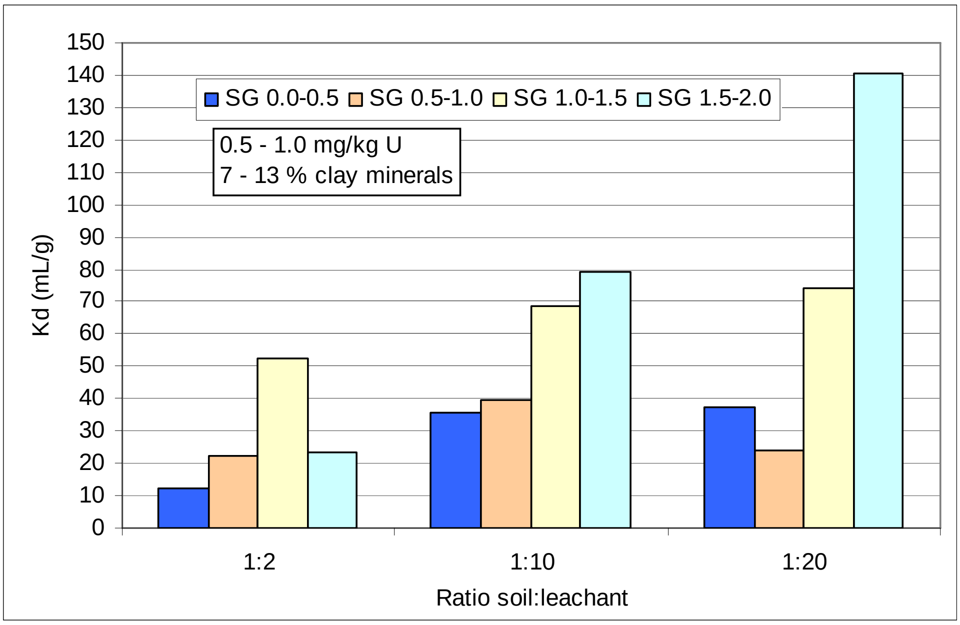

Figure 2-4 K_d Values for Uranium at Different Solid:Liquid Ratios

At an average K_d value of 50 mL/g the uranium concentration of percolate from the RSF could be lowered from 1 mg/L to 0.01 mg/L. However, these preliminary K_d values should be applied with caution as they were obtained for solutions containing only uranium at low concentrations, and factors such as physical and chemical variability, and metal competition, would impact sorption.

In their assessment, ENSR / AECOM summarised K_d values reported in the literature for other metals. As shown in Table 2-18, the results are quite variable. The results suggest that other metals should also be effectively attenuated in the soils and substrates. However, it is important to note that the attenuation may be reversible and would need to be assessed for field conditions.

Attenuation is best viewed as retardation where the retardation factor is defined as follows:

$$R = (1+\sigma K_d) / \theta$$

Where R is the retardation factor
σ is the bulk density
θ is the volumetric moisture content

For example, using the average K_d of 50 mL/g, the retardation factor for uranium would be in the order of 2,200 (assuming a 4% volumetric moisture content). That means that if the travel time of percolate from the base of the TSF to the aquifer is say 10 years, then the uranium will not arrive at the aquifer for another 22 000 years. However, as mentioned before, it is necessary to determine the K_d at conditions representative of field conditions.

Table 2-18 Summary of K_d Values Reported in the Literature for Select Metals

Element	K_d (mL/g)	Soil type	Comments
Cu	703 – 7 418	clay ~ 13.6%, organic matter ~ 3.8%	pH ~ 7; average of 40 measurements
	1650 – 7 500	clay = 40%, iron oxides = 5.6%	pH = 8
	3 – 330	clay = 4%, iron oxides = 0.5%	pH = 7.2
Cd	37 – 3 963	clay ~ 13.6%, organic matter ~ 3.8%	pH ~ 7; average of 40 measurements
	12 – 2 720	clay = 40%, iron oxides = 5.6%	pH = 8
	1 – 22	clay = 4%, iron oxides = 0.5%	pH = 7.2
Zn	319 – 17 965	clay ~ 13.6%, organic matter ~ 3.8%	pH ~ 7; average of 40 measurements
	84 – 41 900	clay = 40%, iron oxides = 5.6%	pH = 8
	2 – 22	clay = 4%, iron oxides = 0.5%	pH = 7.2
Pb	210 – 127 500	clay = 40%, iron oxides = 5.6%	pH = 8
	3 – 22	clay = 4%, iron oxides = 0.5%	pH = 7.2

2.10 Mine rock classification

Based on the static, kinetic and weathering characteristics of the mine rock ENSR/AECOM proposed the following four categories of material classes:

- Class A – Low grade Ore. Elevated metals (including U) with potential to leach, and sulphide mineralogy with the potential to generate acidity i.e. contains >0.25% oxidisable sulphide sulphur and has negligible acid neutralizing capacity. This material is potentially acid forming material.
- Class B – Basement Mine Rock. All basement mine rock excluding low grade. Elevated metals (including U and Cu) with potential to leach under neutral and / or acidic conditions, and sulphide mineralogy with potential to generate acidity. Negligible acid neutralizing capacity; this material is potentially acid forming material.
- Class C – Benign. All overburden mine rock excluding surficial soils and Andamooka Limestone. Relatively low metals content; this material is classed as non acid forming material.
- Class D – Acid neutralizing, comprising surficial soils and Andamooka Limestone mine rock. High acid neutralizing capacity. Relatively low metals content. This material classed as net acid consuming material.

3 Assessment of Significance of Source Estimates

3.1 Plausibility for Source Term Concentrations

By adopting very simplistic assumptions for flow and allowing for fully oxidised conditions, it is possible to show that based on the productions rates obtained for the kinetic testing, concentrations similar to those presented in Table 2-17 are possible. For example, for a net infiltration of 1.64 L/m^2 contacting 1% of the rock, the flow within the channel will equate to 1.64/0.01 = 164 L/m^2. Flow in a 1 m^2 flow channel of a 150 m column would contact about 330 tonnes of rock (assuming an average bulk density of about 2.2 $tonne/m^3$). At a sulphate production rate of about 2 g/t/wk, the column would yield about 34 kg sulphate per year. At an initial volumetric moisture content of about 4% the rock would contain about 9 600 L of water. At that moisture content and the infiltration rate of to the flowpath of 164 L/m^2 the residence time in rock column would be about 58 years. During that time about 58*34 kg = 1990 kg of sulphate would be generated. The concentration of the porewater would therefore be about 1990 kg SO_4/ (9600 + 160*58) = 0.1054 kg/L or about 105 400 mg/L. This is somewhat lower than the maximum sulphate concentration but is well above the base case assessment. Similar calculations can be completed for other parameters. In general the concentrations compare reasonably with this simplified calculation, however it is important to note that the predictions are based on a very few number of kinetic tests and some of the tests were terminated prematurely.

It is concluded the source term concentrations are plausible based on the available information.

3.2 Significance of the Source Term Concentrations

The tailings porewater is acidic (pH values as low as 3.27), has sulphate concentrations ranging from 30 000 to 45 000 mg/L, and uranium concentrations up to about 100 mg/L. In comparison, the RSF percolate is predicted to be near neutral in pH, and while the predicted range of sulphate concentrations is higher, the uranium concentrations are lower. However, the percolation rates from the TSF during operations are significantly higher than is expected for the RSF. Furthermore, whilst the TSF percolate is acidic, the water quality within the mound beneath the TSF to date appears to have been only minimally affected by the percolate due to the neutralization and attenuation reactions that are occurring in the subsoils and overburden material. Since the RSF percolate is expected to be neutral in pH and have lower uranium concentrations the effects on groundwater should be less pronounced but could still be significant. Therefore, as for the TSF, the RSF source concentrations will become significant only if there is a risk that percolate from the RSF may migrate off-site.

Dewatering for the establishment of the open pit will result in a drawdown of the water table in the surrounding area. Furthermore, water balance modelling for the pit has indicated that, due to high evaporation rates, the pit lake would remain below the existing water table and the drawdown zone would be maintained indefinitely. Preliminary groundwater modelling has indicated that the drawdown zone would extend within the limits of the RSF, and beyond depending, on the rate of recharge to the RSF that will occur over time. There is however uncertainty related to the total recharge that could cause recharge to move off-site away from the drawdown.

4 Conclusions

Key conclusions from the geochemical characterizations to date can be summarised as follows:

- The overburden material, with the exception of the pebble conglomerate (ZWP), is non reactive, is net acid consuming and has limited potential for solute release. The limited solute potential is linked to salts associated with saline porewater and gypsum naturally occurring with these materials.
- The basement complex rocks contain elevated concentrations of a range of metals, which have been shown to be released under oxidizing conditions.
- Overall, the mine rock in the RSF will be net acid consuming so that percolate is expected to be net neutral, however the possibility of zones of acidic porewater cannot be ruled out given the large volumes of the basement rock that would be placed within specific zones of the RSF.

Some of the assumptions that were adopted for the water quality predictions may not necessarily have accurately reflected the conditions that may develop within the RSF. However simple calculations show that the higher numbers could be plausible given the geochemical data to date. The range of concentrations resulting from the sensitivity runs, as summarised in Table 2-17, should capture the likely range of concentrations that may result.

Therefore, both the base case and the upper concentrations have been considered by BHP Billiton when evaluating potential loadings to the groundwater system.

5 References

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APPENDIX K6

Stuart Shelf regional groundwater flow model

21 November 2008 Project No. 06641442-L21

Dr Kelly Usher
Olympic Dam Expansion
BHP Billiton
GPO Box 11052
ADELAIDE SA 5001

REVIEW OF THE STUART SHELF REGIONAL GROUNDWATER MODEL
OLYMPIC DAM EXPANSION PROJECT

Dear Dr Usher

Golder Associates Pty Ltd (Golder) has carried out a review of the Stuart Shelf Regional Groundwater Model for the proposed Olympic Dam Expansion. We reviewed the findings of the study as documented in the draft report "Stuart Shelf Regional Groundwater Flow Model. Model Development, Calibration and Predictive Analysis" (Document No ODS-000-GN-RP-00-0001, 15 November 2008).

It is my opinion that the work has been carried out thoroughly and to an appropriate technical standard for the Olympic Dam Expansion EIS. The scope of work and the outcomes are in line with normal industry practice and seem acceptable for the intended purpose.

A detailed review of the draft report will be submitted to you shortly. The standard of report writing is good, but the results and interpretations are not always presented clearly and concisely. We hope that the authors would find our suggestions as provided in the review helpful in their preparation of the final report. In my opinion, none of the suggested changes would substantially affect the results and outcome of the study.

Please do not hesitate to contact me if you have any questions with regards of this review.

Kind Regards

Jan Vermaak
Associate

JJV/JDW/sp

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Uranium CSG – Olympic Dam
Olympic Dam Expansion Project

Stuart Shelf Regional Groundwater Flow Model – ODX EIS

Model Development, Calibration and Predictive Analysis

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1. Executive Summary

BHP Billiton Olympic Dam Corporation Pty Ltd (BHPB) is considering an expansion of its Olympic Dam (OD) operations with an open pit mine as the preferred option for the Olympic Dam Expansion Project (ODX). The open pit operation will require dewatering and depressurisation of the cover sequence stratigraphy and basement rocks, this dewatering will produce groundwater drawdown. ODX will also operate a Tailings Storage Facility (TSF) and Rock Storage Facility (RSF) in conjunction with the open pit. These are likely to produce seepage with some dissolved solutes which may enter the Andamooka Limestone aquifer and potentially the underlying Arcoona Quartzite and Corraberra Sandstone. Saline water is required for construction and dust suppression purposes during mining and ODX has identified the Andamooka Limestone, to the north of the current Special Mining Lease (SML), and the Corraberra Sandstone, within the SML, as having the groundwater resources available for the required saline demand during the construction period. A regional numerical groundwater flow model has been developed to simulate historical groundwater behaviour at OD and to predict the groundwater response to the ODX during operations and post closure.

This report documents the development, calibration and predictive analyses of the numerical model for the purposes of supporting the ODX EIS submission in relation to groundwater impact assessment. The EIS is to address the potential impacts from the mining operation to groundwater conditions and the model incorporates and simulates all significant groundwater effecting activities in order to predict changes to groundwater level and / or water quality in the vicinity of an environmental receptor or 3rd party user.

The numerical model developed is capable of simulating the Stuart Shelf regional groundwater system and is consistent with the conceptual hydrogeological model. The model is considered to be a suitable numerical tool to enable an evaluation of the potential changes to groundwater conditions in order to predict impacts. The model simulates:

- Interaction between the mine drawdown cone and drawdown from the saline water supply wellfield;
- Evaporative losses from a number of salt lakes including Lake Torrens;
- Boundary conditions between the Great Artesian Basin (GAB) and the northern margin of the Stuart Shelf; and,
- Groundwater flow from the Arckaringa Basin (Boorthanna Formation) into the Stuart Shelf groundwater system.

An environmental risk assessment (KBR 2008) has identified the potential receptors and receptor values which could be impacted by changes to water levels or water quality. The changes to groundwater conditions in the vicinity of the primary receptors have been predicted by the numerical model. These receptors include fish species in Yarra Wurta Springs, GAB springs and associated environments and third party user bores located within the Stuart Shelf.

The base case model and the sensitivities predict that all solute seepage from the TSF and RSF will under steady state conditions flow into the open pit. During mining and operations the model predicts that solute movement away from the TSF and RSF is highly unlikely given the proximity to, and active drainage toward, the open pit. Therefore water quality changes from ODX outside of the expanded SML are predicted to be highly unlikely.

The model predicts no change in water levels at the northern model margin with the GAB. Under a range of sensitivities on model parameters no change was observed in the northern model margin. In fact various sensitivity analyses confirm the conceptual model and the model representation.

Water level change at Yarra Wurta Spring was predicted by the base case model and the various sensitivities to be less than 1 m after 500 years. This is considered to be the limit of model accuracy in such a regional model and the level of transient groundwater level information available. The effect of this drawdown at the spring is outside the scope of this report (see Draft EIS, Appendix N8), however there are a number of things that should be considered regarding the accuracy of the model predictions at this location:

- The expected drawdown at this receptor is likely to be in the magnitude of centimetres rather than metres.
- Model nodes around Yarra Wurta Spring are spaced at a minimum of 800 m apart and the entire model domain is 200 km x 150 km x 1 km.

- The model assumes porous media flow. This is a necessary simplification of the real situation and is ideal for simulating large scale groundwater flow where large variations in groundwater level are expected. When small scale flows and groundwater level variations are considered this assumption will have greater effect on model predictions. In reality there are great deals of geological and hydrogeological features (such as faults, fractures, lineations, voids, etc) that will modify the way groundwater flows on a local and regional scale.
- There is no time variant calibration data between the ODX site and Yarra Wurta Spring and model hydraulic parameters are based primarily on best estimates in these areas and the steady state calibration (where observation data does exist).

Drawdown at the 3rd party bores in the Stuart Shelf is predicted at between 1–3 m after 500 years post closure and less than 1 m after 40 years.

The Stuart Shelf regional numerical groundwater flow model was constructed using FEFLOW, a finite element modelling code. Hydraulic parameters for the model were based initially upon values used in previous conceptual groundwater flow models but were varied slightly in certain areas to match known parameter values from recent drilling or to match anecdotal evidence. Changes to model parameters were done not at a local scale but done so on bulk parameter values so as not to increase model complexity and uncertainty.

The steady state and transient models have been successfully calibrated and are considered acceptable given the scale of the model and uncertainty and knowledge of regional and localised hydrogeology. The steady state model has been developed to represent groundwater conditions prior to mine development at OD (i.e. prior to 1983). The transient calibration simulates the historical groundwater response at OD from 1983 through to 2007. This groundwater response relates to seepage or infiltration to the Andamooka Limestone from the TSF and MWEP and abstraction from the Andamooka Limestone and Corraberra Sandstone through production well abstraction, underground development and raise bores. The predictive model simulates groundwater behaviour (from 2007 through to 2550) in relation to ODX groundwater effecting activities, including:

- Discharge from the ODX (July 2008) pit shells from 2011 through to 2050;
- RSF (40 year footprint) with a constant 1% of rainfall recharge seepage;
- Seepage from the ODX TSF footprint;
- Trial depressurisation and active dewatering from the Corraberra Sandstone;
- Abstraction from the SPS Andamooka Limestone saline water (Motherwell) wellfield;
- Abstraction from the SPS satellite wellfields;
- Underground mining and operation of the raise bores coincident with the open cut.

Predictive modelling shows that seepage or infiltration from the TSF causes groundwater mounding in the ZAL with groundwater levels beneath the TSF predicted to be similar to the groundwater levels observed beneath the current TSF. Mounding from the TSF will extend up to 4 to 10 km from the current SML boundary. Particle tracking carried out on the groundwater mound beneath the TSF shows that the transport of solute and seepage away from the pit is highly unlikely.

Seepage from the RSF does not significantly change the behaviour of the groundwater system during mining and post closure. The ZAL beneath the RSF is predominantly unsaturated and mounding within the ZAL does not occur, due to seepage from the RSF draining through the ZAL into the ZWA (Arcoona Quartzite). The ZWA is underdrained by the ZWC due to an increased hydraulic gradient (caused from pit inflow). Ultimately seepage from the RSF is captured by the pit.

Inflows to the pit will occur during mine development and inflows of up to 12,000 m^3/d may occur during the early phases of mining. Additional studies (long term pumping tests and re-calibration of this model) are required during the DPS to confirm these rates. The predicted long term inflow rate to the pit from the ZWC is 3,500 m^3/d (40 L/s). The drawdown in the ZWC is modelled to extend some 10–40 km from the SML and a maximum of 45 km from the pit. The pit will act as a hydraulic sink, whereby all seepage or solute from the TSF, RSF and any other groundwater effecting activities will be captured by the pit during mining or post closure.

During 2027 to 2050, inflows of up to 1,000 m^3/d may be expected from the ZAL when the groundwater mound from the TSF is at its largest and highest. However, post closure pit inflow from the ZAL decreases to 0 m^3/d as downward leakage increases under a higher hydraulic gradient from the ZAL to the ZWC.

Predictive modelling and sensitivity analyses shows that any short term drawdown observed during the construction period from the saline wellfields (Motherwell and Satellite wellfields) is overprinted post closure by downward drainage from the ZAL, and flow to the pit from the ZWC.

2. Glossary and Abbreviations

Term	Definition
BHPB	BHP Billiton Pty Ltd
OD	Olympic Dam Operations
ODX	Olympic Dam Expansion Project
SPS	Selection Phase Study / Pre-feasibility
DPS	Definition Phase Study / Feasibility
SML	Special Mining Lease
LoM	Life of Mine
ML	Megalitre / 1 million litres
DLWBC	Department of Land, Water, Biodiversity and Conservation
EIS	Environmental Impact Statement
GAB	Great Artesian Basin
REM / SKM	Resource Environmental Management / Sinclair Knight Merz
PIRSA	Primary Industries and Resources South Australia
SARIG	South Australian Resources Information Geoserver
DEM	Digital Elevation Model
RL	Relative Level
FEFLOW	Finite element groundwater modelling software
MODFLOW	Finite difference groundwater modelling software
TSF	Tailings Storage Facility
RSF	Rock Storage Facility
GDA94, MGA Z53	Geocentric Datum of Australia 1994, Map Grid of Australia, Zone 53
Kh	Horizontal Hydraulic Conductivity
Kv	Vertical Hydraulic Conductivity
Sy	Specific Yield
Sc	Confined Storage
MAR	Managed Aquifer Recharge
ZAL	Andamooka Limestone
ZWA	Arcoona Quartzite
ZWC	Corraberra Sandstone
ZWT	Tregolana Shale
RMS	Root Mean Square
MWEP	Mine Water Evaporation Pond

3. Document References

No.	Identification/File Name	Description
1	Aquaterra (2007)	Prominent Hill Mine Regional Groundwater Model. Prepared for Oxiana Ltd. By Aquaterra Consulting Pty Ltd.
2	Dalgarno (1982)	Andamooka 1:250,000 Geological Map Sheet SH53-12. South Australian Dept. of Mines and Energy.
3	Douglas & Howe, 2007	Conceptual Hydrogeological Model of South Australia's Stuart Shelf for Assessment of the Olympic Dam Mine Expansion. Unpublished paper.
4	Golder (1995)	Golder (1995), Report on the Hydrogeology of the Gairdner-Torrens Basin, prepared for Western Mining Corporation Ltd by Golder Associates, October 1995,
5	Habermehl (1980)	Habermehl, R. (1980), The Great Artesian Basin, Australia, in BMR Journal of Australia Geology & Geophysics No. 5.
6	HLA (2008)	Pit lake formation report (EIS Draft Appendix J2)
7	Howe et al. (2007)	Howe, P., Baird, D. and Lyons, D. (2008) Hydrogeology of the Southeast Portion of the Arckaringa Basin, South Australia, in Proceedings of the 31st Hydrology and Water Resources Symposium and the 4th International Conference on Water Resources and Environment Research, Adelaide 14–17 April 2008.
8	KBR (2008)	Impact assessment Olympic Dam mine expansion groundwater development and environmental assets discussion paper
9	Kellett et al (1999)	Hydrogeological Assessment of a Region in Central Northern South Australia. Bureau of Rural Sciences Australia. Division of Land and Water Sciences
10	MDBC (2000)	Groundwater Flow Modelling Guideline. Prepared for MDBC by Aquaterra Consulting Pty Ltd.
11	REM (2007a)	Analytical Modeling of Mine Pit Influence on the Regional Stuart Shelf Groundwater System. Report BQ09-R002, August 2007.
12	REM (2007b)	Investigation into the Managed Aquifer Recharge (MAR) Potential of the Andamooka Limestone. Report EV07-01, December 2007.
13	REM & Golder (2004)	Stuart Shelf Groundwater Supply - Desktop Study. Olympic Dam Development Pre-feasibility Study. Prepared for WMC Resources Ltd.
14	Preiss (1993)	Neoproterozoic. In: Drexel J.F., W.V. Priess and A.J. Parker (Eds). The Geology of South Australia Vol. 1. The Precambrian. South Australian Geological Survey. Bulletin 54.
15	SKM (2008)	Groundwater Impact Assessment, Olympic Dam Expansion Project. Report VE30025-R002a, August 2008.
16	Soil & Groundwater (2006)	Regional Groundwater Assessment, Olympic Dam Expansion Project. Prepared for BHPB Billiton by Soil and Groundwater.
17	WASY (2007)	WASY Software, FEFLOW 5.3 Finite Element Subsurface Flow & Transport Simulation System. http://www.wasy.de/english/produkte/feflow/index.html
18	Waterhouse et al. (2002)	Hydrogeology of the Stuart Shelf in South Australia and Impacts of the Olympic Dam Mine, in Proceedings of the 2002 International Association of Hydrogeologists Groundwater Conference: Balancing the Groundwater Budget, Darwin, May 12–17, 2002.
19	WMC (2007)	Olympic Dam Expansion Project. Selection Phase Study, Slope Depressurisation and Pit Dewatering Assessment. Prepared for BHPB Billiton by Water Management Consultants.
20	WMC Resources (1995)	Hydrogeological Investigation and Numerical Modelling Lake Eyre Region, Great Artesian Basin. Internal Report HYD T044.

4. Report Outline

BHP Billiton Olympic Dam Corporation Pty Ltd (BHPB) own and operate the Olympic Dam (OD) underground mining operation north of Roxby Downs in central South Australia. It is the largest underground hard rock mine in Australia yielding a polymetallic resource of copper, uranium, silver and gold. The ore is processed on-site employing both hydrometallurgical and pyro-metallurgical techniques to extract refined copper, silver and gold metal and uranium oxide.

BHPB is considering a major expansion of its OD operation to more than double the current production capacity. An open pit mine is the current preferred option for the Olympic Dam Expansion Project (ODX) to achieve the proposed capacity increase because of the scale of the ore body.

The open pit operation will require dewatering and depressurisation of the cover sequence stratigraphy prior to, and during mining. This dewatering will produce groundwater drawdown in the cover sequence. The ODX will also operate a TSF (Tailings Storage Facility) and RSF (Rock Storage Facility) in conjunction with the open pit. These facilities are likely to produce seepage with low concentrations of dissolved solutes from the base which could reach the groundwater table. Saline water is required for construction and dust suppression purposes during mining. The Selection Phase (pre-feasibility) Study (SPS) has identified the Andamooka Limestone (ZAL), to the north of the current Special Mining Lease (SML), and the Corraberra Sandstone (ZWC), within the SML, as a groundwater resource to meet saline demand during the construction period.

This report outlines the development, calibration and the predictive capacity of a numerical groundwater flow model developed for the purposes of supporting the ODX EIS submission. The EIS is to address the potential impacts from the mining operation. This groundwater model incorporates and simulates all significant past, present and future groundwater perturbing effecting activities for ODX in order to predict the changes to groundwater levels and quality that these activities will have on a third party and environmental receptors. The report does not address what impact a change in groundwater levels and quality will have on the receptor value.

The numerical model will also support the regulatory process and licence applications for the extraction of saline water from the ZAL and ZWC aquifers. Refinement of this numerical model will be undertaken regularly following long term testing and monitoring to enable a reassessment of the potential impacts to the environment and 3rd party users.

4.1. Objectives

The objectives of the numerical groundwater flow model are to:

- Simulate regional and local groundwater flow in the Stuart Shelf groundwater system;
- Assess changes to water quality by predicting particle tracking;
- Support the ODX EIS submission and aid in the impact prediction to a third party or an environmental receptor;
- Support a licence application to the South Australian Department of Land, Water and Biodiversity and Conservation (DLWBC) to extract saline groundwater from the ZAL and ZWC for the construction period;
- Develop a groundwater flow model that can be refined and improved after Definition Phase (feasibility) testing and monitoring;
- Provide greater certainty to the open cut inflow and dewatering estimates;
- Provide an assessment of the post closure, steady state impact of mining on the groundwater system of the Stuart Shelf;
- Identify uncertainties and gaps in hydrogeological knowledge;
- Simulate mitigation measures and contingencies;
- Assist in identifying knowledge gaps;

- Develop a model as an ongoing management tool to evaluate the broader water supply and water management options for OD and ODX.

The model is to represent the regional groundwater system for the Stuart Shelf and take into account current activities at OD and proposed activities for ODX. To do this successfully, the model is to be developed as both a steady state and transient simulation. The steady state model will look predominantly at regional groundwater conditions prior to OD, whereas the transient model is to be representative of the historical and proposed activities at OD and ODX, and how the activities at ODX may affect third party or environmental receptors through water level change (drawdown predictions) or changes to water quality (particle tracking).

4.2. Scope

In order to achieve the objectives discussed in Section 4.1, the model must be capable of simulating the Stuart Shelf regional groundwater system and influences from bounding groundwater systems. The Stuart Shelf groundwater system is surrounded by the Arckaringa Basin to the west. The Arckaringa Basin is a large sedimentary basin with significant groundwater resources which are currently being accessed by the Prominent Hill Mine as a mine water supply. The Arckaringa Basin provides groundwater through flow onto the Stuart Shelf, a major component of the regional water balance, and is considered important in the regional context of the groundwater system (Douglas & Howe, 2007; Howe et al., 2007). Any changes in groundwater levels at this margin need to be addressed in terms of impact.

North of the Stuart Shelf is the Great Artesian Basin (GAB), the GAB is a very large sedimentary basin that extends from South Australia into the Northern Territory, New South Wales and Queensland. The GAB is used extensively throughout the country for pastoral, domestic, mining and industrial purposes and sustains a series of natural springs along its southern margin. OD currently draws water from the GAB from a series of wellfields (A and B) to the north of OD. The GAB proper is separated from the Stuart Shelf by the Adelaide Geosyncline and the Torrens Hinge Zone, both low permeability geological units. These units must be represented in the model area to demonstrate regional scale groundwater behaviour and to predict any water level changes at the margin with the GAB.

Yarra Wurta Spring is a natural, saline, low flow spring located at the northern tip of Lake Torrens. The spring sustains a population of fish (Lake Eyre Hardy Head) and has been identified as the closest, highest value environmental receptor in the region. Whilst the spring appears to originate from the ZAL the mechanism for discharge is not fully understood.

It is important that the numerical model compliments the current understanding of the conceptual hydrogeology and accurately, yet simply represents the groundwater system. It is regarded as unrealistic to double the model area in an effort to simulate the Arckaringa Basin or GAB with this model. Nor is it considered realistic to try and perfectly simulate spring conditions (such as vents, ponds and exact evaporative losses) at Yarra Wurta Spring with a model that covers an area of 26,000 km^2. The model will need to represent the Arckaringa Basin, the northern margin of the Stuart Shelf with the GAB and in particular the presence of Yarra Wurta Spring. These representations are required for the prediction of water level and quality changes at the margins with these bounding groundwater systems and at the third party and environmental receptors in response to activities at ODX. Whilst drawdown will be used to consider water level change over time, changes to water quality will be predicted by the use of particle tracking from the TSF and RSF. If particle tracking indicates the movement of solute away from the mine area, more detailed transport modelling will be carried out.

It is therefore necessary for the model to represent the following geological and hydrogeological conditions:

- Short and long term interaction between the mine drawdown cone and drawdown from the saline water supply wellfield;
- Evaporative losses from a number of salt lakes (e.g. Lake Torrens);
- Boundary conditions between the northern Stuart Shelf and the GAB;
- Representation of a number of environmentally sensitive groundwater flow systems (e.g. Yarra Wurta Spring);
- Groundwater flow from the Arckaringa Basin (Boorthanna Formation) into the Stuart Shelf groundwater system;

- Particle tracking from the TSF and RSF during mining and post closure conditions to predict changes to water quality;
- The ability to adapt the model to assess various water supply options and hydrogeological scenarios for ODX.

5. Conceptual Groundwater Model

5.1. Stratigraphy

The conceptual hydrogeology of the Stuart Shelf has been documented by several authors since the development of the OD underground mine in the 1980's. The latest and most comprehensive work has been carried out by Douglas & Howe (2007) and documented in various reports by REM / SKM following hydrogeological investigations for the ODX SPS.

It is not the intention of this report to document the conceptual hydrogeology of OD or the Stuart Shelf, the reader is advised to refer to further reports and documents for a comprehensive understanding of the hydrogeology (see Section 3 for a reference list and Appendix 1 for Douglas & Howe, 2007). However, for the purposes of understanding the model development, the stratigraphy of the Stuart Shelf is outlined briefly in this report.

The cover stratigraphy in the vicinity of OD comprises Neoproterozoic to Cambrian age sedimentary units. These units include the Nucaleena Conglomerate, Tregolana Shale, ZWC, ZWA and ZAL overlain by a shallow sequence of Quaternary alluvial and Tertiary Aeolian sediments. Outside of the SML, and in particular to the north, the cover sequence stratigraphy is very similar with the inclusion of the Yarloo Shale (located between the ZWA and ZAL) and the Yarra Wurta Shale (conformably overlying the ZAL). The stratigraphy of the Stuart Shelf is summarised in Table 5.2 and for a further description of each unit of the regional hydrogeology the reader is referred to Douglas & Howe (2007). For the purpose of modelling the Stuart Shelf groundwater system, only the most significant geological units of the cover sequence have been considered. The Nucaleena Conglomerate therefore has not been included in the model as it is relatively thin (typically less than 5 m) when present and generally not intersected outside of the SML.

Whilst not explicitly modelled in this regional system, the Boorthanna Formation is discussed a number of times in this document. Douglas & Howe (2007) and Howe et al., (2007) presents the latest hydrogeological conceptual understanding of the Stuart Shelf and Arckaringa Basin respectively. The Boorthanna Formation is described as an extensive regional-scale aquifer, typically occurring as several zones. These zones are separated by significant thicknesses of low permeability sediments, especially in the eastern parts of the Basin where thicker and deeper intersections occur.

As for the Boorthanna Formation, the GAB is not explicitly modelled in the Stuart Shelf regional model. The South Australian portion of the GAB (including OD wellfields A & B) is currently modelled using the ODEX model (WMC Resources, 1995). Whilst the Stuart Shelf groundwater system uses constant head levels referenced from the ODEX model, the reader is referred to this report (WMC Resources, 1995) for a full appreciation of the GAB, the GAB mound springs and the modelling strategy used to represent these features. Habermehl (1980) is also an ideal reference for the hydrogeology of the GAB.

Structure contours of each hydrostratigraphic unit were developed from over 1,400 drill logs and stratigraphic interpretations by BHPB. This data was sourced from resource drilling within the SML, sterilisation drilling within the SML and BHPB mineral exploration holes outside of the SML and on exploration leases. The PIRSA website, SARIG, was used where necessary to obtain additional stratigraphic information and where data was available to fill gaps. A 90 m state DEM (Figure 1) was used to estimate collar RLs were required. The stratigraphic information was compiled, gridded (kriging) and contoured. These contours were then visually assessed to eliminate errors or inconsistencies with the dataset (e.g. bullseyes). This dataset was then regenerated and filtered using a gaussian 3 pass filter for import into the modelling software. The final structure contours for the hydrostratigraphic tops are shown in Figures 2 and 3. Figure 4 shows a 3D representation of the model.

The distribution of data and drill holes used in the generation of hydrostratigraphy is also shown on Figures 2 and 3. The figures show an excellent distribution of data in and around the SML. A good spread of data points exists to the northeast toward Lake Torrens and to the south and southeast towards Andamooka Island. Significant data gaps exist however in the far north of the model domain, and to the west and southwest of the SML.

5.2. Recharge

Kellett et al (1999) carried out significant chloride mass balance calculations to assess groundwater recharge on the Stuart Shelf. The study calculated the highest recharge rates (1–5 mm/yr) for the Algebuckina Sandstone outcrop. However, throughout most of the study area the Bulldog Shale is in outcrop, and average recharge rates of 0.1–1 mm/yr are reported for this unit. Kellett et al., (1999) reported groundwater recharge rates for the ZWA in the order of 0.1 mm/yr, or lower.

Waterhouse et al., (2002) discussed groundwater recharge as part of a regional perspective of OD and the mining operations. Whilst no direct measurements were taken by the authors, they used an average recharge rate of 0.04–0.1 mm/yr, similar to those reported by Kellett et al (1999). Waterhouse et al., (2002) inferred that recharge is likely to be episodic in nature and would be derived during periods of heavy and intense rainfall. These rainfall events would cause runoff into playa lakes that would act as recharge sources.

Further to this, REM & Golder (2004) confirmed similar groundwater recharge rates from another mine site on the Gawler Craton and have suggested that groundwater recharge is unlikely to occur at the playa lakes to the south of OD (e.g. Lake Younghusband and Pernatty Lagoon). The water table at these playa lakes is at, or is very near the ground surface, and they are interpreted as evaporative features in the regional system.

In 2007 Aquaterra developed a regional groundwater model for the Prominent Hill mine north-west of OD. For this model a recharge rate of 0.1 mm/yr was adopted into the numerical model water balance.

5.3. Water Balance

Prior to any attempt at modelling, a simple water balance was carried out to assess the likely water budget of the Stuart Shelf groundwater system. The water balance estimated potential recharge and inflows to the system, the rate of groundwater through flow (based on groundwater contours and hydraulic conductivities) and the estimated outflows (discharge or evapo-transpiration). From this simple water balance an upper, lower and likely water budget was developed for use in the model development (Table 5.1).

Table 5.1 Conceptual Water Budget for the Stuart Shelf

Component	Upper (m^3/d)	Likely (m^3/d)	Lower (m^3/d)
Inflow – Recharge	7,400	5,300	3,300
Inflow from Boorthanna Formation	3,200	2,150	1,050
Total Inflow	**10,550**	**7,400**	**4,350**

The diffuse recharge rate estimated by Kellett et al. (1999) was approximately 0.04–0.1 mm/yr over the investigation area. This recharge rate was calculated from the chloride mass balance method for a number of different geological units. Assuming an annual average rainfall of 150–160 mm/yr at OD, this recharge rate is equivalent to 0.02–0.06% of annual rainfall. These values formed the upper and lower bounds for the water balance estimate.

To assess the inflow onto the Stuart Shelf from the Boorthanna Formation, the calibrated results from the Prominent Hill Mine groundwater model (Aquaterra, 2007) were used. Aquaterra (2007) used a general head boundary to represent the basin margin between the Stuart Shelf (ZAL) and the Boorthanna Formation. This groundwater flow west onto the ZAL was calibrated at 2,142 m^3/d from the Arckaringa Basin (Boorthanna Formation).

Flow and discharge components of the water budget were calculated using the water table contours generated by Douglas and Howe (2007) (see Appendix 1). Transmissivity values were estimated (within measured or observed ranges) to match the inflow component for the Stuart Shelf.

The evapotranspiration potential of Lake Torrens (surface area of 5,700 km^2) was also calculated to confirm the conceptual basis of the lake representing a regional evaporative sink. Assuming a maximum evaporation rate of 200 mm/yr, the lake has the capacity to evaporate over 3,000,000 m^3/d, far in excess of the likely subsurface inflow to the lake. It is therefore considered valid to suggest that Lake Torrens is a regional evaporative sink in the Stuart Shelf groundwater system. The model does not consider any throughflow discharge from Lake Torrens to the south.

Table 5.2 Summary of important Stuart Shelf stratigraphy and lithology [1]

Age	Unit	Description	Approx Thickness (m)	Notes
Quaternary	Undifferentiated	Clayey sands, sand plains and dunefields, playa and drainage lakes	0-20	Extensive occurrence, but variable
Cretaceous & Jurassic	Bulldog Shale	Siltstones, conglomerates, shales and carbonaceous clays	0-50	Remnants scattered across Study Area, part of Eromanga Basin
Cambrian	Yarra Wurta Shale	Calcareous and micaceous shale and siltstone with thin interbedded sandstone	0 - 100	Overlays the Andamooka Limestone in the north-east
	Andamooka Limestone	Indurated limestones (various facies), variably dolomitic and shaley	Up to 200	Variable sedimentary sequence, dips and becomes thicker to the northeast, part of the Arrowie Basin
Neoproterozoic	Yarloo Shale	Laminated shale, discontinuous, absent beneath and south of OD	0-50	Separates the Andamooka Limestone and Arcoona Quartzite northeast of OD, thickest near Hinge Zone, possible remnants in area of OD
	Tent Hill Formation			
	Arcoona Quartzite	Quartzite with shale interbeds in its upper part	150-200	Upper section interbedded with shales and lower section more massive, dips to the northeast
	Corraberra Sandstone	Silty sandstone and micaceous siltstone, with shaley interbeds	30	Indurated and vuggy in the vicinity of OD and dips and becomes thicker to the northeast
	Tregolana Shale	Laminated shale and siltstone; dominantly fine detrital quartz	150-300	Dark strongly laminated rock, thins over the basement high interpreted in the area of OD
Mesoproterozoic	Basement	Diverse igneous and metamorphic rocks	-	Altered granite in the vicinity of OD

Notes:
1. Adapted from Golder (1995), and Dalgarrno (1982)
2. Preiss (1993)
3. Source: SA Geodata base

6. Model Development

6.1. Model Code

The numerical groundwater flow model was constructed using the finite element code FEFLOW (WASY, 2007). FEFLOW was chosen over MODFLOW for the following reasons:

- Better representation of the pit for mine dewatering and inflow;
- Better numerical stability for steep groundwater gradients and permeability contrasts;
- Ability to only refine areas of interest; and,
- Ability of FEFLOW to better handle rewetting compared with MODFLOW.

FEFLOW is considered to be the industry standard finite element groundwater modelling software and has been used for numerous national and international mining and water resource models.

6.2. Model Extent and Mesh

The finite element mesh generated for this model covers the known outcrop and sub-crop extent of the ZAL, ZWA and ZWC (Figure 5). These three geological units are the major groundwater flow systems that have been identified in the Stuart Shelf. Where possible the model domain incorporates no flow boundaries or catchment divides (western and north-east boundaries). Whilst this approach has led to a large model area, it does mean that the model incorporates few assumptions of cross boundary flow.

The model is bounded by Lake Torrens to the east, and to the south by Lake Windabout, Island Lagoon, Lake Hart and Lake Younghusband, south of Woomera and the Arcoona Plateau. The western boundary follows the regional catchment divide, outside the outcrop and sub-crop extent of the major Stuart Shelf aquifers. To the northwest, the model boundary has been defined by the 60 mRL groundwater head contour from the Prominent Hill numerical groundwater flow model (Aquaterra, 2007). The northern extent has been extrapolated beyond the ZAL, out to the Torrens Hinge Zone, Adelaide Geosyncline and the southern margin of the GAB.

The model mesh was defined in FEFLOW using the “Triangle” method of mesh generation. This method generates automatic mesh refinement based on the defined model extent, point, line or polygon features, and allows for user definition of finer mesh density in areas where numerical predictions are required, or coarser mesh density away from the area of interest. The background grid is built with triangles with nodes separation of over 5,000 m. The model mesh was refined around several physical features these were:

- Yarra Wurta Spring (800 m minimum node separation);
- SPS saline water wellfield (Motherwell) configuration (800 m minimum node separation);
- open cut pit (40 m minimum node separation);
- Tailings Storage Facility (TSF) existing and proposed (180 m minimum node separation);
- Rock Storage Facility (RSF) (500 m minimum node separation); and,
- Coorlay Lagoon and Andamooka Creek (1,400 m minimum node separation).

The model domain was generated in the GDA94 spatial projection (MGA Zone 53) and covers an area of 26,000 km^2. There are 6,756 elements in each model layer and 3,472 nodes in each model slice. The major fault margins bounding the Torrens Hinge Zone (Torrens Fault) and the Adelaide Geosyncline (Norwest Fault) were included in the model mesh as features without refinement.

6.3. Model Layers

FEFLOW model slices are used to define the hydrostratigraphic layers and constrain the model vertically. The slices are surfaces on which the finite element nodes are situated and the area between two adjacent slices forms a model layer. Boundary conditions are applied to nodes on the slices and material properties are applied to the layers.

Nine slices have been combined to represent the 6 main lithologies found in this area (Table 6.1). Three slices are used to represent the ZAL. This has been included to represent the dense hyper-saline brine found beneath Lake Torrens and to the north-east of OD, identified by REM (2007) (this is discussed further in Section 7.2).

Where a stratigraphy is known to pinch out, the associated FEFLOW layer is reduced to a nominal thickness of 1 m and the properties of the slice are copied from the slice below. Therefore throughout each slice, other geological formations may be represented as discrete zones, particularly in areas where the unit is known not to be present. Structure contours of the major formation tops (slices) are shown in Figures 2 and 3, with the layer thicknesses represented in Figure 4.

Table 6.1 FEFLOW Model Slice Representation

Model Slice	Major Geological Representation
1	Topography
2	top of ZAL
5	top of Yarloo Shale
6	top of ZWA
7	top of ZWC
8	top of Tregolana Shale
9	Base of Model (-1,000 mRL)

Note: The Torrens Hinge Zone and Adelaide Geosyncline are represented in all model slices.

The base of the model has been extrapolated to -1,000 mRL and is done so they represent Tregolana Shale and basement material in the open pit. The model report refers to properties of the Tregolana Shale however does not mention the basement parameters. For the purposes of modelling, the properties of the Tregolana Shale and basement are considered similar and this assumption has been made to incorporate a greater depth in the model and to keep the layering simple (i.e. the properties of the two units are not completely different and the basement contains very complex geology which could not be accurately represented with this model).

6.4. Boundary Conditions

Boundary conditions are defined by MDBC (2000) as “constraints imposed on the model domain to represent the interface between the model and the surrounding environment”. Model boundary conditions were kept as simple as possible so that model runtime and numerical stability were not compromised. This was however balanced with the need to maintain flexibility and the predictive capacity of the model. Two “active” boundary conditions were used in the model. These can be described as:

- Constant head boundaries. These allow water in and out of the model depending on the difference between a user defined reference head (which is usually defined based on the elevation of a particular hydrological feature) and the simulated head
- Seepage boundaries. These allow water to flow out of the model only. Water flows out depending on the difference between a user defined reference head (which is usually defined as the elevation of the model node on which it is placed) and the simulated head

All boundary conditions employed in the steady state model are also used (unmodified) in the time variant historical and predictive models. As the requirements of the simulation become more complex, more boundary conditions are needed. The additions to the steady state boundary conditions required in the historical time variant calibration are discussed below in Section 6.4.2. The additions to the predictive time variant model depend largely on the predictive scenario, and these are described in more detail in Section 8.1.

Constant heads are very powerful factors in any numerical model and can completely dominate results if they are not used carefully. In this case very few constant heads were used and were located at a significant distance from areas of the model where critical predictions of groundwater flow are required.

6.4.1. Steady State Model

Figure 6 illustrates the various boundary conditions used in the steady state model. These can be summarised as:

- Seepage nodes with a user defined head of 25 mRL located on slice 1. These simulate evaporative discharge from Lake Torrens. Aquaterra (2007) used an evaporation rate extinction depth of 10 m, the bed of Lake Torrens is estimated to be at an elevation of 35 mRL and hence in this model the seepage node elevations were set at 10 m below the lake bed (25 mRL). Numerous smaller salt lakes on the southern model boundary were also represented using seepage nodes placed at natural surface elevation.
- No Flow Boundaries representing the regional surface water catchment divide on the western boundary and the north-eastern boundary along the northern Flinders Ranges (Adelaide Geosyncline and Torrens Hinge Zone).
- Constant head nodes at a head of 60 mRL located on slice 2. These simulate inflow from the Boorthanna Formation of the Arckaringa Basin. This model boundary has been derived from the 60 mRL groundwater level contour predicted by the calibrated Prominent Hill groundwater model (Aquaterra, 2007) and provides subsurface flow into the ZAL aquifer.
- Constant head nodes (set at a head of 22 mRL in slice 1) and seepage nodes (set at natural surface in slice 1) placed on the northern model boundary to represent artesian conditions in the GAB and spring or evaporative conditions at the northern margin of the Stuart Shelf. The 4 nodes representing the GAB were set as constant head nodes so as to allow water to be fed back into the model if groundwater heads surrounding the nodes dropped below 22 mRL.

In this model seepage nodes have been used effectively to represent evapotranspiration at the numerous salt lakes in the region and seepage near Andamooka Creek and at the margin of the Stuart Shelf and the GAB.

With the exception of a few seepage nodes located at Coorlay Lagoon (15 km south of OD), all boundary conditions mentioned above are located a significant distance from the mine (> 50 km) and because of this, their impact on the transient calibration and predictive scenarios are likely to be minimal, this is demonstrated later in the report. All boundary conditions, in particular, those representing discharge conditions the northern Stuart Shelf margin with the GAB, inflow from the Arckaringa Basin and those representing discharge around the northern tip of Lake Torrens have been monitored during model calibration, predictive simulations and sensitivity analysis to ensure the inflow or outflow is both within reasonable bounds identified in the preliminary water balance and that this flow is realistic over time. Variations to these boundary condition fluxes are reported in Sections 7.3 and 8.1.

6.4.2. Time Variant Model

All boundary conditions and the recharge distribution used in the steady state model have been maintained in the transient historical model. In order to accurately simulate historical mining activities (abstraction from well bores, flow to underground workings and leakage from tailings and rock dumps) a number of boundary conditions were added to the model. These are described below.

Seepage from mine infrastructure

Seepage from the TSF1, 2, 3 and 4 and MWEP. The seepage values were derived from WMC (2007) and have been modelled using a the FEFLOW well boundary condition. The wells are configured to inject water into the footprint of the TSF. This approach is consistent with WMC (2007). The basis for assessing the seepage rates is outlined as follows:

> *"The seepage schedule for the period up to 1997 developed for the 1998 model of the TSF (WMC Resources, 1998). MWEP discharge was based on records presented in the "Annual Report on Groundwater in the Mine Area" and TSF seepage on the photographic record of the history of ponding.*
>
> *Measurements of tailings permeability. Previous work was reviewed and extensive testing undertaken as part of the Cell 4 construction plan. Coffey-Metago (1998) report low density unconsolidated permeability in the range 4.0 E^{-8} to 8.6 E^{-7} reducing by a factor of 10 for consolidated/confined tailings.*
>
> *Direct estimates of the porosity of the Andamooka Limestone and the volume of the seepage mound. Typical porosity of about 3% was indicated from laboratory analysis of core samples from fresh material (Grigg, 2002). The drawdown cone induced by pumping from LP02 from 2000-2005 was calculated at 19.2 GL. Abstraction from the bore over 5 years totalled 1.52 GL giving a porosity of 7.9% for this shallower (more weathered)*

sample of the ALA. The volume of the TSF mound using early 2006 data gave a calculated rock volume of 160 GL. The indicated seepage volume is 11.2 GL at a porosity of 7%.

Within the above constraints, the previous (1998) seepage schedule was extended and modified. For cells 1 to 3, the adopted seepage schedule is based on an initial tailings permeability of 4.0 E^{-7} m/s which declines with tailings compaction according to the function 1/ (1 + log b) where b = the tailings thickness. For cell 4 initial seepage rates use a permeability of 2.5 E^{-7} m/s. For all cells an additional beach seepage factor was included to allow 30% of total seepage from beaches as estimated from tailings surface water balance models.

The old mine water evaporation pond located immediately east of the TSF was a substantial source of seepage until decommissioning in 1999. Seepage estimates presented in the previous TSF numerical model (WMC Resources, 1998) and based on mine water discharge rates were used in this assessment."

Abstraction from the ZAL

Extraction from the ZAL via production well LP02 was simulated using the standard FEFLOW well boundary condition. Abstraction rates assigned to this well were based on those documented in WMC (2007). This data was derived from measured extraction volumes reported in annual reports and ranged between 0–1,000 m^3/d.

Abstraction from the ZWC

Groundwater flow to the raise bores (RB1 – 31) and abstraction from the saline wellfield (RD809 etc) was simulated using the standard FEFLOW well condition. The likely flow rates were sourced from WMC (2007). Due to the spacing of the nodes in the model mesh, several of the abstractions were grouped together. The combined abstraction from the ZWC from these two processes was modelled using a total of 7 wells. Abstraction rates used to represent underground development at OD was between 500 and 2,000 m^3/d.

6.5. Hydraulic Parameters

The initial (pre-calibration) hydraulic parameters used to populate the steady state and transient models were based upon values used in previous groundwater flow models, in particular the ODX SPS report for the mine dewatering WMC (2007). The values of hydraulic conductivity (Kh and Kv), specific yield (Sy) and specific storage (Sc) were varied slightly in certain areas to match known parameter values from recent drilling (REM, 2007) or to match anecdotal evidence (Table 7.1). Section 7.1 discusses the calibration methodology in terms of bulk parameter modification over localised changes.

6.6. Recharge

Recharge applied to slice 1 of the model was based on the recharge rates documented by Kellett et al. (1999). The recharge rates used in the model are shown in Figure 7 and are summarised in Table 6.2. Five zones of recharge were used for the model representing recharge to the ZAL (a porous and transmissive aquifer), the Arcoona Plateau (low permeability area with high runoff) the Adelaide Geosyncline and Torrens Hinge Zone (very low permeability area, see REM, 2007), the northern Flinders Ranges (low permeability area with steep topography) and the southern salt lakes. These recharge zones are based upon a geomorphological rationale and the estimations provided by earlier studies. In order to maintain model complexity and assumptions, additional recharge zones were not applied to the model to improve local model calibration.

Table 6.2 Summary of recharge rates applied to slice 1

Recharge Zone	Recharge Rate (mm/yr)	% of rainfall recharge
ZAL outcrop	0.075	0.05
Arcoona Plateau	0.045	0.03
Northern Flinders Ranges	0.0062	0.004
Adelaide Geosyncline and Torrens Hinge Zone	0.0037	0.0025
Southern salt lakes	0	0

6.7. Simulation Period and Time Stepping

Several models were produced to simulate the Stuart Shelf groundwater system. Together they replicate:

- the groundwater flow system prior to the commencement of mining activity in 1980 (the steady state model) (see Section 7);
- the system from the commencement of mining to the present day (the historical model)(see Section 7); and,
- predictions about groundwater behaviour during the ODX (the predictive model) (see Section 8).

The steady state groundwater flow model calibration has no time component and therefore no steps. Groundwater heads from the steady state calibration were used as the starting conditions for the historical model. The transient or time variant model has been developed to simulate the groundwater system in response to mining and mining operations, and simulates activities from 1983 through to 2007. Mine development commenced in 1983 with production starting in 1988. Time steps in the transient model were defined automatically by FEFLOW using the automatic time step control function. This changes time step length in response to changes in stress and successful convergence and provides flexibility and increased processing speed in the modelling process.

The final heads from the transient calibration were used as starting heads for the predictive scenarios. The predictive model was used to simulate groundwater conditions from 2007 through to 2550, some 500 years after closure of the mining operations.

6.8. Observations

Both the steady state and historical (transient) models were calibrated against observed groundwater data. Figures 8 and 9 show the locations of the steady state model calibration data points.

The groundwater level monitoring network at OD and ODX is comprehensive within the SML and numerous monitoring facilities exist for the ZAL, ZWA and ZWC. The facilities at OD are typically designed to assess seepage from the existing TSF and drawdown from underground mining operations. Monitoring facilities installed by ODX since 2006 have been designed to consider groundwater conditions of the cover sequence and basement within the proposed pit footprint in order to assess pit inflows and dewatering requirements. Several regional baseline water level monitoring facilities have been installed in the SML by OD and ODX.

Outside of the SML the groundwater monitoring facilities have been improved since 2006 through a variety of drilling campaigns, these include EIS drilling to improve the conceptual hydrogeological model, and SPS investigations into saline water supply and managed aquifer recharge (MAR). This drilling has resulted in the installation of several monitoring networks within the ZAL, ZWA and ZWC. Additional regional water level data has been collected by Soil & Groundwater (2006) as part of the EIS.

The steady state and transient model calibrations used different water level observation datasets. The steady state calibration incorporated all known facilities outside of the SML including the majority of regional water levels collected by Soil & Groundwater (2006). Steady state observations within the SML were selected to ensure that the data point was collected either in the early 1980's prior to any impact from mining or processing at OD, or of a significant distance away from the mine so as not to be impacted by water level change. The steady state observation dataset is summarised in Appendix 2.

The transient calibration observation dataset is limited to the ZAL and ZWC within the SML. The transient observation dataset is very similar to that used by WMC (2007) in the SPS report for pit dewatering and groundwater inflow. This transient observations ranges typically from 1985 through to 2006 has been updated to include an additional data point outside the SML (near Roxby Downs) to gain better sub-regional calibration.

Table 6.3 summarises the transient observation dataset.

Table 6.3 Summary of Transient Observation Wells

Well	Easting	Northing	Slice	Unit	Model_ID	Date of Observations
LM43	682324.50	6632191.10	2	ZAL	1	Jan 1999 – Sept 2006
LT17	678202.80	6630860.71	2	ZAL	2	Aug 1994 – Sept 2006
LT26	676879.50	6629983.80	2	ZAL	3	Jul 1996 – Sept 2006
LT34	675595.50	6629667.10	2	ZAL	4	Aug 1998 – Aug 2006
QT4	678204.99	6630840.00	7	ZWC	7	Aug 1994 – May 2006
RD1006	674810.03	6631172.17	2	ZAL	5	Mar 1994 – Aug 2006
RD999	676536.40	6631862.39	2	ZAL	6	Mar 1994 – Aug 2006
RD115	680426.68	6631719.88	7	ZWC	8	Nov 1985 – Jun 2006
RD141	682889.95	6631670.11	7	ZWC	9	Nov 1985 – Jun 2006
RD222	684372.35	6628703.12	7	ZWC	10	Oct 1988 – Jun 2006
RD299	681400.66	6630091.40	7	ZWC	11	July 1985 – Jun 2006
RD479	681765.99	6633043.00	7	ZWC	12	Nov 1985 – Jun 2006
RD54	682055.34	6630850.96	7	ZWC	13	Apr 1989 – Jun 2006
RD66	682138.12	6630459.71	7	ZWC	14	Nov 1985 – Jun 2006
RD436	680299.29	6625895.50	7	ZWC	15	Oct 1988 – Jun 2006

7. Model Calibration

7.1. Method

Model calibration is defined by MDBC (2000) as the process by which independent variables (such as parameters and fluxes) of a model are adjusted within realistic limits, to produce the best match between simulated and measured data.

The steady state and transient historical models were calibrated in parallel. This was necessary for two reasons:

- A steady state model has no time component and therefore storage does not play a part in the numerical flow calculations. Storage values can only be calibrated with the transient model.
- Any changes made to the hydraulic conductivity values in the transient historical model must first be reflected in the steady state model. Therefore there is little to be gained from investing a great deal of time calibrating the steady state model independently of the transient.

The model was calibrated using a manual “trial and error” process by which bulk model hydraulic parameters were varied in order to reduce the difference between observed and simulated heads. At the same time boundary condition fluxes were monitored to ensure that they approached a qualitative fit of field estimated or measured values. The boundaries of most interest were:

- Inflow from the constant heads representing the flow from the Arckaringa Basin
- Outflow from the seepage/drain nodes representing evaporation/spring flow from Lake Torrens

This method of calibration using a combination of measured head data and inferred flow data was considered particularly robust for the steady state model, bearing in mind that it is hard to guarantee that single time observed groundwater level data measured 25 years ago actually reflects a steady state, and whether a real steady state even exists. Calibration to steady state conditions was done using the water level observations listed in Appendix 2. The majority of these observations were collected by Soil & Groundwater (2006) as part of a baseline groundwater survey of the Stuart Shelf. The majority of BHPB observation well data from outside the SML were used in the calibration with only a small number of observations used from within the SML.

The transient calibration was carried out using the observations summarised in

Table 6.3. Whilst these observations are by no means the entire dataset, they are considered representative of groundwater response since mine development in 1985. The observations are located within the ZAL (slice 2) and the ZWC (slice 7).

It is important to note that the calibration methodology was based upon the variation of bulk parameter values of hydraulic conductivity and storage. The intent was not to achieve a perfect calibration fit at each observation point yet to provide a quality fit of regional contours (in the case of the steady state model) and a trend match of the hydrographs (for the transient calibration). To try and mimic observed local values, particularly around the mine area would involve the inclusion of a number of assumptions which would introduce complexity and greater uncertainty. The homogenous calibration approach was preferred given the uncertainties associated with TSF seepage rates and ZWC abstraction rates. Only after long term testing has taken place to improve confidence in the dataset and the understanding of the system response will localised model refinement be carried out on hydraulic parameters such as K and storage.

7.2. Calibrated model parameters

Steady state water level contours for the ZAL (slice 2) are shown in Figure 8 and for the ZWC (model slice 7) in Figure 9. The statistical results of the steady state calibration (observed vs. modelled heads) are shown in Figure 10. Hydrographs of the transient calibration are shown in Figures 11 and 12. These hydrographs provide a comparison between observed and modelled groundwater levels. The model conditions assume a bulk rock permeability or homogeneity within each layer and consideration has not been given to anisotropic features which are known and / or inferred within the mine area and on a regional scale.

Table 7.1 summarises the hydraulic property values assigned to the final calibrated steady state and historical time variant models.

These values are considered to be within reasonable bounds when compared with measured values and anecdotal evidence. Figures 13 and 14 show the spatial distribution of the hydraulic conductivity values assigned to each model lithology. The model conditions assume a bulk rock permeability or homogeneity within each layer and consideration has not been given to anisotropic features which are known and / or inferred within the mine area and on a regional scale.

Table 7.1 Calibrated Model - Hydraulic Parameters

Description	Data Origin	Hydraulic Conductivity		Unconfined Specific Yield (Sy)	Confined Storage (Sc)
		m/s	m/d	%	1/m
Adelaide Geosyncline	Estimated	1×10^{-10}	8.6×10^{-6}	Slice Dependant	Slice Dependant
Torrens Hinge Zone	Estimated	1×10^{-8} - 1×10^{-10}	8.6×10^{-4} - 8.6×10^{-6}	Slice Dependant	Slice Dependant
Bulldog / Yarra Wurta Shale	Estimated	1×10^{-8}	8.6×10^{-4}	1	1×10^{-6}
Andamooka Limestone	WMC (2007) and SKM (2008)	0.075–2.5	0.65 - 22	7.5	1.67×10^{-3} –1×10^{-4}
Yarloo Shale	Estimated	1×10^{-7}	8.6×10^{-3}	1	1×10^{-6}
Arcoona Quartzite	WMC (2007)	1×10^{-8}	8.6×10^{-4}	1	5×10^{-6}
Corraberra Sandstone	WMC (2007)	0.02	0.17	5	5×10^{-5}
Tregolana Shale	WMC (2007)	1×10^{-10}	8.6×10^{-6}	1	1×10^{-6}

Hydraulic conductivity distribution

The only units of relatively higher hydraulic conductivity (K) in the model domain are the ZAL and ZWC (see Table 7.1 and Figures 13 and 14). The distribution of K within the ZAL (slices 2, 3 and 4) is quite complex whereas K in the ZWC (slice 7) is relatively simple.

The ZAL is dominated by a large area of high K. Whilst the extent of this area is estimated to the west based on anecdotal evidence from Howe et al., (2007), high K is known to exist in the ZAL to the north of OD and to the north-east toward Lake Torrens (SKM, 2008). Several zones of lower K have been included in the model domain to simulate various observed or conceptual conductivities. These are:

- A thin strip of lower K along the western model boundary. This has been used to represent the Billa Kalina Fault system that runs north-south and is postulated to be the discharge mechanism from the Arckaringa Basin to the Stuart Shelf (Howe et al., 2007).
- A lower K strip along the southern margin of the ZAL. This has been included to represent a thinning of the ZAL and a lower permeability dolomitic limestone.
- The K around OD is based upon numerous drill hole data around the mine and the SML. This K value is extrapolated toward the extent of the ZAL, and to the north where the first major water intersections have been drilled.
- Lower K around Lake Torrens has been used to represent water density rather than observed conductivity. Drilling investigations have established the presence of hyper-saline brine beneath Lake Torrens in the ZAL. It is hypothesised that this brine has originated from Lake Torrens under evaporative conditions and has migrated slowly under a density driven gradient to the north-west of the lake. It is further hypothesised that this ‘brine wedge’ has followed the path of least resistance along a high permeability corridor of limestone in the deepest part of the aquifer. The footprint of the ‘brine wedge’ is greatest in slice 4 and reduces in size from slice 3 and slice 2. The ‘brine wedge’ is considered to be relatively immobile given its higher density. Survey and additional drilling is planned to gather further information regarding the extent of this brine. The information available on the extent and definition of the hyper-saline brine is discussed in SKM (2008). The brine is believed to

be 'holding heads up' within the greater limestone aquifer due to the density contrast. To model such a density variation in 3D is a complex and computationally demanding task in any regional model and would require a great deal of information that is not yet available. For the purposes of this modelling exercise, the density contrast was represented by a simple change in K. WMC (pers. comm, 2008) have modelled a similar density variable aquifer system for Escondida using SEAWAT and modelling results suggested that this dense hyper-saline brine would not move significantly (a maximum movement of 8 m) even if throughflow in the system is reduced by up to 50%. A change to the position or composition of this brine interface is not expected to affect any environmental receptors, and if it occurs, is only expected to affect ODX in terms of quality of saline water supply.

ZWC K is representative of properties within the mine area and the area to the south (assumed to be a constant K value). To the west of OD, the ZWC thins and is not believed to be present, the K in this area has been made very low to represent this. To the north of OD, several holes have been drilled to intersect the ZWC. Observations from these holes indicate that the ZWC is of very low permeability to the north (airlift yields < 0.1 L/s), and it is postulated that this low permeability is associated with burial depth (i.e. the fracture width in the ZWC decreases with burial depth). Therefore where the ZWC structure contour is below an elevation of -250 mRL, a low permeability has been designated to the ZWC.

There is a need to recognise that there is range of uncertainty in the hydraulic parameters assigned to the model. Where possible, model parameters have been assigned based upon measured or observed values however in some areas these parameters were changed slightly (within reasonable bounds) during the calibration process to provide a better calibration.

Storage distribution

The initial storage values used in the model calibration are based upon those used by WMC (2007) in the pit dewatering model. Very minor changes were made to the confined storage of the ZAL outside of the mine area, in particular to the zone of high K that has been identified during drilling and testing. The value of Sc has been modified to match values assessed from interpretation of short term (up to 5 days) pumping tests. For the other geological representations in the model, the storage values remained the same as the WMC (2007) model calibration.

Minor changes were made to the raise bore data (ZWC abstraction) to better match the observed responses during the transient calibration (see Figures 13 and 14 and Section 7.3.2). The data used in WMC (2007) to represent the flow to the raise bores was based on relatively sparse data, therefore the confidence in this dataset is low and to put too much emphasis on this data in the calibration process is considered unnecessary. Furthermore, given the uncertainty with this data it was considered better to adjust both these input data and the hydraulic parameters of the ZWC during the calibration process.

7.3. Comparison with observed data and numerical analysis

7.3.1. Steady state model

For the steady state calibration, the RMS (Root Mean Square) amounts to 12.5 m for all observed values. RMS is defined by MDBC (2000) as an absolute measure that is problem dependent. RMS is thought to be the best error measure if errors are normally distributed and has the following equation:

$$RMS = \sqrt{\frac{1}{n}\sum\left[Wi\left(hi - Hi\right)\right]}\quad ^2$$

The RMS amounts to 7.29 m for the ZAL (46 observations), 19.35 m for the ZWA (38 observations) and 3.15 m for the ZWC (17 observations).

The steady state model SRMS (Scaled Root Mean Square) amounts to 13.5% for all observed data. SRMS is defined by the following equation:

$$SRMS = \frac{100.RMS}{\Delta H}$$

SRMS for the ZAL amounts to 16.2%, 21.4% for the ZWA and 22.1% for the ZWC. A scattergram showing modelled heads against observed heads is shown in Figure 10.

The statistics for the steady state calibration show that the greatest error occurs within the ZWA. The majority of these observations are located far (up to and greater than 50 km) to the south-west, south and south-east of the SML. Whilst the fit between observed and simulated heads could be improved through further modifications to hydraulic conductivity or recharge to the ZWA, there is limited information with which to constrain these changes and the error is considered adequate given the distance from the mine area and SPS saline water wellfields. Should additional information become available, the model can be adjusted accordingly. The calibration is considered suitable for the mine area and ZAL in the vicinity of the SPS saline water wellfield.

Table 7.2 shows the water budget for the steady state calibration. During the steady state calibration the evaporative discharge or seepage at the northern model margin with the GAB was 43 m^3/d. This flux value is considered acceptable and is within the expected range of flow to this area. Inflow to the steady state model from the constant head nodes representing the Arckaringa Basin to the Stuart Shelf was modelled at 3,056 m^3/d. This value is greater than the 2,150 m^3/d inflow predicted by Aquaterra (2007) however given the range of uncertainty of the Prominent Hill and ODX models, and the size of the model domains, this scale variation (40%) is considered acceptable.

Table 7.2 Flow Balances for the Steady State Calibration

Steady State Water Balance	Inflow (m^3/d)	Outflow (m^3/d)
Storage	n/a	n/a
Recharge	3,248.8	0
Spring Discharge Flow (Seepage) to northern tip of Lake Torrens	0	5,254
Spring Discharge Flow (Seepage) to Northern model margin	0	43
Remaining Spring Discharge Flow (Seepage)	0	1,008.4
Boundary Inflow (Arckaringa Basin)	3,056.6	0

7.3.2. Time variant (historical) model

ZAL hydrographs show that the model generally overestimates the impact of the TSF and MWEP seepage (e.g. LT34, RD1006 and LT26). Observation well LM43 shows a considerable difference between the observed and modelled heads however this spike in observed heads is attributed to local infiltration from the new MWEP which was not included as a stress in this model calibration. No data exists on potential seepage or flow into the new MWEP therefore it was decided not to model this feature. LT17 and RD999 show good correlation between observed and modelled heads. However there is approximately 10 m offset between observed and modelled heads in LT17, this can only be explained by local anisotropy in a vuggy limestone aquifer. Whilst the model could be locally calibrated to achieve better visual results in the ZAL, it is considered that this would introduce unjustified complexity into the model. There is uncertainty in the seepage rates used to represent the TSF and MWEP and it is recommended that further work be done in the future to clarify the seepage rates and the spatial variation of these seepage rates prior to any localised calibration of the regional model. Furthermore, any changes to K or S on a local mine scale are unlikely to have a change on a regional scale (e.g. water level change at Yarra Wurta Spring).

Hydrographs for the ZWC monitoring wells show that the model is typically overestimating the drawdown. QT4 and RD115 are both located adjacent to the underground mine and show good correlation between observed and modelled heads. RD141, RD299, RD479, RD54 and RD66 all show an overestimation in drawdown by up to 20–30 m. These monitoring wells are located within or south of the Mashers Fault zone (a known high permeability structure trending east northeast). If Mashers Fault was to be included in the model domain as a high permeability feature, the trends between observed and modelled heads would improve. However, given the scale and application of this model, the inclusion of a localised feature is only expected to change the short term dewatering and inflow rates predicted by the model by contributing more water along a high permeability structure. In the longer term, inclusion of Mashers Fault is unlikely to have significant impacts on a regional scale, particularly considering that the model is typically overestimating the current mine drawdown. It is important to note that anisotropy has not been included in the modelling process. To date there is little evidence (with the exception of Mashers Fault around the mine area) to suggest regional or sub-regional scale faults or structures. Whilst these structures have been mapped from regional and local geophysics, there is little observation data to base these on. Groundwater system response to existing abstraction is sub-radial indicating that there is good connectivity of the ZWC in the SML, whilst recognising that there are localised areas of higher K.

RD222 is the only monitoring well to show an underestimation of recharge and this is put down to anisotropy in a fractured rock aquifer. RD436 is located toward Roxby Downs and may be considered representative of regional drawdown. The model overestimates the drawdown at this monitoring well by up to 10 m. This general overestimation of drawdown is considered acceptable as it provides conservatism in the predictive capacity of the model. There is also considerable uncertainty in the extraction data (raise bore) used in the model.

With the calibrated model parameters the discharge at the northern model margin of the Stuart Shelf with the GAB remains constant throughout the historical simulation (43 m^3/d) (see Table 7.3). Model inflow from the constant head nodes representing the Arckaringa Basin also remained constant throughout the historical simulation (3,056 m^3/d).

Table 7.3 Flow Balances for the Transient Calibration

Transient Water Balance	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Inflow (m^3/d)**	**Outflow (m^3/d)**
	Jan 1983	Jan 1983	Dec 2006	Dec 2006
Storage	n/a	n/a	0	588.4
Recharge	3,248.8	0	3,248.8	0
Spring Discharge Flow (Seepage) to northern tip of Lake Torrens	0	5,254	0	4,757
Spring Discharge Flow (Seepage) to Northern model margin	0	43	0	43
Remaining Spring Discharge Flow (Seepage)	0	1,008.4	0	506.9
Boundary Inflow (Arckaringa Basin)	3,056.6	0	3,056.6	0
Extraction from ZWC (Raise Bores and Saline Water Wellfield)	0	0	0	2,684
Extraction from ZAL (LP2)	0	0	0	0
Seepage from TSF1, 2, 3 and 4 and MWEP	0	0	2,273.9	0

7.4. Calibration summary

The steady state model calibration is considered to adequately representative of the steady state groundwater system prior to mine development at OD (i.e. prior to 1983). The steady state calibration may be improved by additional data to the south of OD on the Arcoona Plateau and in the far north of the model domain, the model may be updated to reflect any new datasets.

The transient calibration is considered acceptable given the identified uncertainty in seepage rates to the ZAL and extraction from the ZWC through underground development and raise bores. Mashers Fault, a known geological and hydrogeological structure within the mine area, was not represented in the calibration process. Whilst the location of Mashers Fault is well known, the structure is understood to be local to the mine area only and the inclusion of the structure would have no impact on the predictive capacity of the model when assessing environmental receptors distant from the mine. During the DPS it is planned to recalibrate the model in the mine area against the long term results of the trial depressurisation and trial injection. It is the intention during this work to also include Mashers Fault in the calibrated transient model to better predict short and long term dewatering and pit inflow rates.

8. Predictive Scenarios

8.1. Base Case Predictive Model Set-up

The base case predictive model uses the final heads from the transient calibration (2007) as initial head conditions. All boundary conditions and recharge rates have been maintained from the steady state and transient calibrations (i.e. leakage, raise bore abstraction and saline wellfield abstraction all continue at same values as they ended the historical model). As well as the boundary conditions from the historical calibration, the predictive model includes a number of other stresses to represent ODX. Due to the complex nature of the boundary conditions that are applied to represent the ODX pit development, 9 separate models are required to cover the predictive model time period. These models are summarised in Table 8.1 below and are based on the following major timeframes:

- Starts from 2007 (time 0 days);
- EIS approval and mine start-up in Q2 2010 ;
- a 40 year LoM (2010–2050);
- 500 years post closure (2050–2550).

The majority of the boundary conditions (such as seepage from the existing TSF and abstraction from the underground and raise bores) were copied from the transient to the predictive model. They were only modified when they fell within the ODX pit footprint, and in such case they were removed from the model. Several new stresses were introduced however, including dewatering, pit inflow and seepage from the ODX TSF.

Table 8.1 Predictive Scenario models

Predictive Model	Time Period (from)	Time Period (to)	Duration (days)	Description
2007 - 2010	0	1,186	1,186	Current underground mining operations including trial depressurisation. OD saline water wellfield requirements.
2010 - 2013	1,186	2,282	1,096	Start of open pit (starter pit) mining following EIS approval. Active dewatering wellfield. Saline water supply from Motherwell and satellite wellfields.
2013 - 2015	2,282	3,012	730	Major pushback. Extension of dewatering wellfield. Saline water supply from Motherwell and satellite wellfields.
2015 - 2016	3,012	3,378	366	Open pit extends down into ZWC for the first time. Saline water supply from Motherwell and satellite wellfields.
2016 - 2020	3,378	4,839	1,461	Major pushback. Extension of dewatering wellfield. Saline water supply from satellite and Motherwell wellfields finishes 2017.
2020 - 2027	4,839	7,396	2,557	Major pushback. Extension of dewatering wellfield.
2027 - 2038	7,396	11,414	4,018	Major pushback. Extension of dewatering wellfield.
2038 - 2050	11,414	15,797	4,383	Major pushback. Extension of dewatering wellfield.
> 2050	15,797	198,297	185,500	End of 40 year mine life (under EIS approval). Post closure.

Details of the extra boundary conditions used in the predictive model follow below.

- The ODX pit is simulated using seepage nodes (for a description see Section 6.4). Where the pit walls intersect a model slice, these are represented with seepage nodes with a reference head set to equal the elevation of the model node. The bottom of the pit is simulated with seepage nodes placed on the model slice directly below the pit floor. The reference head is set to the elevation of the pit floor. In this case, these inputs are based on the July 2008 pit shells from 2011;
- The RSF (40 year footprint) is simulated using standard FEFLOW well boundaries placed on slice 1, which are configured to inject water rather than remove it. The rate at which the wells inject water to

the model is based on a constant 1% of rainfall recharge (equivalent to 281 m^3/d infiltration for the total RSF) from the 40 year footprint from EIS approval in Q2 2010;

- The TSF (assumed 9 x 400 ha paddocks) is simulated in the same way as the RSF (with wells on model slice 1). The TSF seepage rates (Table 8.2) have been defined by BHPB (pers. comm., 2008) and are based on 65% paste thickener underflow and are calculated using 2 km x 2 km cells. Post closure seepage rates are assumed to be equivalent to 1% rainfall recharge (consistent with the RSF seepage rates).

Table 8.2 ODX TSF operational seepage rates and commissioning schedule

Cell	Stage	Commissioning Date	Steady State Date	Commissioning Seepage (m^3/ha/d)	Steady State Seepage (m^3/ha/d)
5	1	Jan 2010	Jan 2012	4	0.88
6	2B	May 2015	May 2017	4	0.88
7	2B	Nov 2015	Nov 2017	4	0.88
8	4	Nov 2016	Nov 2018	4	0.88
9	4	Feb 2018	Feb 2020	4	0.88
10	4	Aug 2018	Aug 2020	4	0.88
11	5	Apr 2019	Apr 2021	4	0.88
12	5	Oct 2019	Oct 2021	4	0.88
13	5	Feb 2020	Feb 2022	4	0.88

- Trial depressurisation and active dewatering from the ZWC (designed to intercept pit inflow) has been simulated using 10 - 24 wells on slice 7 (for 2007–2013 only);
- Abstraction from the SPS ZAL saline water (Motherwell) wellfield (maximum demand capacity of 27.5 ML/d) for the construction period (2010–2017) has been modelled using 11 wells on slice 2;
- Abstraction from the SPS satellite wellfields at Roxby Downs (0.7 ML/d), Hiltaba / Airport (0.9 ML/d) and MMIA / Process Plant (4.5 ML/d) over the construction period (2010–2017) has been applied using 9 wells on slice 7;
- Extraction from tailings area production wells TPW4 and TPW5 (combined 1 ML/d) during the current operation through to the construction period (2011–2017) This abstraction has been modelled used 2 well nodes on slice 7; and,

8.2. Results

The groundwater water levels and drawdown for both the primary groundwater aquifers, the ZAL (slices 2, 3 and 4) and ZWC (slice 7) at 2007, end of construction period (2017), end of mining (2050) and 500 (2550) years post closure are shown in Figures 15 to 28.

The predicted water level hydrographs at the identified environmental receptors (Yarra Wurta Spring, Coorlay lagoon, pastoral wells and Bamboo Swamp) are shown in Figures 29 to 31. These graphs also show the results from predicted sensitivity analyses described in Section 9.

8.2.1. ZWC Inflow and Abstraction

The base case predictive model simulates lead and active dewatering from the ZWC during the period 2007–2013. Following this, there is no active dewatering simulated and groundwater flows directly into the open pit (mostly from the ZWC). As the ZWC is a relatively transmissive lithology, it is unlikely that the predictions made by the model (in terms of change at distant receptors) with or without active dewatering during this period would be significantly different. For the purposes of assessing change due to long term dewatering this representation is considered sufficient. During definition phase testing, more modelling may be required to refine the dewatering rates required to maintain dry pit conditions.

The base case predictive models simulate satellite saline water supply wellfields during the construction period. These satellite wellfields extract groundwater from the ZWC, and assist in the dewatering process at the pit. The model also continues to simulate drainage from raise bores to the underground; this abstraction has been carried through from the transient calibration. Table 8.3 summarises the abstractions from the ZWC.

Table 8.3 Predictive Model Abstraction from the ZWC

Predictive Model	Satellite Wellfields	Inflow to Pit	Active Dewatering and Underground	Total Abstraction Rate from ZWC
	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)
2007 – 2010	0	0	3,450	3,450
2010 – 2013	7,100	0	4,350	11,450
2013 – 2015	7,100	4,150	790	12,000
2015 – 2016	7,100	4,100	650	11,850
2016 – 2020	6,550	4,000	370	10,900
2020 – 2027	0	4,850	470	5,350
2027 – 2038	0	3,550	270	3,850
2038 – 2050	0	4,100	0	4,100
> 2050	0	3,450	0	3,450

The total abstraction from the ZWC during the base case predictive model varies between 12,000 m^3/d (140 L/s) during the early mine development (2010–2016) through to 3,500 m^3/d (40 L/s) post closure. The early abstraction rates are dominated by the satellite wellfield abstraction comprising 1 ML/d from the tailings area, 4.5 ML/d from the MMIA (process plant), 0.7 ML/d at Roxby Downs and 0.9 ML/d at Hiltaba and airport (total of 7.1 ML/d). Should the satellite wellfields not be required for ODX, it is likely that the dewatering and inflow rates from the ZWC will increase.

WMC (2007) provided early time dewatering estimates of between 80 - 140 L/s for the ODX SPS mine dewatering model. These dewatering rates (WMC, 2007) are considered comparable to those provided by this model. REM (2007) also provided an analytical solution to dewatering and calculated long term inflow rates of approximately 14 L/s. The analytical solution resulted in radial drawdown contours extending 10 km from the mine under steady state conditions. The analytical model appears to underestimates the long term pit inflow and the predicted drawdown compared with this numerical model. HLA (2008) considered pit lake formation at ODX under post closure conditions. In this report HLA (2008) used a pit inflow rate of 40 L/s with an assumed 30 L/s reaching the pit lake. The inflow rates used in the pit lake assessment are comparable with the results predicted by this model.

Drawdown contours for the ZWC at the end of the construction period show localised areas of drawdown around the individual satellite wellfields and the open pit. The greatest drawdown (130 m) at the end of construction is in the MMIA wellfield. The groundwater levels in the MMIA wellfield are only at -90 mRL compared with water level contours of -120 mRL around the pit. A contour of 1 m drawdown at the end of construction is approximately 8 km from the SML boundary.

Drawdown at the end of mining (2050) is significantly more radial in response compared with the drawdown at end of construction. Maximum drawdown around the pit is 110 m and the 1 m contour has extended up to 10–15 km to the north of the SML (20 km north of the pit) and up to 20 km to the south (25 km south of the pit). The drawdown influence of the pit at the end of mining has overprinted the drawdown caused from the satellite wellfields during the construction period.

Post closure, the maximum drawdown at the pit has not increased, remaining at 110 m. However, the full extent of the drawdown has increased to quasi-steady state conditions with the 1 m drawdown contour extending up to 10–15 km to the north of the current SML (25 km north of the pit) and up to 40 km to the south (45 km south of the pit). In general, drawdown within the current SML has increased by up to 20 m in the ZWC. The localised drawdown generated from the satellite wellfields during the construction period have been completely overprinted post closure by the influence from the pit. Drawdown in the ZWC post closure exhibits a radial to sub-radial response which is limited to the north by observed lower permeability in the unit, and limited to the west by a thinning and removal of the ZWC.

8.2.2. ZAL Inflow

The base case predictive model produces a maximum modelled seepage rate of 990 m^3/d (11.5 L/s) from the ZAL to the pit during mining (2038–2050) (Figure 32). The inflow from the ZAL is at its highest from 2027–2050 and is attributable from the groundwater mound beneath the TSF and not from the RSF (see Section 8.2.4 for discussion on this). Seepage from the ZAL to the pit is predicted to reduce from 990 m^3/d to 0 m^3/d approximately 50 years post closure. Whilst, seepage from the ZAL reduces to 0 m^3/d post closure, the groundwater level contours in the ZAL still suggest drainage toward the pit. This drawdown is not occurring through direct discharge from the ZAL to the pit but by downward leakage from the ZAL to the ZWA and ZWC. This leakage through the ZWA is driven by the head of the overlying ZAL, the vertical hydraulic conductivity of the ZWA and the underlying head in the ZWC.

8.2.3. Saline Water Supply

The Motherwell wellfield has been designed for the ODX selection phase study and is based on a network of 11 wells pumping a total maximum capacity of 27.5 ML/d (2.5 ML/d per well). The wellfield extracts from the ZAL and is active during the construction period only.

Modelled pre-mine ZAL groundwater levels in the Motherwell wellfield are at 46–47 mRL. Drawdown at the end of the construction period from the Motherwell wellfield is shown in Figure 33 with 1 m maximum drawdown within the wellfield. Figure 33 also shows the location of wells used in the simulation of the Motherwell wellfield. Minimum groundwater level in the Motherwell wellfield at the end of construction is 44 mRL. At the end of mining in 2050, water levels in the Motherwell wellfield have recovered to pre-mine conditions. Post closure (2550) the groundwater level in the wellfield has declined slightly to 45–46 mRL (equivalent to a drawdown of less than 1 m). At post closure, the mine inflow dominates the groundwater level contours within the ZAL. A large capture zone is predicted that extends 5 km to the north of the SML and up to 20 km to the south-west of the SML. As per the satellite wellfields in the ZWC, the drawdown generated from the Motherwell wellfield during the construction period is overprinted post closure by the influence from the pit.

8.2.4. TSF and RSF Seepage

The estimated seepage from the ODX TSF is shown in Figure 34 and summarised in Table 8.2. A maximum seepage rate of 8,160 m^3/d was predicted during 2020. The historical model predicts the maximum head in the ZAL in the existing TSF and MWEP at approximately 63 mRL (compared with an observed maximum level of approximately 70 mRL). The predictive model shows a maximum groundwater level in the ZAL of 65 mRL during 2020 when the seepage rate is at the highest.

The groundwater mound beneath the TSF is predicted to rise by approximately 14 m by the end of the construction period. The mound is radial in nature and extends up to 2 km beyond the northern and southern SML boundaries and up to 7 km from the western boundary of the current SML. It is important to note that the ODX TSF footprint is constructed outside of the existing SML boundary. By the end of mining, the groundwater mound is only 10 m above pre-ODX water levels (due to a reduction in seepage rates after tailings cell commissioning). At 2050, the mound has extended spatially and is now modelled to be 4 km to the north of the SML and up to 10 km to the west of the existing SML. Post closure (2550), the mounding generated by the TSF is completely removed and drawdown (up to 10 m below pre-ODX water levels) is evident below the TSF. This post closure drawdown extends up to 6 km to the north of the SML and 10 km to the west of the SML.

Seepage from the 40 year RSF footprint was modelled at a 1% of rainfall recharge (280 m^3/d over 68,390,000 m^2) for the entire simulation (including post closure). This RSF seepage rate is significantly less than the seepage rate emanating from the TSF and accordingly there is very little response in the behaviour of the ZAL beneath the RSF. The RSF also fringes the pit and this has a greater impact on the water levels in this area. The ZAL is currently unsaturated beneath the proposed RSF footprint, with the development of the open cut; the extent of unsaturation within the ZAL is expected to increase. Therefore any infiltration from the RSF is likely to travel through the unsaturated ZAL, into the underlying ZWA. The ZWA is underdrained by the ZWC with groundwater discharging to the pit.

8.2.5. Particle Tracking

Particle tracking has been carried out using the base case predictive model to simulate the flow path that solute from the TSF and RSF would advance in the groundwater system (see Figures 25 and 28). The particles were set at, and outside of, the outer boundaries of the TSF and RSF. The particle movement was defined using a different symbol to represent the position of particles at a point in time. These time frames were defined at the end of mining, 100 years post closure, 500 years post closure and steady state. Tracking of these symbols shows that a particle that is placed directly into the top of the ZAL from the TSF or RSF at the start of the predictive model will not migrate far by the end of mining (cross), nor by 100 years post closure (square). Greatest particle movement is observed between 100–500 years post closure, where particles migrate between 500–1,500 m towards the open pit. At steady state, all particles at the boundary, and outside of the TSF and RSF, reach the pit. Therefore, even with dispersion of solute within the ZAL during mining, it is predicted that the inflow to the pit is sufficient to create drawdown and solute capture in the ZAL.

Back tracking of particles from the pit in the ZWC shows a radial capture zone of approximately 1,500 m over the predictive model scenario (up to 500 years post closure) whereby particles within that halo flow to the pit.

8.2.6. Receptors

Figures 29 to 31 show model generated water level hydrographs at a number of environmental and 3rd party receptors on the Stuart Shelf. These sites were mapped by Soil & Groundwater (2006) in a regional survey of groundwater users and springs and identified as a receptor by KBR (2008). The hydrographs show very minor drawdown at the receptors. Table 8.4 also shows a summary table of water level and flux changes predicted at the identified receptors.

Predicted drawdown at the 7 pastoral wells is less than 1 m in the base case model and this is considered insignificant in terms of the available drawdown for pumping at these wells (see Soil & Groundwater, 2006 for details of pumping setting depths for these wells). A 1 m drawdown is considered to be the limit of model prediction and accuracy given the regional scale of this model domain. Whilst the model predicts water level change in the order of centimetres, it is considered unrealistic to suggest accuracy below 1 m given the assumptions and uncertainty in model inputs.

The base case model predicts drawdown less than 1 m (0.14 m) at Yarra Wurta Spring 500 years post closure. The effect of this drawdown at the spring is outside the scope of this report however there are a number of things that should be considered regarding the accuracy of the model predictions at this location:

- The expected drawdown at this receptor is likely to be in a magnitude of centimetres rather than metres.
- Model nodes around Yarra Wurta Spring are spaced at a minimum of 800 m apart.
- The entire model domain is 200 km x 150 km x 1 km.
- The model assumes porous media flow. This is a necessary simplification of the real situation and is ideal for simulating large scale groundwater flow where large variations in groundwater level are expected. When small scale flows and groundwater level variations are considered this assumption will have greater effect on model predictions. In reality there are a great deal of geological and hydrogeological features (such as faults, fractures, lineations, voids, etc) that will modify the way groundwater flows on a local scale.
- There is no time variant calibration data between the ODX site and Yarra Wurta Spring and model hydraulic parameters are based primarily on best estimates in these areas and the steady state calibration (where observation data does exist).

Model outflow representing evaporative discharge from the Stuart Shelf towards the margin of the GAB does not change during the predictive simulation. This indicates that ODX will not drawdown water levels or reduce flow conditions at the GAB.

The impact assessment of water level change at these receptors has been addressed in a separate impact assessment report (SKM, 2008) and risk assessment (KBR, 2008) and is not discussed in this document.

Table 8.4 Summary of Water Level and Flux Change at the Identified Receptors

	Change in groundwater level (m)									Comment
	7 years			40 years			500 years			
	sensitivity range			sensitivity range			sensitivity range			
Receptor	**lower**	**basecase**	**upper**	**lower**	**basecase**	**upper**	**lower**	**basecase**	**upper**	
Yarra Wurta Spring	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.14	0.88	Potential risk of impact to Lake Eyre Hardy Head assuming a saline wellfield operates for 40 years and a high storativity value for ZAL is used in the numerical model.
Discharge from Stuart Shelf onto GAB margin (m^3/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	No potential for impact due to the presence of a low permeability hydraulic divide
Flow from Arckaringa Basin (m^3/d)	8.82	0.00	338.00	16.00	0.00	641.00	544.00	58.78	490.00	Arckaringa basin will contribute throughflow to the Stuart Shelf.
Coorlay Lagoon	0.00	0.00	0.04	0.23	0.30	0.83	3.29	3.83	8.58	Vegetation in Coorlay Lagoon is not supported by the regional groundwater system.
Bamboo swamp	0.00	0.00	0.00	0.00	0.02	0.21	0.12	0.19	1.36	Bamboo swamp is not supported by the regional groundwater system.
Comet Well, New Parakylia Bore, Southern Cross, Old Homestead	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.84	water levels fall <5% of the saturated well thickness over the long term (>40 years) and an impact to well production and sustainability are unlikely
Alex's Bore 2	0.00	0.00	0.05	0.00	0.00	0.32	0.05	0.07	2.01	
No. 1 Well	0.00	0.00	0.07	0.00	0.00	0.37	0.00	0.00	2.84	
Knoll Well 2	0.00	0.00	0.05	0.00	0.00	0.26	0.15	0.21	1.63	

potential for impact	low	moderate	high

8.3. Summary

The predictive model includes all the major groundwater effecting activities associated with ODX. Modelling shows that the major aquifers of the groundwater system (ZAL and ZWC) see the greatest change during mine development. This originates from the TSF and the open pit and is reflected in the groundwater observations at site, with the current TSF providing seepage to the ZAL and the underground mine draining (via raise bores) and abstracting groundwater from the ZWC.

During ODX mine operations, modelling shows that seepage from the TSF causes groundwater mounding in the ZAL, groundwater levels beneath the TSF are expected to increase to 65 mRL, similar to the present day groundwater levels observed beneath the current TSF. Mounding from the TSF will extend up to 4 to 10 km from the current SML boundary. Particle tracking carried out on the groundwater mound beneath the TSF shows that during mining, particle movement within the ZAL is minimal (less than 100 m) and that the transport of solute and seepage away from the pit is highly unlikely.

Seepage from the RSF is not considered to be a major concern in terms of changing the final flow conditions of the groundwater system during mining and post closure, with seepage equivalent to 1% of rainfall (20 times the modelled recharge rate for the ZAL). The ZAL beneath the RSF is predominantly unsaturated and mounding does not occur. Seepage from the RSF drains through the ZAL into the ZWA. The ZWA is underdrained by the ZWC so this water ends up being captured by the pit.

Inflow of groundwater to the pit will occur during mine development. This will require a dewatering and mine water management strategy. Inflows of up to 12,000 m^3/d (140 L/s) may occur during the early phases of mine development however additional work (long term pumping tests and re-calibration of this model) is required to refine these predictions. The predicted long term inflow rate to the pit from the ZWC is 3,500 m^3/d (40 L/s); this rate is consistent with predictions from earlier numerical and analytical models and is in line with estimates from a number of experienced hydrogeologists. The drawdown in the ZWC is modelled to extend some 10–40 km from the SML and up to 25–45 km from the pit.

The predicted long term inflow rate to the pit from the ZAL is 0 m^3/d, however during mining, particularly from 2027–2050, inflows of up to 1,000 m^3/d may be expected from these units especially when the groundwater mound from the TSF is at its largest and highest. Post closure, pit inflow from the ZAL decreases to 0 m^3/d as downward leakage increases under a higher hydraulic gradient from the ZAL, through the ZWA to the ZWC.

HLA (2008) demonstrate that the base case predictive model shows that the pit acts as an evaporative hydraulic sink, where all seepage or solute from TSF, RSF and any other groundwater effecting activities are captured by the pit either during mining or post closure. A radial to sub-radial drawdown response is predicted in the ZWC due to pit inflows, mine dewatering and the application of relative uniform K values.

Modelling also shows that any short term drawdown observed during the construction period from the saline wellfields (Motherwell and Satellite wellfields) is essentially overprinted post closure by downward drainage from the ZAL, and flow to the pit from the ZWC.

A water level change of less than 1 m is predicted at Yarra Wurta Spring after 500 years. Given that the entire model domain is 200 km x 150 km x 1 km in size, the model nodes at the spring are spaced about 800 m apart, the model assumes porous flow on a regional scale and there is no time variant data in the area for calibration, should be considered when assessing the level of accuracy in the model predictions at this location.

The model predicts no change in flow to the northern model margin with the GAB, therefore it is highly likely that ODX will not drawdown water levels or reduce flow conditions at the GAB.

9. Sensitivity Analysis

9.1. Introduction

A number of sensitivity analyses have been carried out on the base case predictive model for the Stuart Shelf groundwater system to address the uncertainty in hydraulic parameters, boundary conditions and management options. Sensitivities have been performed by changing key parameter values and considering the effect this change has on the model predictions. The sensitivities were carried out by making the relevant changes to the steady state model (except for changes to storage and pumping scenarios), the historical model and the predictive model and running them in succession. Table 9.1 shows a summary of the sensitivity analyses.

As discussed in Section 8.1, the base case model consisted of nine (9) individual models set-up to simulate various coincident activities of the ODX. To carry out sensitivity analyses using these nine individual models would have been a computationally demanding and time consuming process. In order to speed this process up, the nine models were condensed into a single model that used the 40 year pit shell (2050) as an initial and continuing boundary condition (seepage nodes) in the model.

The long term results of this single model were compared with the results from the series (9) of base case models, with almost identical results at post closure (2550). Given the comparable long term results, it was decided to use this single model representation during the sensitivity analyses where the quasi-steady state effects are more of concern than changes during the mining period.

Table 9.1 Summary of Sensitivity Analyses

Sensitivity	Description of Change
Low Storage in the ZAL	The Sc in slices 2, 3 and 4 was assigned to an equivalent S of 0.015
High Storage in the ZAL	The Sc in slices 2, 3 and 4 was assigned to an equivalent S of 0.075
Wellfield Scenario – No Motherwell	The Motherwell Wellfield was not active during the predictive model simulation
Wellfield Scenario – Position	The Motherwell wellfield was shifted to the south-west, further away from Yarra Wurta Spring
High K in the ZWC	Where Kh (Kv) in slice 7 was equal to 0.02 (0.002), this value was increased to 0.05 (0.005)
Increased Seepage from RSF	Seepage from the RSF was increased from 1% of rainfall recharge (281 m^3/d) to 5% of rainfall recharge (1,405 m^3/d)
Recharge (± 40%) – Steady State	The steady state model was run with increased then decreased recharge to the entire model domain.
Recharge (- 40%) – Transient	The predictive model was run with a decreased recharge component.
Change at GAB – change in K	The Kh and Kv of the Torrens Hinge Zone and Adelaide Geosyncline were increased from 1 x 10^{-10} m/s.
Constant Head – Constant Flux	The constant head nodes in slice 2 were replaced by well nodes injecting water into the model at a set rate determine during the steady state model calibration.
Constant Head – Reduced Heads	The constant head nodes in slice 2 were replaced by well nodes injecting water into the model however, the wells were injecting at a reduced rate.

9.2. Storage in the ZAL

9.2.1. Low Storage in the ZAL

This model sensitivity was run using a lower storativity in the ZAL (slices 2, 3 and 4). The base case model uses storativity of 0.05, this storage value is supported by short term pumping and injection test data. This model variant uses storativity of 0.015. This is considered to be at the lowest end of reasonable storage values. The result of this lower storage value is seen in both the ZAL and ZWC as measured drawdown. Drawdown in the ZAL post closure is greater than the base case model. The 1 m drawdown contour has extended out towards the model boundary in the west and toward the Lake Torrens in the east. Drawdown at

Yarra Wurta Spring is modelled at 0.51 m at 500 years post closure, 0.37 m greater than the base case model predictions. In general, drawdown is predicted over the majority of the ZAL after 500 years.

Drawdown in the ZWC has also increased considerably; in particular the 1 m contour extends further to the west toward the model boundary. The increased drawdown in the ZWC is interpreted through the following:

- The ZAL provides a constant head like condition to the ZWC.
- When the groundwater level in the ZWC is decreased this causes leakage through the ZWA from the ZAL.
- If the storage of the ZAL is lower than expected, the water drawn from the ZAL into the ZWA has to be sourced from further out causing a greater drawdown extent.

Based on the results of this model scenario, the model is deemed to be sensitive to changes in storage in the ZAL.

9.2.2. High Storage in the ZAL

This model variant was run with a higher storativity value of 0.075 (the base case is 0.05) within the ZAL. This is considered to be at the upper limit of reasonable values. As expected this sensitivity shows slightly less drawdown in the ZAL and ZWC. However, the change is not considered to be significant.

9.3. Wellfield Scenarios

9.3.1. Removal of Saline Water Supply Wellfield (Motherwell)

In order to assess specifically the effect of the Motherwell wellfield on the Yarra Wurta Spring receptor, the abstraction was removed completely from this run.

After 500 years, the drawdown within the ZWC is very similar to the base case predictive model. There is slightly less drawdown in the ZAL however the change is not significant. Based on the results of this sensitivity it is assessed that the drawdown produced from the Motherwell wellfield during the construction period is overprinted by the drawdown produced from the open pit post closure. That is, operation of the wellfield for the construction period does not result in significant change in water levels compared with a no wellfield model.

9.3.2. Motherwell Wellfield Location

In this sensitivity the Motherwell wellfield was relocated from the north of the mine to the north-west. The pumping regime of the wellfield remained the same with 11 wells pumping a maximum rate of 2.5 ML/d per well for a total extraction rate of 27.5 ML/d.

The impact of this change to the model set-up is deemed to be insignificant when comparing the post closure (2550) drawdown contours for both the ZAL and ZWC, the contour sets are very similar with no noticeable change. Given the very similar drawdown, it is assessed that the model is insensitive to changes to the wellfield position over the timeframe of reporting (that is 500 years).

9.4. High Hydraulic Conductivity of ZWC

Horizontal and vertical hydraulic conductivity of the ZWC (slice 7) was more than doubled from the base case for this sensitivity. The area over which this change occurs is essentially limited to 20 km surrounding the SML and the region to the south of the SML, beneath the Arcoona Plateau (Figure 3). Outside of this area, the ZWC is either not present or is observed to be of very low permeability.

This sensitivity modification has an effect on the drawdown contours within both the ZAL and ZWC when compared with the base case predictive model. The extent of drawdown in the ZWC, particularly in the south has increased as the model allows more water to discharge to the pit during mining and post closure. The rate of inflow to the pit post closure has increased from 3,500 m^3/d (base case) to 5,000 m^3/d. Drawdown to the south, in the vicinity of Coorlay Lagoon has almost doubled from 8 m (base case) to 15 m. Drawdown to the north and west has not extended much further than the base case model. This is due to the lower observed permeability to the north and the thinning and removal of the unit to the west.

The cone of depression in the ZAL has generally increased by up to 5 km, this is interpreted to be due to an increase in the downward drainage or leakage through the intervening ZWA, driven by an increased hydraulic gradient between the ZAL and ZWC below. Drawdown in the ZAL beneath the TSF and within the SML has only increased by 1 m. However, water level change at Yarra Wurta Spring is comparable to the base case model.

9.5. Increased seepage from the RSF (5%)

This model sensitivity applies a 5% rainfall recharge over the RSF footprint (compared to 1% in the base case transient model). This is equivalent to a rate of 1,405 m^3/d over the RSF footprint, compared with 281 m^3/d for the base case. This 5% of rainfall recharge is equivalent to 100 times the base case model recharge rate to the ZAL.

The amount and extent of predicted drawdown in the ZAL is reduced significantly in this model variant, in particular beneath the RSF footprint where the 1 m contour now extends below the RSF footprint. Previously in the base case model, the drawdown beneath the RSF was a minimum of 4 m.

During the steady state calibration and historical modelling, the ZAL and ZWA beneath the RSF are unsaturated or partially saturated. Therefore the groundwater levels and hence drawdown in the RSF footprint is expressed within the ZWA not the ZAL. Significant rewetting of the profile is therefore required after the construction of the RSF, as any seepage from the RSF is required to saturate both the ZWA and then the ZAL before mounding is evident in these units.

The base case model is conservative as it assumes that the full RSF footprint is present from the first day of ODX operations, this was done to simplify the modelling process and reduce the simulation times. Actual seepage volumes into the ZAL are likely to be less during the mine operation (2010–2050).

Particle tracking in the post closure sensitivity model shows that all seepage on the outer boundary of the RSF is captured by the pit during steady state. Particles outside of the RSF footprint are also captured by the pit during steady state. This result therefore negates the requirement for solute transport modelling to ascertain whether or not contaminants are intercepted by flow to the pit. With 5% recharge to the RSF footprint the capture zone for the pit is well outside the RSF footprint suggesting that an even higher recharge rate may be applied to the RSF before it impacts the flow condition in the post closure model. Furthermore, a recharge rate of 1% is considered to be representative of an arid environment and is 20 times higher than the natural background recharge rates.

9.6. Recharge (± 40%)

9.6.1. Introduction

Climatic modelling to assess the impacts of global warming (http://www.csiro.au/science/ps1f2.html) suggests variable changes to rainfall over the region. To capture the modelled variability in potential rainfall, sensitivity has been carried out on a large reduction to rainfall recharge. The total amount of recharge to the model area in the base case model is 3,248 m^3/d, a 40% reduction changes this to 2,320 m^3/d. A 40% reduction was an arbitrary value derived from CSIRO (http://www.csiro.au/science/ps1f2.html).

Low recharge model sensitivity was run in both the steady state and transient predictive models. In steady state the model is essentially incorrect and diverges away from the established calibration, however the purpose of this sensitivity is to assess the long term behaviour of the groundwater system to a lower recharge environment. The model has not been recalibrated because of this. What is unclear is the time it would take the model to equilibrate to these new conditions. The transient sensitivity is much more realistic in terms of the true impact from a lower recharge system. The transient model is also run using a 40% reduction in recharge to the base case rates.

9.6.2. Steady State

Table 10.1 compares the steady state flow rates at Yarra Wurta Spring and flow to the GAB in these two variants and the base case. As expected , the flows to Yarra Wurta Spring and the GAB decrease under the low recharge scenarios and increase under the high recharge scenarios. Flows from the constant head nodes representing the Boorthanna Formation change to compensate for the modification to the water balance.

Table 9.2 Comparison of Flow for the recharge sensitivity analysis

Area	Base Case (m^3/d)	Increased Recharge (m^3/d)	Decreased Recharge (m^3/d)
Flow to the GAB	43.05	57.35	28.72
Inflow from the Boorthanna	3,056	2,596	3,527

The base case steady state calibration produces a water level at Yarra Wurta Spring of 33.73 mRL compared with an observed survey level of 37.84 mRL. The steady state reduced recharge model shows a modelled level of 33.11 mRL, this is a 0.62 m reduction compared with a 0.14 m reduction in the base case predictive model after 500 years. The steady state increased recharge sensitivity model shows a modelled level of 34.33 mRL, this is a 0.60 m increase.

9.6.3. Transient

This transient sensitivity produces differences in both the ZAL and ZWC. Drawdown in the ZAL and in particular the 1 m drawdown contour has moved toward to the north and west away from the pit. This would be in response to a reduced hydraulic head on the ZAL and ZWC. Drawdown in the ZWC shows the most significant change when compared to the base case model. The 1 m drawdown contour in the ZWC has extended throughout the entire southern model domain and is in response to the reduction in recharge on the Arcoona Plateau. The 10 m drawdown contour for the ZWC does not appear to have moved compared with the base case model. Pit inflows from the ZWC are modelled post closure (500 years) at 3,390 m^3/d in this sensitivity, compared with 3,430 m^3/d modelled in the base case.

As per the previous section relating to a steady state reduction in recharge rates, the model and it's fluxes are sensitive to a lower recharge rates on the Stuart Shelf. However, the sensitivity also shows no further impact from mining due to changes in recharge.

9.7. Change at GAB – Increase K of Torrens Hinge Zone & Adelaide Geosyncline

Under this sensitivity analysis, the post closure predictive model was run to steady state conditions. Steady state flow to GAB under post closure conditions is 39.11 m^3/d as compared with the pre-mine steady state calibration flow of 43 m^3/d. During the steady state post closure sensitivity model the 4 constant head nodes representing the GAB are still letting water out of the model.

The steady state model was modified by gradually increasing the hydraulic conductivity of the areas representing the Adelaide Geosyncline and Torrens Hinge Zone until any of the 4 constant head nodes representing the GAB started to put water back into the model.

It was found that as the hydraulic conductivity (horizontal and vertical) of the Adelaide Geosyncline and Torrens Hinge Zone was increased, the flow discharging from the northern model margin and the 4 constant head nodes representing the GAB also increased. This increase in flow is due to the presence of the 60 mRL constant head nodes representing the Arckaringa Basin or Boorthanna Formation. These constant heads continually feed water into the model at a set elevation and hence any increase in hydraulic conductivity between the 60 mRL constant heads and the northern model margin and GAB will result in an increase in flow. Therefore discharge toward the northern model boundary and GAB is relatively insensitive to the K of the Adelaide Geosyncline and Torrens Hinge Zone but appears more dependent upon flow from the Boorthanna Formation.

A modelled high K zone has the effect of eliminating the groundwater divide that separates the ZAL and the northern margin with the GAB. Furthermore, this higher K attributed to the Torrens Hinge Zone and Adelaide Geosyncline does not match the conceptual hydrogeological model presented by Douglas & Howe (2007).

9.8. Sensitivity to Constant Heads

9.8.1. Declining Heads

The base case model assumes a 60 mRL constant head on the model boundary representing the Arckaringa Basin or Boorthanna Formation resulting in a flux of 3050 m^3/d. This sensitivity analysis assumes a decreased in fluxes (2,600 m^3/d) and hence hydraulic head, from the Arckaringa Basin due to wellfield extraction from the Prominent Hill Mine water supply. It is understood that Prominent Hill currently has a licence to abstract from the Boorthanna Formation for a 5 year period. However, it must be considered that this abstraction may continue for the LoM at Prominent Hill which is understood to be till 2030.

A comparison of drawdown contours in the ZAL and ZWC shows a very similar response (if not identical) between the base case and the sensitivity analysis. The only change appears to be over at the model margin itself where heads in the ZAL have dropped by up to 2 m. The rest of the model area is not affected.

Given the similar drawdown between the base case model and this sensitivity, it is postulated that the model is insensitive to changes in boundary conditions over the timeframe of reporting (that is 500 years).

9.8.2. Constant Flux

In this sensitivity the constant head nodes assigned to the Arckaringa Basin boundary in slice 2 of the model were changed to well nodes injecting water into the model at a set rate (3,056 m^3/d) rather than a constant head (60 mRL). This was done so that if a change in head resulted from mine activities, the flux into the model would remain constant.

A comparison of drawdown for the ZAL and ZWC aquifers show very similar responses (if not identical) between the base case and the sensitivity analysis. Given the similar drawdown between the base case model and this sensitivity, it is postulated that the model is insensitive to changes in boundary conditions over the timeframe of reporting (that is 500 years). This is consistent with the previous model sensitivity (Section 9.8.1).

9.9. Summary

In summary the sensitivity analyses show that the base case predictive model is more sensitive to a reduction in storativity in the ZAL. However, even with a reduction in storage in the ZAL, the water level change at Yarra Wurta Spring is still less than 1 m after 500 years post closure. Whilst changes to model recharge rates show increased drawdown at post closure, there is no additional impact from mining because of this. The degree of uncertainty with climate modelling is high and the predictions on changes rainfall distribution and intensity are highly variable.

Increased seepage from the RSF causes modification to the water level and drawdown contours beneath the RSF footprint however particle tracking indicates that solute is still captured by the pit under steady state conditions. A high K scenario in the ZWC has the effect of allowing greater seepage to the pit. As a consequence, increased drawdown is observed in the ZWC and also the ZAL. The increased drawdown in the ZAL is due to increased leakage through the ZWA under an increased gradient.

The model appears insensitive to changes to the Motherwell wellfield location and also a model scenario that does not include the Motherwell wellfield. The model is also insensitive to variations to the boundary condition representing inflow from the Boorthanna Formation. Constant flux and reduced flux sensitivities have insignificant change when compared with the base case predictive model.

Sensitivity analyses on the hydraulic conductivity assigned to the Torrens Hinge Zone and Adelaide Geosyncline shows that the diffuse discharge to the northern model boundary toward the GAB is dependent upon inflow from the western model boundary representing the Boorthanna Formation. A reduction in K, increases discharge to the northern model boundary, eliminates the groundwater divide that occurs between the Stuart Shelf and the GAB and results in a groundwater regime that is incorrect when compared with the conceptual hydrogeological model.

10. Assumptions and Uncertainty

BHP Billiton has high confidence in several areas of this model development, these are:

- Stratigraphy and geological interpretation particularly around the mine area and SML. This information is generally of high quality and interpretations are considered reliable.
- Groundwater level data both for steady state and transient calibrations particularly around the mine and current SML. This information has been collected since the start of mining and a recent baseline survey of the Stuart Shelf has provided a dependable starting point for model calibration. The available groundwater data is growing considerably as part of ODX and a number of drilling programs are planned in order to collect additional data and bridge identified gaps in knowledge.

There are several areas of uncertainty associated with the Stuart Shelf hydrogeology, these are:

- Hydraulic properties of the ZWA to the south of OD on the Arcoona Plateau. The steady state calibration shows that this area provides the greatest steady state model inaccuracy. Very little information exists in this area and further investigation may be carried out on available mineral exploration holes to obtain hydraulic data.
- Transient behaviour of the ZAL to the north of the SML. A 12 month MAR injection trial is planned and will provide a greater understanding on the behaviour of the ZAL under an injection regime (to commence late 2008). This injection will be carried out in accordance with strict licensing guidelines, conditions and monitoring imposed by the EPA.
- Stratigraphic and water level data to the far north and west of OD. This data gap will be addressed through additional drilling to establish geological and hydrogeological data on the northern and western extent of the ZAL. This will also provide an increased number of water level observations in this area (in progress);
- Abstraction rates used for the historical calibration of the ZWC. A trial depressurisation will provide an excellent understanding on the hydraulic behaviour of the mine area geology in response to longer term pumping. This trial is due to commence in late 2008 and will be coupled with the MAR injection test and GAB water minimisation strategy.
- Seepage rates used for the transient calibration of the ZAL. The seepage rates used in this model will be revisited and possibly remodelled using the latest monitoring and TSF data. A strict water balance and monitoring program will be carried out during the trial depressurisation and MAR injection test to look at seepage rates from the new MWEP.

Further to this data gaps, model uncertainty will be addressed in the future by updating and re-calibrating this numerical groundwater flow model against long term monitoring data and new hydraulic data points. This modelling will be carried out under the DPS for the ODX and will look in detail at pit dewatering requirements and saline water supply from a number of wellfields.

10.1. Conservatism

The Stuart Shelf numerical groundwater flow model assumes porous flow media. Whilst this assumption is fine for regional scale, long term impact prediction it is not likely to be the most accurate representation of the system at ODX. It is highly likely that structures such as faults or lineaments will impact (retard) groundwater flow as mining progresses and the extent of drawdown increases. However, to predict the location of these structures is considered virtually impossible without a close spaced drill program which is not feasible over such an area.

The Stuart Shelf model simulates hydraulic continuity between the mine area and Yarra Wurta Spring. Whilst the exact position is debateable, the Torrens Fault (a regional structure) is known to exist between Yarra Wurta Spring and the mine area. It is unknown whether this structure is associated with vertical displacement, increased hydraulic conductivity or decreased hydraulic conductivity. Providing hydraulic conditions along or around this structure are different to those assumed in the model domain, the drawdown effect at Yarra Wurta Spring is likely to be significantly less than predicted by the numerical model.

Furthermore, water chemistry at Yarra Wurta Spring suggests that the spring is fed by groundwater flow from the northern Flinders Ranges, to the north-east of the spring rather than from the main flow field to the west in the ZAL. The model could have been better calibrated in this region by including a low permeability barrier in the ZAL to increase flow to the spring from the north-east. However, the model has been developed so that the spring discharges water that originates from the main flow field within the ZAL receiving flow from the Arckaringa Basin. This key assumption is considered to be a worst case scenario.

11. Summary

The Stuart Shelf regional numerical groundwater flow model was constructed using FEFLOW, a finite element modelling code. The model uses Lake Torrens as the eastern extent, and Lake Windabout, Island Lagoon, Lake Hart and Lake Younghusband, south of Woomera and the Arcoona Plateau, as the southern boundary. The western boundary follows the regional catchment divide, outside the outcrop and sub-crop extent of the major Stuart Shelf aquifers. There are 54,000 elements and 31,221 nodes in the 9 model slices which covers an area of 26,000 km^2.

Hydraulic parameters for the model were based initially upon values used in previous groundwater flow models. These values were varied slightly in certain areas to match known parameter values from recent drilling or to match anecdotal evidence.

The steady state model has been successfully calibrated and is considered acceptable given the scale of the model and uncertainty and knowledge of regional and localised hydrogeology. The steady state model has been developed to represent groundwater conditions prior to mine development at OD (i.e. prior to 1983). The transient calibration successfully simulates the historical groundwater response at OD from 1983 through to 2007. Groundwater is known to respond to seepage to the ZAL from the TSF and MWEP, and to abstraction from the ZAL and ZWC through production well abstraction, underground development and raise bores.

This numerical model is considered to be a good representation of the latest conceptual hydrogeological model that has been developed since the start of the ODX in 2006.

The predictive model simulates groundwater behaviour (from 2007 through to 2550) in relation to a number of mining and groundwater effecting activities, including:

- Discharge from the ODX (July 2008) pit shells from 2011 through to 2050;
- RSF (40 year footprint) with a constant 1% of rainfall recharge seepage;
- Seepage from the ODX TSF footprint;
- Trial depressurisation and active dewatering from the ZWC;
- Abstraction from the SPS ZAL saline water (Motherwell) wellfield;
- Abstraction from the SPS satellite wellfields;
- Continuation of underground mining and operation of the raise bores coincident with the open cut.

Predictive modelling shows that seepage from the TSF causes groundwater mounding in the ZAL with groundwater levels beneath the TSF predicted to be similar to the groundwater levels observed beneath the current TSF. Mounding from the TSF will extend up to 4 to 10 km from the current SML boundary. Particle tracking carried out on the groundwater mound beneath the TSF shows that the transport of solute and seepage away from the pit is highly unlikely.

Seepage from the RSF does not change the behaviour of the groundwater system during mining and post closure. The ZAL beneath the RSF is predominantly unsaturated and mounding does not occur. Seepage from the RSF drains through the ZAL into the ZWA which is underdrained by the ZWC and captured by the pit.

Inflows to the pit will occur during mine development which will require a dewatering and mine water management strategy. Inflows of up to 12,000 m^3/d may occur during the early phases of mine development however additional work (long term pumping tests and re-calibration of this model) is required during the DPS to confirm these rates. The predicted long term inflow rate to the pit from the ZWC is 3,500 m^3/d (40 L/s). The drawdown in the ZWC is modelled to extend some 10–40 km from the SML and up to 15–45 km from the pit. The pit acts as an evaporative hydraulic sink, where all seepage or solute from TSF, RSF and any other groundwater effecting activities are captured by the pit during mining or post closure.

The predicted long term inflow rate to the pit from the ZAL is 0 m^3/d, however during mining, particularly from 2027–2050, inflows of up to 1,000 m^3/d may be expected from these units especially when the groundwater mound from the TSF is at its largest and highest. Post closure, pit inflow from the ZAL decreases to 0 m^3/d as downward drainage or leakage increases under a higher hydraulic gradient from the ZAL, through the ZWA to the ZWC.

Modelling shows that any short term drawdown observed during the construction period from the saline wellfields (Motherwell and Satellite wellfields) is overprinted post closure by downward drainage from the ZAL, and flow to the pit from the ZWC.

Sensitivity analyses show that the base case predictive model is sensitive to recharge rates, increased seepage from the RSF, low storage in the ZAL, high K in the ZWC and longer term pumping from the Motherwell wellfield. The model appears insensitive to any changes to boundary conditions representing the Boorthanna Formation and the position of the Motherwell wellfield. Sensitivity analysis on discharge to the northern model boundary indicates that it is more dependent upon inflow from the Boorthanna Formation.

Appendices

Appendix 1 – Douglas & Howe (2007)

Conceptual Hydrogeological Model of South Australia's Stuart Shelf for Assessment of the Olympic Dam Mine Expansion

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Abstract

The geological Stuart Shelf has not previously been the focus of detailed investigations into regional-scale groundwater processes and interactions. This is primarily due to a lack of demand on the region's groundwater resources, with the typically saline to hypersaline water quality a contributing factor. With the proposed expansion of the Olympic Dam Cu-U-Au-Ag mine, there is a need to develop this knowledge so that potential 'environmental' effects associated with proposed open pit mining and possible saline water supply development can be adequately assessed. This paper presents the results of a comprehensive investigation of regional groundwater conditions (drilling, aquifer testing and hydrogeochemistry), and forms the basis for developing a comprehensive conceptual hydrogeological model of the Stuart Shelf, including the interaction between regional groundwater systems and groundwater and surface systems.

Important developments in the conceptual understanding of the hydrogeology of the Stuart Shelf are: i) the artesian Eromanga Basin (GAB) groundwater water flow system is considered to be hydraulically separate from the non-artesian 'Stuart Shelf' groundwater flow system; ii) recharge to the non-artesian 'Stuart Shelf' groundwater system occurs via diffuse rainfall recharge as well as groundwater throughflow from other groundwater systems to the west of Olympic Dam, particularly the Arckaringa Basin; iii) groundwater flow in the Stuart Shelf is dominated by the highly transmissive Andamooka Limestone aquifer to the north, and the fractured rock Tent Hill aquifer to the south; and iv) groundwater flow converges and discharges to the Lake Torrens groundwater system, resulting in evaporative concentration of salts and salinity stratification near and beneath the Lake. Salinity stratification within the groundwater system in the area of Lake Torrens is likely to causes regional groundwater to discharge predominantly into the shallower lake sediments under density gradients resulting in the development of the Yarrawurta spring complex.

1. INTRODUCTION

The Olympic Dam (OD) Cu-U-Au-Ag mine is located in South Australia's Far North, within the Stuart Shelf geological province (Figure 1). Because a secure and sustainable supply of water for OD mining and processing operations is currently sourced from wellfields that draw water from aquifers of the Great Artesian Basin (GAB), there has been little need to develop large supplies from 'local' hard rock saline aquifers. However, in response to a planned expansion of the OD mining operation, detailed groundwater investigations have been undertaken to provide a better basis for understanding how the regional groundwater system will respond to proposed open cut mining activities during operations and post closure, and to assess the potential for developing saline groundwater supplies from saline fractured rock aquifers near to OD. Although proposed mining activities are unlikely to have an impact on adjoining groundwater systems such as the GAB due to controls imposed by the geological structure, an improved conceptual understanding of Stuart Shelf groundwater processes is necessary to identify potential risks posed to groundwater quality and flow by an expanded mining operation, including risk posed to Yarrawurta Springs, a spring complex located at the northern end of Lake Torrens that supports refuge populations of the Lake Eyre Hardy Head fish.

An improved conceptual hydrogeological model of the Stuart Shelf has been developed in order to understand groundwater recharge and discharge mechanisms and water supply potential, and to establish the hydraulic relationship between the Stuart Shelf groundwater system and bounding groundwater systems such as the GAB (to the north), Arckaringa Basin (to the west) and Torrens Basin (to the east). A total of 34 monitoring and test wells were drilled to maximum depths of 650 m to characterise regional groundwater conditions. These wells supplement the existing groundwater monitoring network that has been established on the OD Special Mining Lease (SML).

The Stuart Shelf groundwater system supports low discharge saline springs along the western margin of Lake Torrens. Groundwater use for irrigation or stock watering is limited due to poor quality (salinity concentrations are typically greater than 30,000 mg/L TDS), but brackish aquifers are known to occur to the northwest in association with non-artesian Eromanga Basin sediments that are often limited in extent and depth.

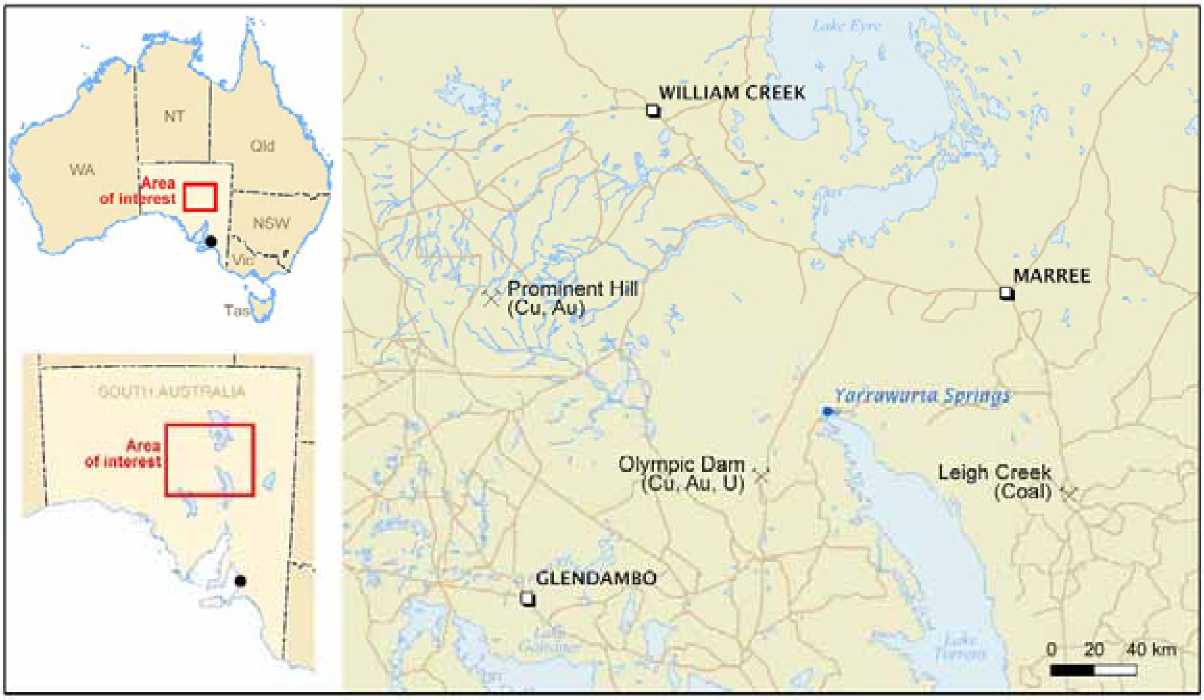

Figure 1 – Locality plan for OD and the broader study area

2. REGIONAL GEOLOGICAL SETTING

The Neoproterozoic sedimentary rock sequence of the Stuart Shelf and Adelaide Geosyncline geological provinces are separated by the Torrens Fault and the Torrens Hinge Zone (a zone of approximately parallel synclinal and anticlinal structures), which are aligned along the north–south axis of Lake Torrens and then strike to the north-west, running between OD and Lake Eyre through to and beyond the Peake-Denison Inliers (Figure 2).

Stuart Shelf rock formations, comprising the Tent Hill Formation (a sequence of shales, sandstones and quartzites) and the Andamooka Limestone (dolomitic limestones), are much thinner and less deformed than their Adelaide Geosyncline equivalents. The Stuart Shelf rock sequence is underlain by Proterozoic crystalline and sedimentary basement rocks of the Gawler Craton, such as the Pandurra Formation and the Olympic Dam Breccia Complex.

Three important sedimentary basins occur adjacent to and, in some cases, overlie Stuart Shelf and Adelaide Geosyncline rocks. These basins are also shown in Figure 2 and include the:

i) Permian Arckaringa Basin, located to the west of OD, which is a suite of sandstones, siltstones, diamictite and, north of the Boorthanna Fault, coal formations;
ii) Mesozoic Eromanga Basin, which is the largest of three sedimentary basins that comprise the GAB. It is comprised of the Algebuckina Formation, Cadna-owie Formation and Bulldog Shale but in the area around OD only the Bulldog Shale occurs as remnants; and
iii) Torrens Basin, which lies predominantly to the east of the Torrens Fault and is a large synclinal structure of folded Adelaide Geosyncline rocks infilled with Tertiary sediments to depths of about 300 m.

Figure 3 presents block diagrams showing the stratigraphic relationship between the various geological units described above and presented in Figure 2, as well as important geological structures. The most significant structural features of the broader study area are the Torrens and Norwest Faults, which bound the Adelaide Geosyncline; the Boorthanna Fault, which marks the northern limit of relatively shallow occurrences of the Boorthanna Formation (a sandstone and diamictite sequence of the Arckaringa Basin); and the Billa Kalina Fault, which essentially marks the eastern extent of the Arckaringa Basin. Of interest, Yarrawurta Springs is located on the eastern side of the Torrens Fault (and this is supported by drilling investigations near the springs that show Adelaide Geosyncline rocks underlie the northern end of Lake Torrens).

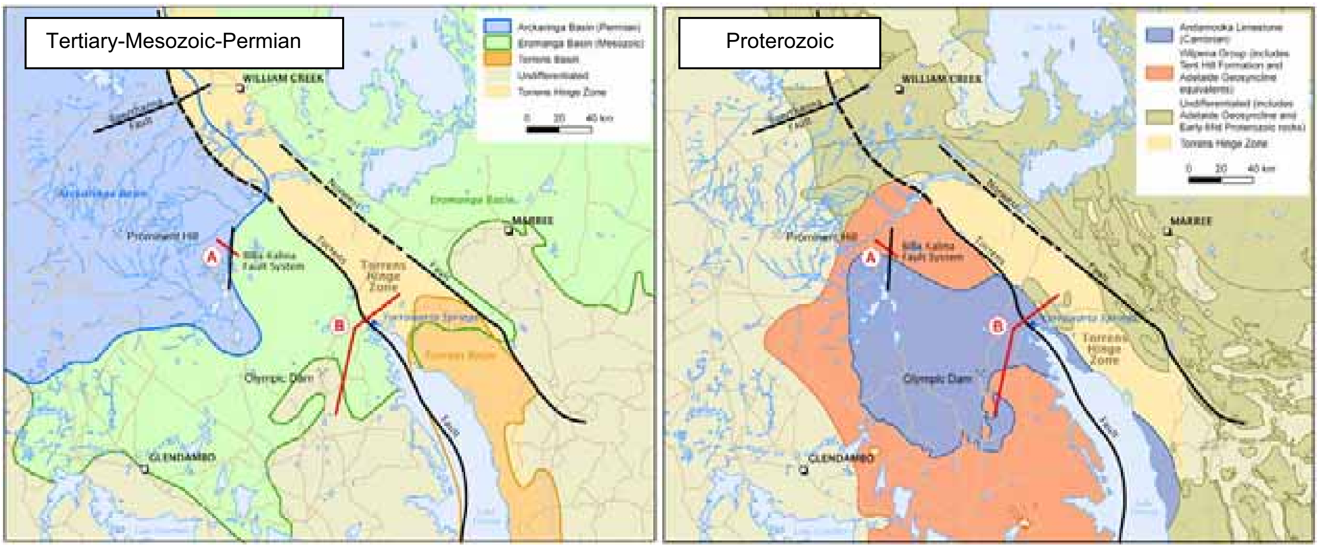

Figure 2 –Regional geological setting

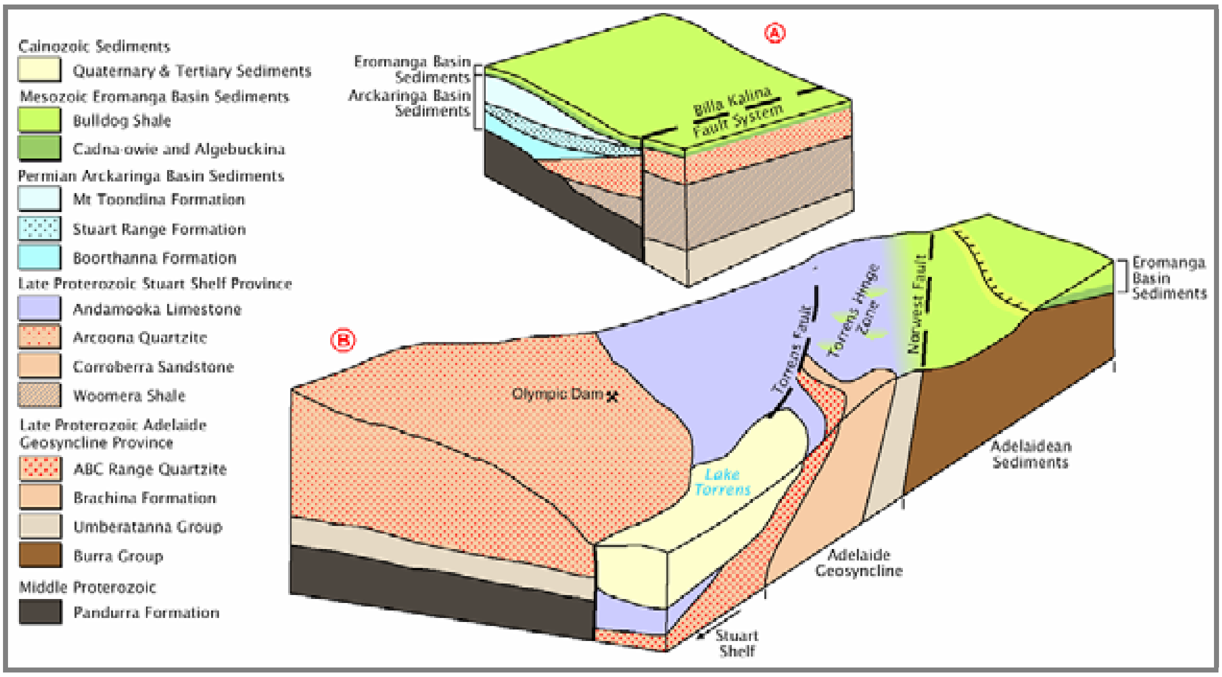

Figure 3 – Major structural features and geology of the Stuart Shelf and environs

3. REGIONAL HYDROGEOLOGICAL SETTING

3.1. Hydrostratigraphy of the Stuart Shelf

A summary of the hydrostratigraphy for the Stuart Shelf and broader study area is presented in Table 1. In summary, the hydrostratigraphy of the Stuart Shelf west of the Torrens Fault is quite uniform and, in most cases, is consistent with the regional stratigraphy described above (Section 2).

The shallowest sedimentary rocks of the Stuart Shelf are the most important aquifers around OD. The Andamooka Limestone is the regional water table aquifer comprising a dolomitic limestone having significantly developed karst (airlift yields of up to 60 L/s have been reported). The Tent Hill aquifer (typically comprising the Corraberra Sandstone and the lower part of the Arcoona Quartzite) is a fractured rock water table aquifer to the south of OD. To the north of OD, the Tent Hill aquifer is confined by the Yarloo Shale, which separates the Andamooka Limestone and Tent Hill Formation.

Table 1 – Hydrostratigraphic units of the Stuart Shelf (oldest to youngest)

Unit	Description
Basement rocks	
Various	Typically the crystalline basement rocks of the region form saline / hypersaline aquifers only where fractured. This is also the case for sedimentary basement rocks, although primary porosity-associated permeability exists (eg. Pandurra Formation).
Stuart Shelf (& Adelaide Geosyncline equivalents)	
Tent Hill aquifer	Corraberra Sandstone and lower Arcoona Quartzite units. Moderate permeability aquifer with variable degree of secondary porosity. Can be high yielding in association with major structures. Typically hypersaline, with brines beneath and adjacent to Lake Torrens. There is no real equivalent Adelaide Geosyncline aquifer.
Tent Hill aquitard	Upper Arcoona Quartzite unit. Low permeability but leaky aquitard confining the underlying Tent Hill aquifer. Can yield water where significant secondary porosity is induced by fracturing. Equivalent to the ABC Range Quartzite.
Yarloo Shale	Low permeability unit overlying Tent Hill aquitard north of OD.
Andamooka aquifer	Regional water table aquifer with significant transmissivity at the regional scale, associated with karst and (possibly fracture) related secondary porosity. Becomes confined by Yarra Wurta and Bulldog Shale to the north. Typically hypersaline, with brines sitting at the base beneath and adjacent to Lake Torrens.
Arckaringa Basin	
Boorthanna aquifer	Extensive regional-scale aquifer, typically occurring as several zones within the Boorthana Formation, separated by significant thicknesses of low permeability sediments, especially in the eastern parts of the Basin where thicker and deeper intersections occur. Moderate permeability. Likely to form a water table aquifer west of OD, but is confined by the Stuart Range aquitard to the northwest.
Stuart Range aquitard	Significant low permeability aquitard, where present northwest of OD, that separates the Boorthanna aquifer from overlying aquifers of either the Arckaringa or Eromanga Basins. Where present, the lower silty sediments of the Mount Toondina Formation are also contained within this hydrostratigraphic unit.
Mount Toondina aquifer	Shallow sandstones and carbonate sequences form an aquifer. Variable degree of hydraulic connection with shallower GAB aquifers exists. [5]
Eromanga Basin	
Eromanga aquifer	Sandy aquifers occurring extensively throughout northern South Australia. About 100 km north of OD, these aquifers are commonly artesian. West and northwest of OD, water table aquifers and non-artesian aquifers overlie Arckaringa Basin sediments. Commonly referred to as the GAB aquifers but this term is considered misleading because they are not always artesian. Groundwater salinity ranges from <2000 mg/L (artesian Eromanga aquifer) to brackish / saline (non-artesian Eromanga aquifer).
Bulldog Shale aquitard	Mudstone unit with some silty and sandy intervals. Can be a confining unit to the Eromanga aquifer, and may contain laterally discontinuous perched aquifers.
Tertiary & Quaternary	
Various	Tertiary palaeochannel aquifers are common in the Gawler Craton, although none has been mapped in the immediate area of OD. The Torrens Basin holds the most important Tertiary and Quaternary aquifers in the immediate study area, but these are poorly studied. Tertiary aquifer groundwater salinity is typically hypersaline. Quaternary aquifer groundwater salinity is expected to be variable, being brackish near recharge and hypersaline within Lake Torrens.

The Andamooka Limestone aquifer (ALA) covers an area of approximately 14,500 km^2, extending from about 50 and 80 km south and northwest of OD, respectively, to around 35 km north of the top of Lake Torrens (Figure 2). The aquifer gently dips and thickens to the north-northeast of OD (up to a maximum of 160 m at the northern end of Lake Torrens). The underlying Tent Hill aquifer (THA) also dips and thickens to the northeast of OD, although the lower permeable sections of the aquifer (Corraberra Sandstone) reduce in thickness and degree of fracturing.

3.2. Groundwater occurrence and flow

The water table aquifer typically occurs at depths of greater than 50 m in the vicinity of OD and shallows to depths of less than 10 m in areas having low topographic relief, eg. near the edges of Lake Torrens and at the southwesterly extent of the artesian Eromanga (GAB) aquifers to the north and northwest of OD. This is consistent with these areas being the major regional groundwater discharge features (Waterhouse et al, 2002). Groundwater flows from the west and south converging towards the northern end of Lake Torrens and towards the GAB (Figure 4) to discharge via evaporation. Groundwater hydraulic gradients are relatively flat north of OD where the ALA is extensive. The very flat hydraulic gradients indicate either evaporative losses from the aquifer, which is unlikely due to the depth at which groundwater occurs, or relatively high aquifer transmissivity, which is supported by high airlift yields (ranging up to 60 L/s) and significant saturated thicknesses typically reported during drilling in this region. Figure 5 shows the saturated thickness of the ALA at drill site RT-1 to be in the order of 200 m, compared to less than 20 m at site PT-24, and an airlift yield of 10 L/s.

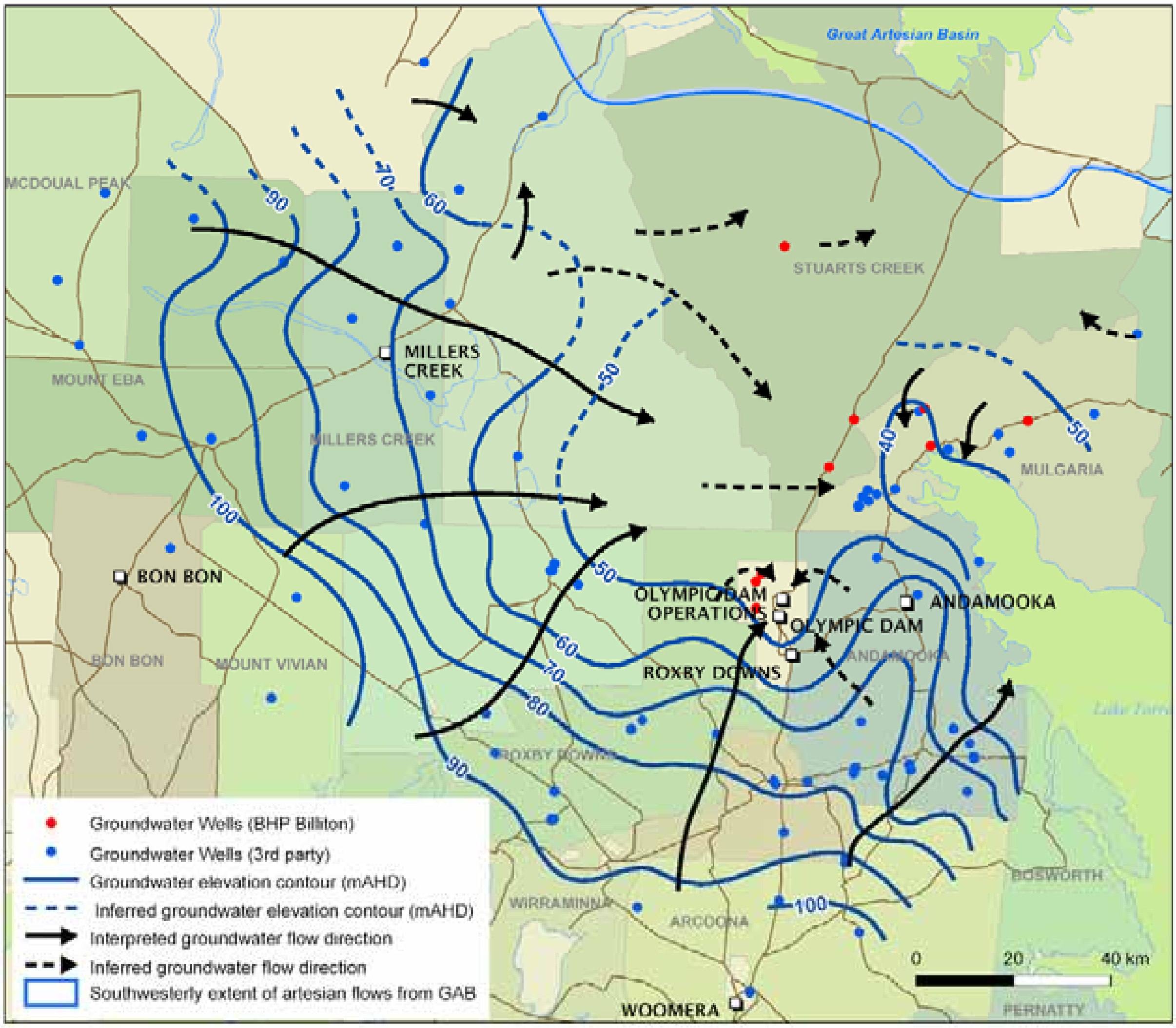

Figure 4 – Interpreted groundwater elevation contours and flow directions

The extent and saturated thickness of the ALA south of OD is variable, because the base of the Andamooka Limestone rises above present day water table elevations in some areas (see flow logs presented for drill sites PT-24 and PT-5d, Figure 5). Permeability within the ALA is secondary in nature, being associated with fracturing and dissolution of the limestone matrix. Karst is typically associated with collapsed and open dolines, as well as dissolution along bedding planes. Figure 5 shows that higher groundwater yields are typically encountered in the ALA at depths of 10 or more metres below the water table, and that, at drill site RT-1, the aquifer is confined (by the Bulldog Shale, the youngest member of the Eromanga Basin suite of sediments). Analysis of test pumping data using published solutions provides estimates of ALA transmissivity and storativity: (i) north of OD ranging up to 4000 m^2/day and 0.005 to 0.1, respectively; and (ii) in the area of the SML of less than around 50 m^2/day and 0.001, respectively.

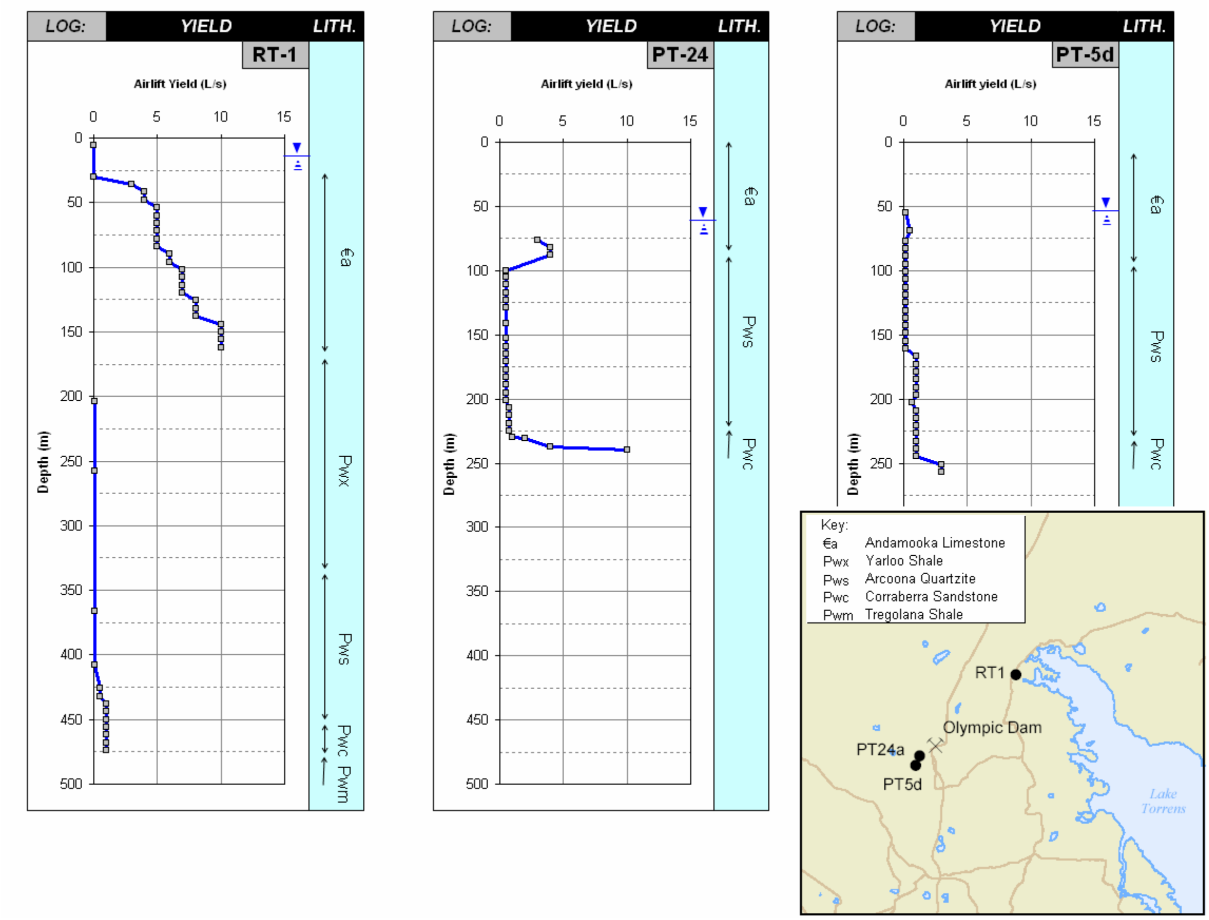

Figure 5 – Airlift yield profiles and lithological logs for selected drilling sites

The Tent Hill fractured rock aquifer (THA) is the most important aquifer over the southern portion of the Stuart Shelf, where it can underlie a thin saturated sequence (less than 20 m) of Andamooka Limestone or form the regional water table aquifer. Airlift yields during drilling typically range between 3 and 20 L/s and are consistently highest in the lower (confined) Corraberra Sandstone unit where a higher density of fracturing and fissuring is apparent. However, a high degree of anisotropy is evident in the collected hydraulic testing data, where enhanced permeability (by at least an order of magnitude) known to occur in fault zones. Groundwater flow is largely fracture-controlled, however primary porosity contributes useful degrees of permeability, possibly as a result of chemical weathering of the sandstone matrix. North of OD, however, where the THA occurs at depths of up to 400 m, the aquifer becomes noticeably less permeable (airlift yields of less than 1 L/s are typical; see flow log for RT-1, Figure 5), possibly as a result of compressional effects on the aquifer skeleton.

Connectivity between the THA and the ALA is primarily constrained by the vertical permeability (K_v) of the upper part of the Arcoona Quartzite. Analysis of pumping test data shows that K_v can be an order of magnitude lower than the horizontal permeability (K_h), or less. The saturated thickness of the THA is variable, although the Corraberra Sandstone ranges around 20 m in thickness, secondary porosity development in the lower Arcoona Quartzite can range from a few to tens of metres. The comparison of airlift yield profiles and lithology presented in Figure 5 shows permeability associated only with the deeper and confined Corraberra Sandstone (PT-24), and due to fracturing through a greater thickness of the Tent Hill Formation (PT-5d).

The increase in yield is often consistent with an increase in groundwater salinity (refer Figure 6).

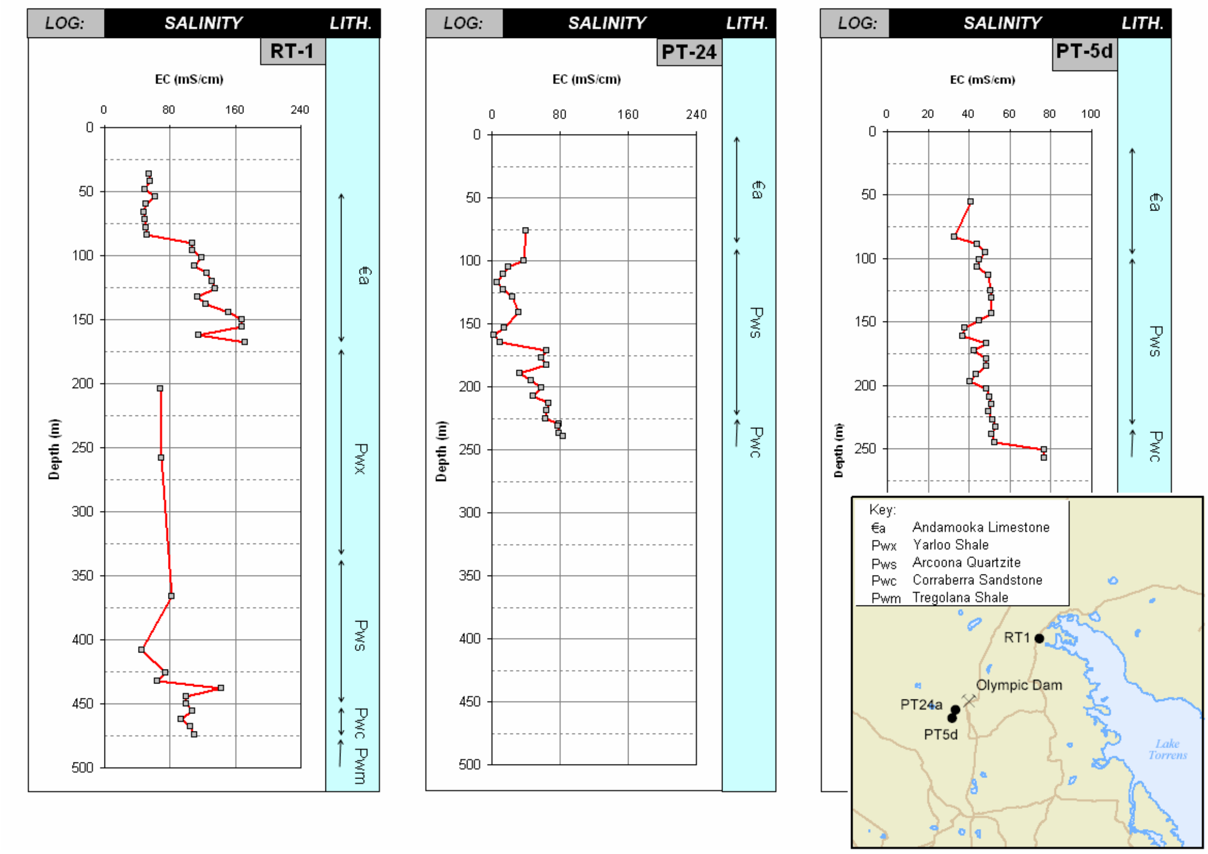

Figure 6 Groundwater salinity profiles and lithological logs for selected drilling sites

Pumping yields are proportional to the extent of brittle fracturing, and pumping rates of between 3 L/s and 16 L/s can be sustained from 200 mm DN cased production wells on this basis. Pumping test data have been analysed using published solutions. The results have been used to constrain analytical modelling (ref. Clarke) of the pumping tests to assist in developing conceptual aquifer models of the THA (Figure 7), and assessing aquifer anisotropy. The results of the analytical modeling show that:

- Where fracturing is well developed, the response to pumping is consistent with what might be expected of a semi-bounded leaky strip aquifer having transmissivities of up to 900 m^2/day (see results for well TPW-1, Figure 7).

- Away from structurally controlled fractured rock 'strip' aquifers, the THA responds to pumping in a manner more consistent with a leaky confined, semi-bounded uniform porous media (see results for wells TPW-2 and 3, Figure 7). TPW-2 test data (Figure 7) shows the presence of a significant recharge boundary (fracture) very close to the pumping well.

The estimated permeability of the THA, (having a semi-bounded, leaky confined response to pumping) can be more than an order of magnitude less than where a fractured rock 'strip' response occurs, and pumping yields can be more than half.

Monitoring data from nested monitoring sites at OD and within the northern and eastern part of the Stuart Shelf indicate upward groundwater gradients exist from the Corraberra Sandstone to the Andamooka Limestone. The extent of leakage between the THA and ALA in the vicinity of OD are dependent on the extent and degree of geological structural control. Further north, the effective hydraulic connectivity between the ALA and the THA is likely to reduce due to the increased distribution of the Yarloo Shale and a lowering of permeability in the Tent Hill aquifer.

Density-corrected groundwater level data for nested monitoring sites on the OD SML and north of OD (near Lake Torrens) indicate downward hydraulic gradients between the ALA and THA (potentially due to mine dewatering activities), however, closer to Lake Torrens, these gradients are reversed with head potentials in deeper parts of the groundwater systems being above ground level, which is around 40 mRL (Table 2). This is consistent with salinity data collected during drilling investigations that indicate brine formation near the base of the ALA nearer to Lake Torrens (see RT-1, Figure 6). The effect of these density gradients near Lake Torrens is that groundwater moving from the west of Lake Torrens will be forced to discharge into Lake Torrens sediments at relatively shallow depths.

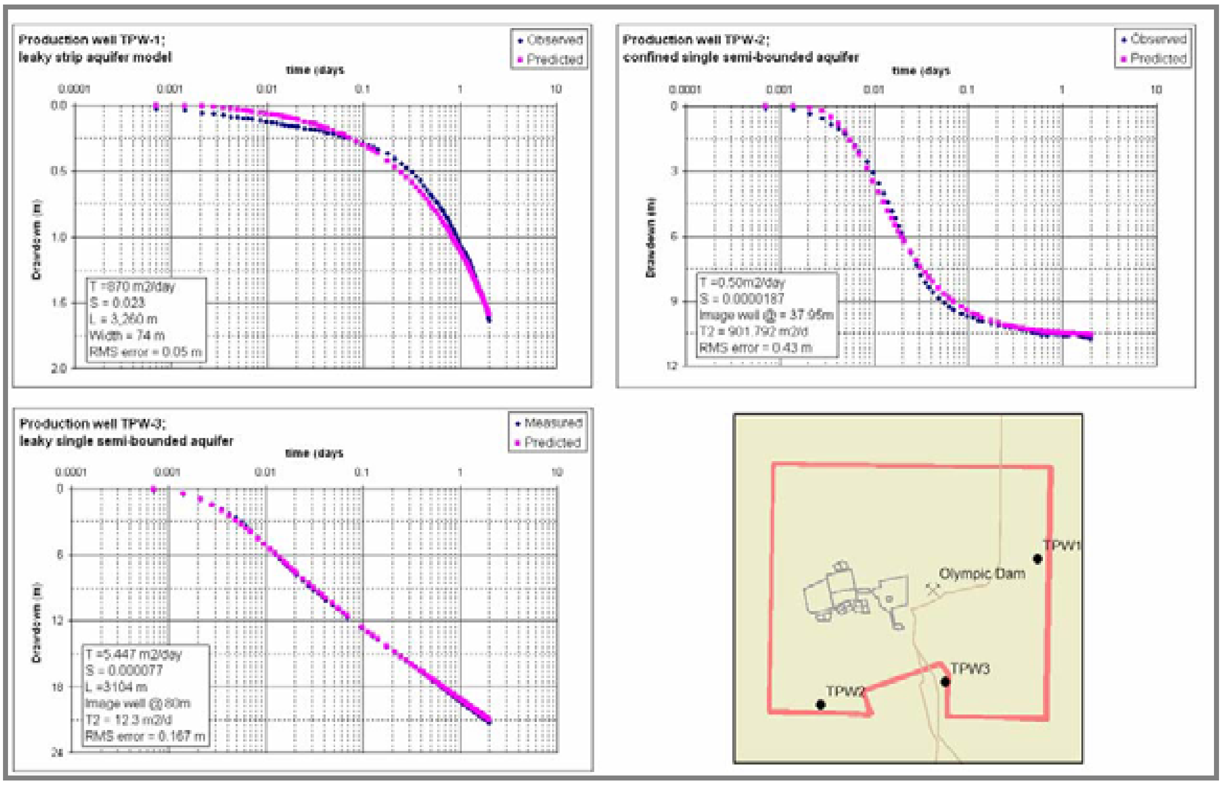

Figure 7 – Groundwater flow models developed from test pumping the Tent Hill aquifer

Table 2 – Density corrected groundwater levels [1]

Investigations site	RT-1[3]		RT-2[3]		RT-16[4]		RT-17[4]	
Well name	**LR-10**	**RT-1**	**RT-2a**	**RT-2b**	**RT-16a**	**RT-16b**	**RT-17b**	**RT-17b**
Screen mid-point [2]	17.3	-424.0	-21.0	-110.1	-37.4	-101.6	29.6	-140.1
Water level [2]	38.5	102.5	40.4	47.0	43.5	36.6	49.1	35.9

Notes: 1. source: REM (2007a) 2. mRL, rounded to nearest 0.1 m
3. located north of OD 4. located in the vicinity of OD

3.3. Recharge and Discharge Mechanisms

Rainfall recharge (0.1 mm/yr; Kellett et al, 1999, and Waterhouse, 2002) is very low by comparison with rainfall (more than 150 mm/yr) as a result of large evaporative losses prior to recharge occurring. Plant transpiration will also contribute to these 'evaporative' losses, but to what extent is uncertain.

While very low rates of diffuse recharge occur across the Stuart Shelf and broader region, enhanced rates of recharge are likely to occur at terminal lakes that lie above the water table and possibly via dolines formed in the Andamooka Limestone. Salinity profiles (Figure 6) support the assumption of diffuse recharge.

The groundwater catchment for the Stuart Shelf Groundwater Flow System (GFS) extends south to the Stuart Highway and west to the geological Arckaringa Basin (Figure 2). Although, water table gradients across the Stuart Shelf are very shallow (Figure 4), large volumes of water can be expected to be moving through the Stuart Shelf ALA due to its very high transmissivity (REM, 2007a). Figure 4 shows the groundwater flow field across the Stuart Shelf is contributed to by other groundwater systems occurring further 'upstream' of Lake Torrens (Howe et al, 2008), and that Lake Torrens and (possibly) low lying areas north of OD along the margin with the artesian GAB form groundwater sinks via evaporative losses. These other contributing groundwater systems include the Arckaringa Basin and possibly the non-artesian Eromanga aquifers (Figure 2).

Figure 8 presents a conceptual model of groundwater discharge processes in the broader study area, and draws on data presented in Figure 4. Yarrawurta Springs is shown to be located within a groundwater flow field originating from the east (i.e. from Adelaide Geosyncline 'aquifers').

A preliminary water balance calculation (assuming ALA transmissivity of 4,000 m^2/day and thickness of 100 m, and a hydraulic gradient of 0.001) suggests that about 0.4 m^3/day groundwater discharges to the Lake Torrens groundwater basin per metre width of the discharge zone. Aquifers to the east of Lake Torrens, including those formed within Adelaide Geosyncline rocks and Torrens Basin sediments, are likely to contribute a significant discharge flux to the Lake Torrens groundwater system, possibly supporting shallow saline springs around the northern and eastern margin of the Lake (eg. Yarrawurta Springs). Groundwater discharging to the Lake Torrens Basin is accommodated by diffuse evaporative discharge (Golder, 1995) or possibly via through flow to groundwater systems in the south.

3.4. Hydrogeochemistry

Regional groundwater is saline to hypersaline, typically ranging from 20,000 to 80,000 mg/L around the SML, increasing to over 200,000 mg/L near the margins of Lake Torrens and at depths below 200 m in the lower sections of the ALA north of OD.

Major ion data for sampled groundwaters (sourced from wells screening Stuart Shelf, Arckaringa Basin and Eromanga Basin aquifers) are presented as a Piper diagram in Figure 9. The data shows that Stuart Shelf, Arckaringa Basin and non-artesian Eromanga Basin aquifers (west of OD) report similar hydrogeochemical signatures and are distinct from groundwater quality from artesian Eromanga Basin (GAB) wells (Howe et al, 2008), suggesting: (i) Stuart Shelf, Arckaringa Basin and non-artesian Eromanga Basin groundwater possibly share a similar source (consistent with groundwater data presented as Figure 4); and (ii) these groundwater systems are not connected to the GAB.

4. CONCEPTUAL HYDROGEOLOGICAL MODEL OF THE STUART SHELF REGION

To place the proposed expansion of OD into context, an understanding of the interactions between groundwater systems, and groundwater and surface water systems is required at a regional-scale. Based on the information presented above (drawn from comprehensive drilling and groundwater testing programs), Figure 10 describes the essential elements of the regional conceptual hydrogeological model, importantly: (i) a subtle groundwater divide separates the Stuart Shelf GFS and GAB GFS; (ii) evaporative loss of shallow groundwater is an important groundwater discharge process for both GFSs, causing salinisation of shallow and deep soil profiles and groundwater; and (iii) spring discharges supported by flow from the eastern seaboard are also a loss mechanism for the GAB GFS, but these springs are not supported by Stuart Shelf groundwater.

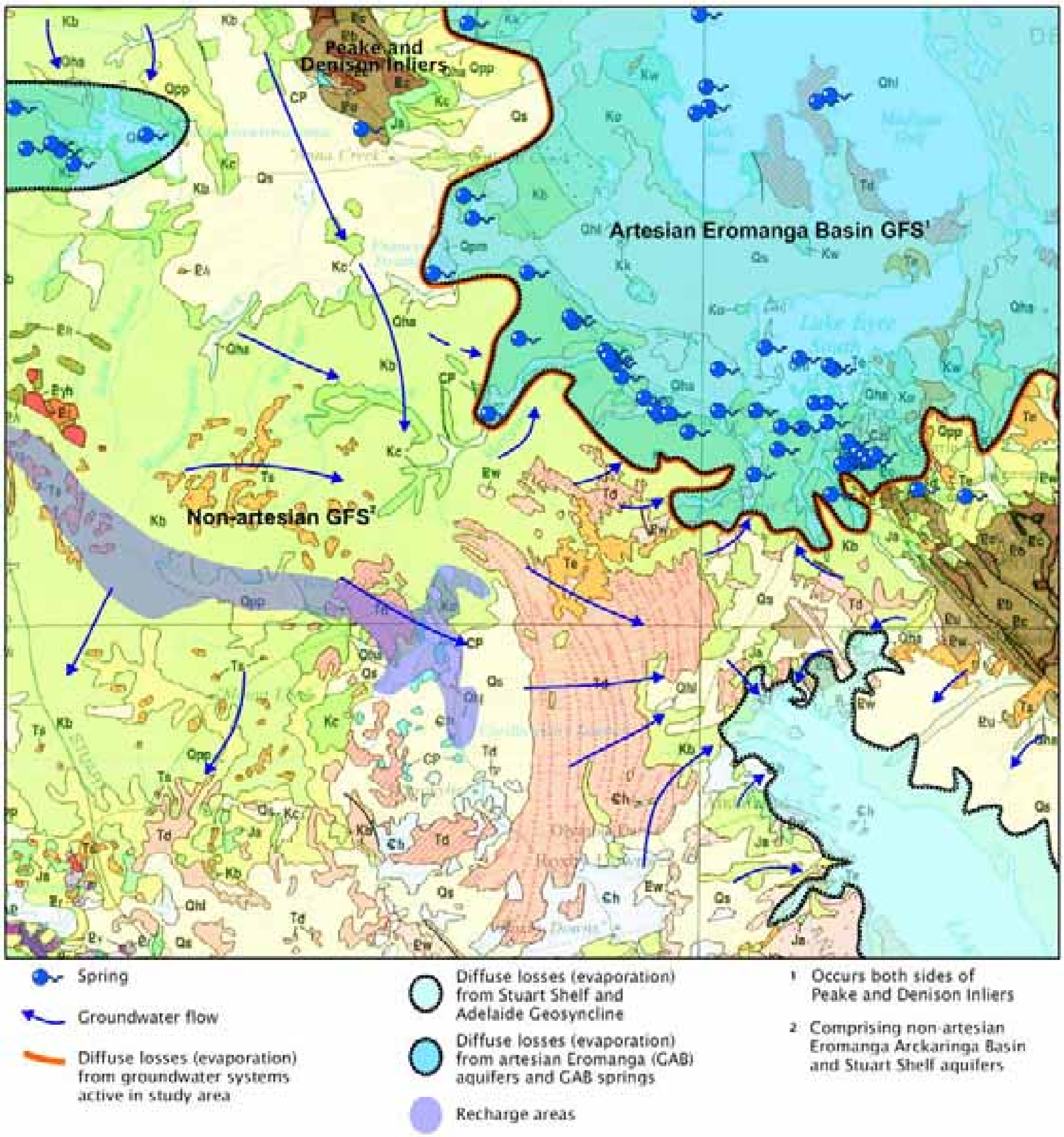

Figure 8 – Recharge and diffuse groundwater discharge in the northern Stuart Shelf

The artesian Eromanga Basin (GAB) GFS is recharged along the Great Dividing Range of Australia's eastern seaboard and around the Northern Territory-South Australian border (Habermehl, 1980), both of which are located outside the area presented in Figure 8. Groundwater moves from the recharge areas to converge on the southwestern extent of the artesian Eromanga Basin, to discharge either via GAB springs or as diffuse evaporative losses from low lying areas (Figures 8 and 10 present this concept).

The non-artesian 'Stuart Shelf' GFS receives diffuse rainfall recharge as well as groundwater throughflow from other groundwater systems to the west of OD, particularly the Arckaringa Basin, where groundwater probably moves from northwest of the Peake-Dennison Inliers along structural corridors (troughs and faults) to merge with groundwater moving from further west (Howe et al, 2008). Some watercourses and freshwater swamps (creek floodouts) form important recharge areas, as shown on Figure 8, which also shows likely groundwater discharge to the southwest of the broader region via Tertiary palaeochannels.

Discussion from here relates to the non-artesian 'Stuart Shelf' GFS. The artesian Eromanga Basin (GAB) GFS is considered hydraulically separate from the non-artesian 'Stuart Shelf' GFS, supported by groundwater level and hydrogeochemical data as well as the presence of geological and structural controls. As a result the GAB GFS does not warrant further discussion in relation to the proposed expansion of OD.

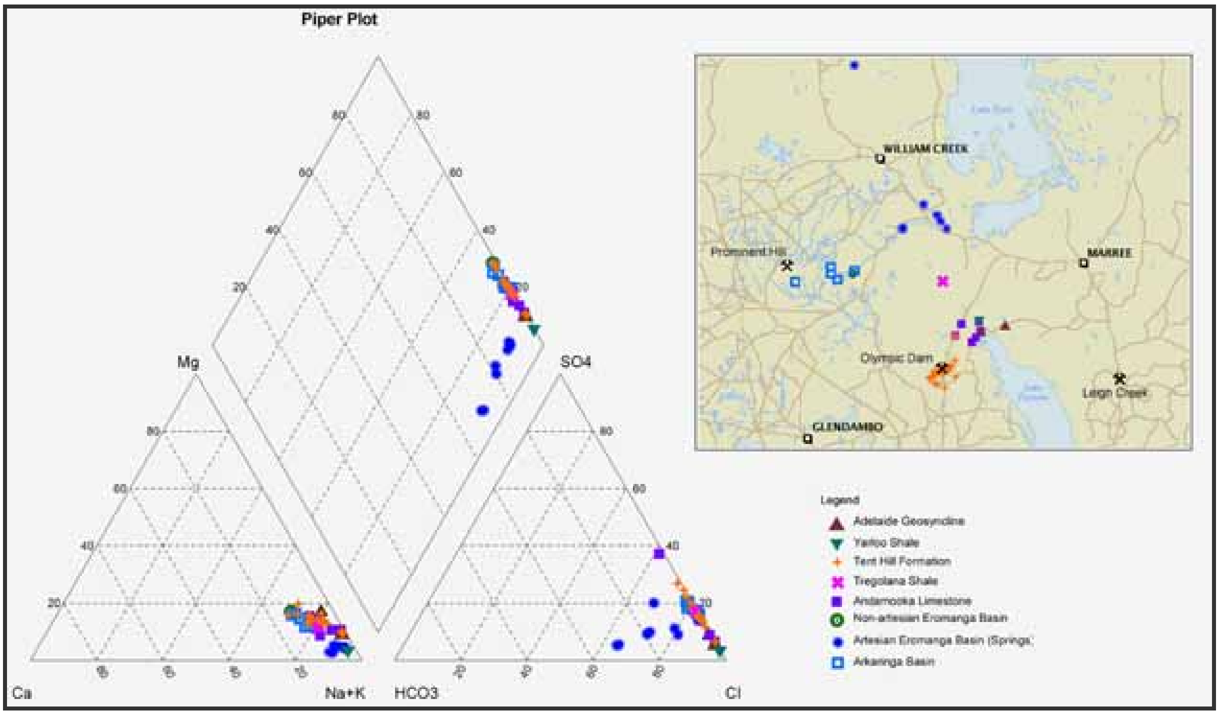

Figure 9 – Piper Plot for Stuart Shelf aquifers and surrounding groundwater systems

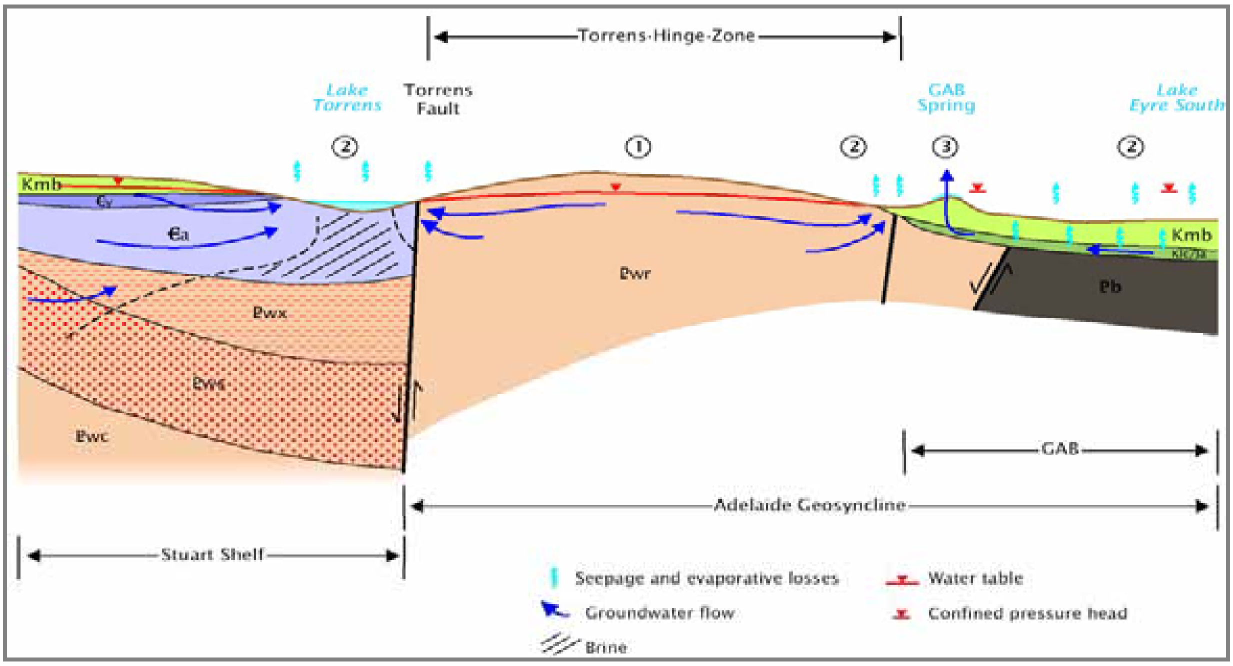

Figure 10 – Conceptual model of Stuart Shelf and artesian Eromanga Basin GFSs.

Groundwater flow in the Stuart Shelf is dominated by the ALA to the north and the THA to the south. ALA permeability and yield is largely associated with karst features, while THA permeability is largely associated with brittle fracturing. A significant increase in groundwater salinity occurs in the ALA to the north of OD at depths below 200 m, and at depth beneath the SML in the THA. Aquifer connectivity between the ALA and the underlying THA is dependent upon the degree of leakage induced from vertical faulting and vertical flow gradients, and to the north of OD due to the presence of intervening confining shales.

Surface water catchments of the study area typically terminate at large salt lakes, salt pans and 'swamps', and surface water outflow from these catchments does not normally occur. Evaporative losses from low-lying salt lakes and shallow water tables form the greater component of water losses from the study area. Lake Torrens is one of the more important groundwater 'sinks' of the broader region (Figure 10 presents this concept), as well as a surface water 'sink' at those times when rainfall is sufficient to generate significant run-off into the Lake, principally from the Flinders Ranges. The evaporative discharge of water from Lake Torrens has caused groundwater that occurs within the very thick lake sediments to become concentrated in salts, as evidenced by the salinity stratification observed near and beneath Lake Torrens (REM, 2007a), which probably causes regional groundwater flowing toward Lake Torrens to discharge predominantly into the shallower lake sediments under density gradients.

Groundwater outflow from the Stuart Shelf / Torrens Basin groundwater system is not expected to form a large component of the regional water budget, if at all. Digital elevation models of the region between the southern tip of Lake Torrens and Port Augusta suggest groundwater might discharge along structural corridors or palaeochannel aquifers extending through to Gulf St Vincent (REM, 2007b).

Because of the density stratification of groundwater beneath Lake Torrens, it is considered very unlikely that Tent Hill aquifer groundwater supports Yarrawurta Springs. However, it is possible that shallow groundwater moving from Adelaide Geosyncline rocks toward Lake Torrens supports some or all of the springs' environmental flows. ALA waters may also contribute to these flows.

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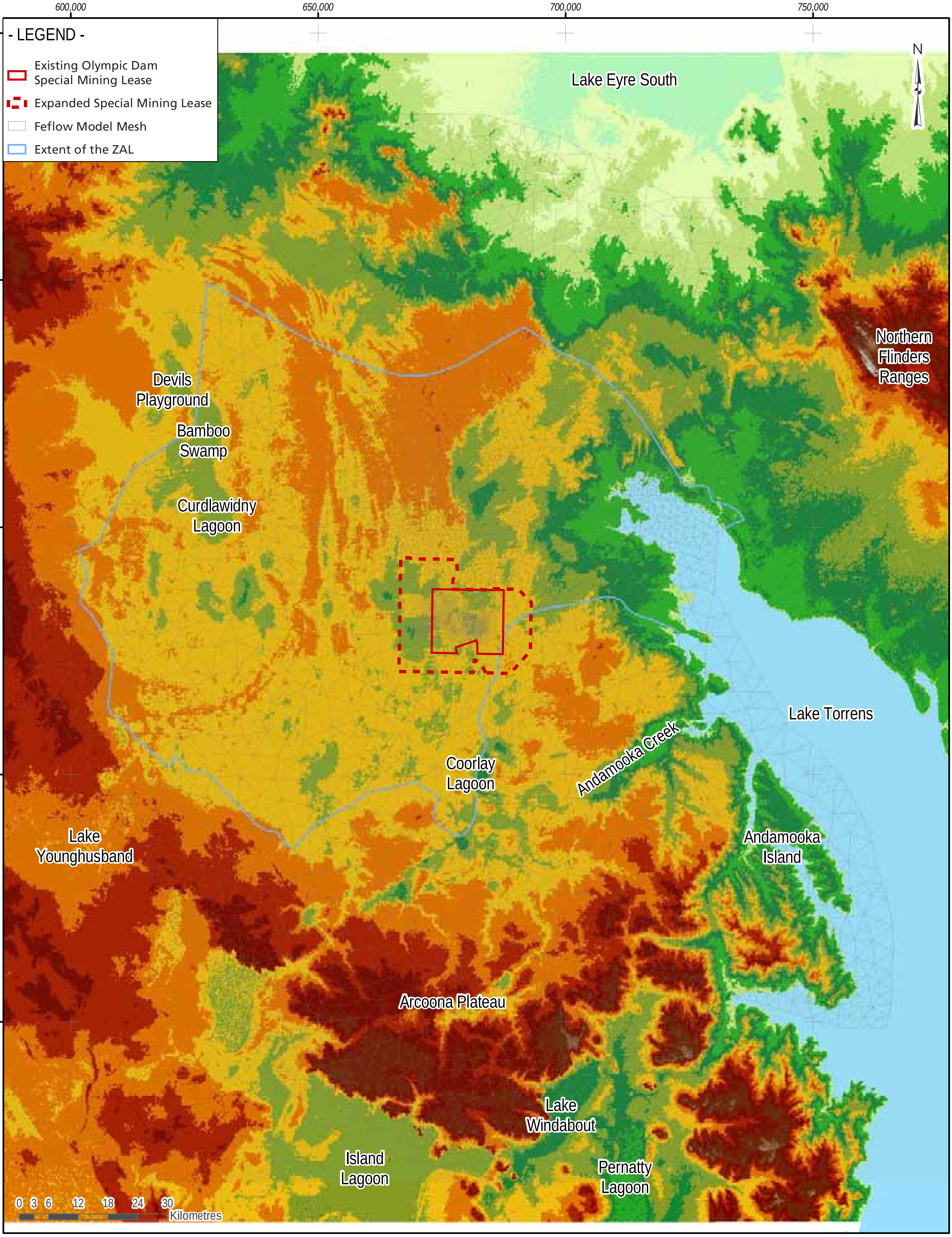
Appendix 2 – Steady State Groundwater Observations

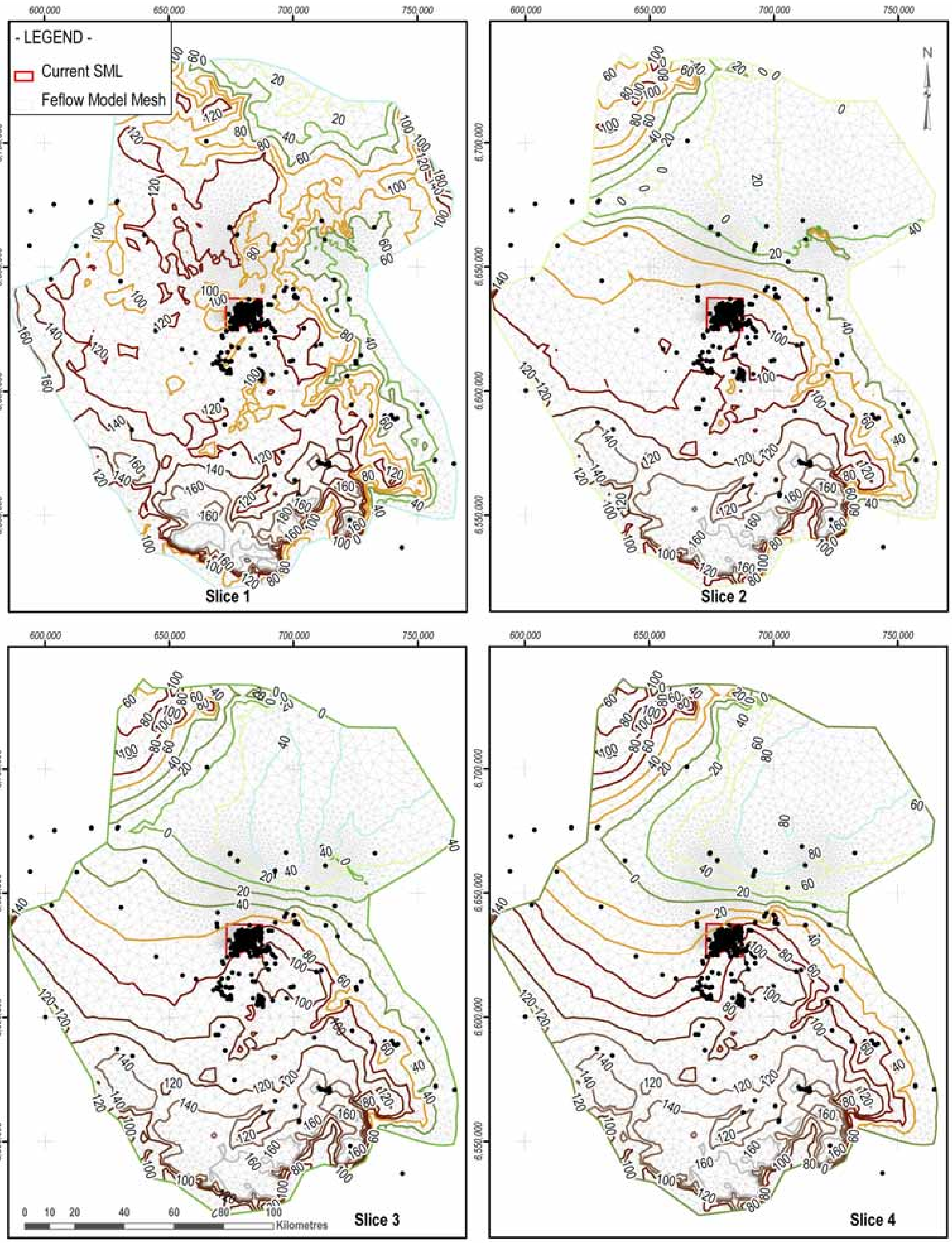
Well	Easting	Northing	Slice	Unit	Model_ID	Observed Head (mRL)
Apollo Bore	755246	6684084	1	Hinge	Obs 1	86.73
Census Dam Spring	728997	6659842	1	Hinge	Obs 2	39.38
Rocky Creek Spring	726670	6663338	1	Hinge	Obs 3	38.54
RT-5c	712713	6661127	1	Hinge	Obs 4	29.79
RT-9	682696	6702115	1	Hinge	Obs 5	42.69
Sister Well	746376	6667481	1	Hinge	Obs 6	57.46
RT-7a	732710	6666104	1	Pfa	Obs 7	51.98
RT-7b	732710	6666104	1	Pfa	Obs 8	46.50
19 Mile Bore	608852	6644932	2	ZAL	Obs 9	69.26
Bambridge Well	653451	6604383	2	ZAL	Obs 10	71.82
Curdlawidny Well	627888	6659000	2	ZAL	Obs 11	53.63
LR1	675631	6636422	2	ZAL	Obs 12	47.77
LR10	705533	6652117	2	ZAL	Obs 13	37.69
LR11	701711	6651123	2	ZAL	Obs 14	40.33
LR2	685788	6637306	2	ZAL	Obs 15	45.45
LR4	691261	6628948	2	ZAL	Obs 16	42.56
LR5	683005	6618220	2	ZAL	Obs 17	52.38
LR6	681278	6617067	2	ZAL	Obs 18	51.95
LR7	682022	6617637	2	ZAL	Obs 19	51.79
LR8	678841	6641778	2	ZAL	Obs 20	42.88
LR9	668483	6624887	2	ZAL	Obs 21	47.86
LT14	677039	6628629	2	ZAL	Obs 22	48.09
LT19	672989	6630470	2	ZAL	Obs 23	48.40
MAR1	686082	6645061	2	ZAL	Obs 24	43.24
MAR3	691905	6656771	2	ZAL	Obs 25	42.31
MAR4	689954	6650868	2	ZAL	Obs 26	42.76
MS4	700009	6649691	2	ZAL	Obs 27	38.80
MSWB	697823	6648561	2	ZAL	Obs 28	40.44
MSWB 2	699893	6651955	2	ZAL	Obs 29	40.44
New Parakylia Bore	634733	6635361	2	ZAL	Obs 30	53.07
North Dam Bore	701765	6638000	2	ZAL	Obs 31	55.30
Old Homestead Well	635432	6636758	2	ZAL	Obs 32	51.17
PT-24a	676819	6627756	2	ZAL	Obs 33	48.54
PT-40	699594	6672967	2	ZAL	Obs 34	27.81
PT-42	690624	6663940	2	ZAL	Obs 35	43.45
PT-44	684972	6657514	2	ZAL	Obs 36	39.17
PT-45	681922	6653391	2	ZAL	Obs 37	43.17
PT-48	685471	6673126	2	ZAL	Obs 38	44.63

Well	Easting	Northing	Slice	Unit	Model_ID	Observed Head (mRL)
PT-50	680065	6665665	2	ZAL	Obs 39	38.42
PT-51	679082	6659712	2	ZAL	Obs 40	42.64
PT-60	691178	6674079	2	ZAL	Obs 41	43.92
PT-66	696951	6666399	2	ZAL	Obs 42	27.30
Red Lake bore	640271	6632422	2	ZAL	Obs 43	52.43
RT-3	696948	6666399	2	ZAL	Obs 44	40.02
RT-4a	711500	6668734	2	ZAL	Obs 45	39.65
RT-5a	712725	6661144	2	ZAL	Obs 46	39.25
RT-5b	712713	6661127	2	ZAL	Obs 47	26.74
Sister Well 2	651173	6602599	2	ZAL	Obs 48	71.07
TOD2	669130	6637822	2	ZAL	Obs 49	45.00
WMC Bore	722665	6637239	2	ZAL	Obs 50	32.49
WP1	698789	6650554	2	ZAL	Obs 51	40.48
Yarra Wurta East Springs 1	716364	6660489	2	ZAL	Obs 52	37.37
Yarra Wurta Spring	715490	6660890	2	ZAL	Obs 53	37.84
Yarra Wurta Well	710294	6668066	2	ZAL	Obs 54	40.92
RT-4b	711497	6668745	5	Yarloo	Obs 55	33.20
AD8	702130	6557972	6	ZWA	Obs 56	99.00
Alex's Bore 2	623339	6597790	6	ZWA	Obs 57	94.63
Arcoona Clave Well	621477	6605710	6	ZWA	Obs 58	91.45
ASW1	700730	6564172	6	ZWA	Obs 59	86.00
Boundary Well	635241	6584243	6	ZWA	Obs 60	93.58
Centenary Well	720839	6599755	6	ZWA	Obs 61	59.29
Chances Well 2	668823	6601717	6	ZWA	Obs 62	78.29
Coorlay Well	687491	6591897	6	ZWA	Obs 63	79.39
Engine Well	698068	6560786	6	ZWA	Obs 64	119.45
Flowing Bore Spring	717427	6602732	6	ZWA	Obs 65	52.91
Horse Well	695155	6575031	6	ZWA	Obs 66	99.06
HRD2	690389	6627222	6	ZWA	Obs 67	45.00
IDD2	741930	6589272	6	ZWA	Obs 68	29.00
Knoll Well 2	635445	6590040	6	ZWA	Obs 69	94.15
Miracle Dam Bore	702888	6593316	6	ZWA	Obs 70	100.43
Mulga Well	697104	6593669	6	ZWA	Obs 71	76.27
Mungapote Well	652424	6566031	6	ZWA	Obs 72	103.73
MW4	675575	6548631	6	ZWA	Obs 73	118.52
Myall Bore	721740	6596610	6	ZWA	Obs 74	59.23
Myall Well	721611	6597128	6	ZWA	Obs 75	60.93
Nick of Time	720304	6589909	6	ZWA	Obs 76	62.41
Pine Bore	697310	6594788	6	ZWA	Obs 77	82.58
PT-2	671734	6621617	6	ZWA	Obs 78	49.96

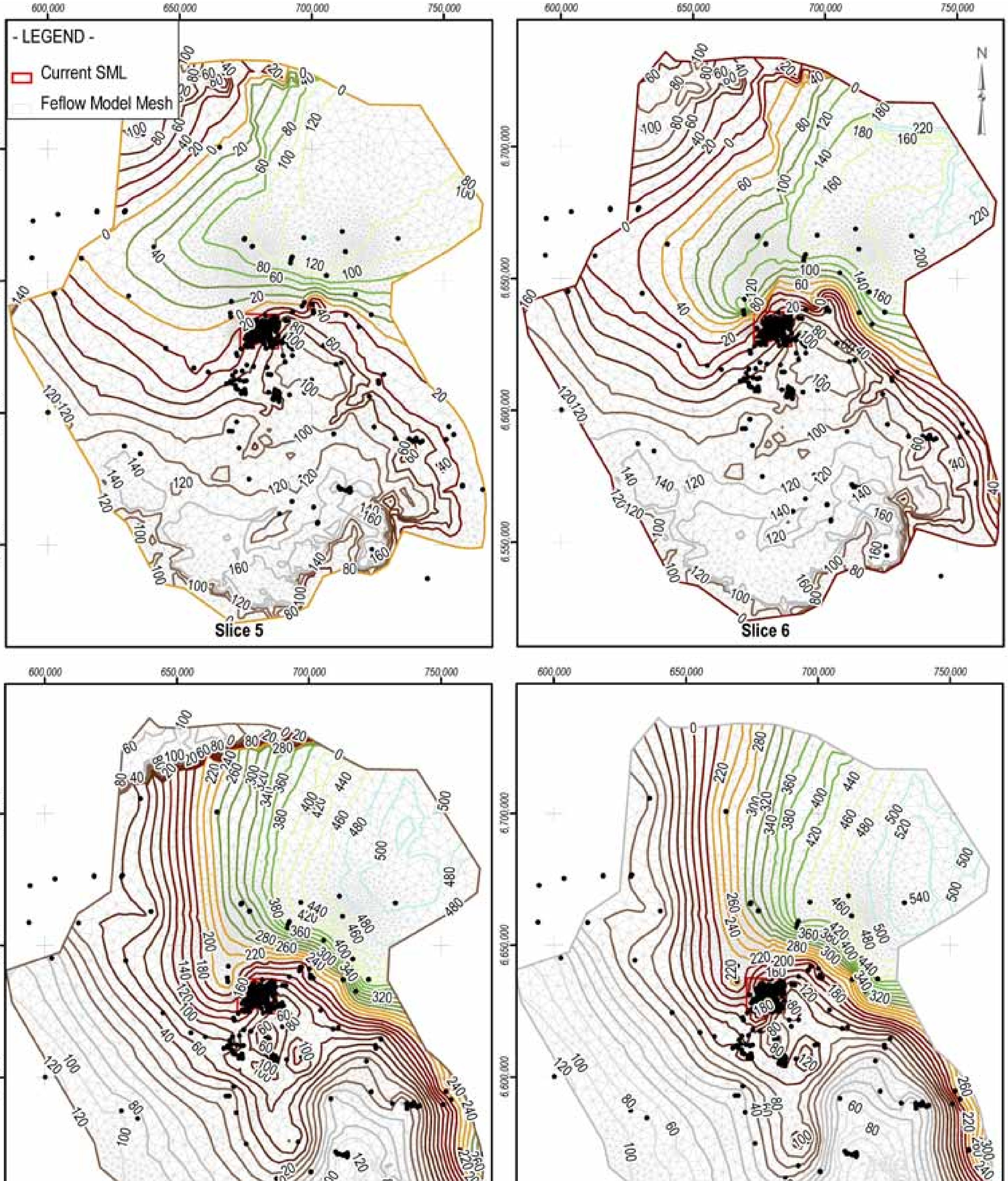
Well	Easting	Northing	Slice	Unit	Model_ID	Observed Head (mRL)
PT-3/4b	673203	6624296	6	ZWA	Obs 79	49.16
Purple Swamp 2	680518	6592130	6	ZWA	Obs 80	77.53
Purple Swamp 3	680844	6591395	6	ZWA	Obs 81	78.00
QR1	675648	6636430	6	ZWA	Obs 82	46.06
QR2	685766	6637299	6	ZWA	Obs 83	44.86
QR3	681197	6618638	6	ZWA	Obs 84	53.41
Rubbish Dump Well	710017	6630333	6	ZWA	Obs 85	65.99
Tod Ridge Well 6	708680	6594213	6	ZWA	Obs 86	66.22
WB6	682578	6581470	6	ZWA	Obs 87	92.67
WB7	681631	6567413	6	ZWA	Obs 88	114.56
Whip Well	708351	6595399	6	ZWA	Obs 89	67.19
Wilson Well	695214	6575986	6	ZWA	Obs 90	98.31
Wirrda Well	698507	6604108	6	ZWA	Obs 91	73.87
WRD10	685980	6608171	6	ZWA	Obs 92	46.00
WRD25	685575	6604984	6	ZWA	Obs 93	50.00
PT-1	674762	6622612	7	ZWC	Obs 94	49.03
PT-12	675343	6618127	7	ZWC	Obs 95	49.69
PT-15	678297	6627344	7	ZWC	Obs 96	49.55
PT-24b	676809	6627766	7	ZWC	Obs 97	48.20
PT-31	692705	6624123	7	ZWC	Obs 98	47.20
PT-5a	674764	6628089	7	ZWC	Obs 99	49.58
PT-5d	675653	6624931	7	ZWC	Obs 100	48.33
PT-7	683531	6614555	7	ZWC	Obs 101	53.67
PT-9	677991	6617548	7	ZWC	Obs 102	50.45
RD116	681097	6625004	7	ZWC	Obs 103	52.93
RD125	681294	6625252	7	ZWC	Obs 104	51.74
RD303	678559	6629052	7	ZWC	Obs 105	52.93
RD305	677775	6628881	7	ZWC	Obs 106	45.29
RD436	680299	6625895	7	ZWC	Obs 107	49.93
RD526	678769	6628266	7	ZWC	Obs 108	44.40
RD575	677808	6626906	7	ZWC	Obs 109	48.13
RT-1	705545	6652082	7	ZWC	Obs 110	39.42



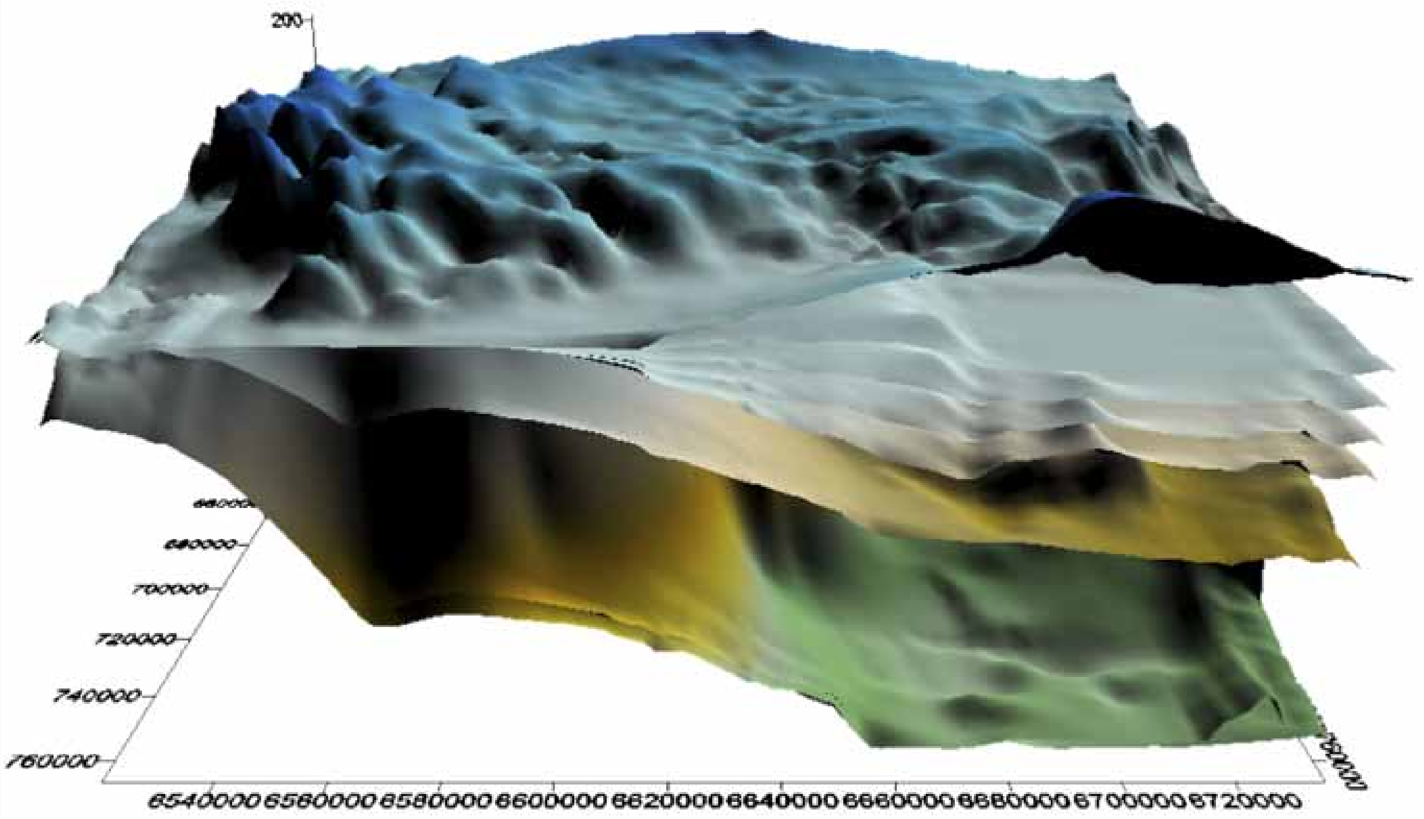
bhpbilliton Olympic Dam Expansion Uranium CSG	Author: Daniel Barclay Date: 5/08/2008 Scale: 1:1,000,000	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model - ODX EIS General Location Plan and Digital Elevation Model
GDA 94, MGA Zone 53	Figure No: 1	
Map ID: 080805_Figure1.mxd		



bhpbilliton Olympic Dam Expansion Uranium CSG	Author: Daniel Barclay	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model - ODX EIS
	Date: 5/08/2008	
	Scale: 1:2,000,000	Slice Elevations Slice 1, 2, 3 & 4
GDA 94, MGA Zone 53	Figure No: 2	
Map ID: 080805_Figure2.mxd		



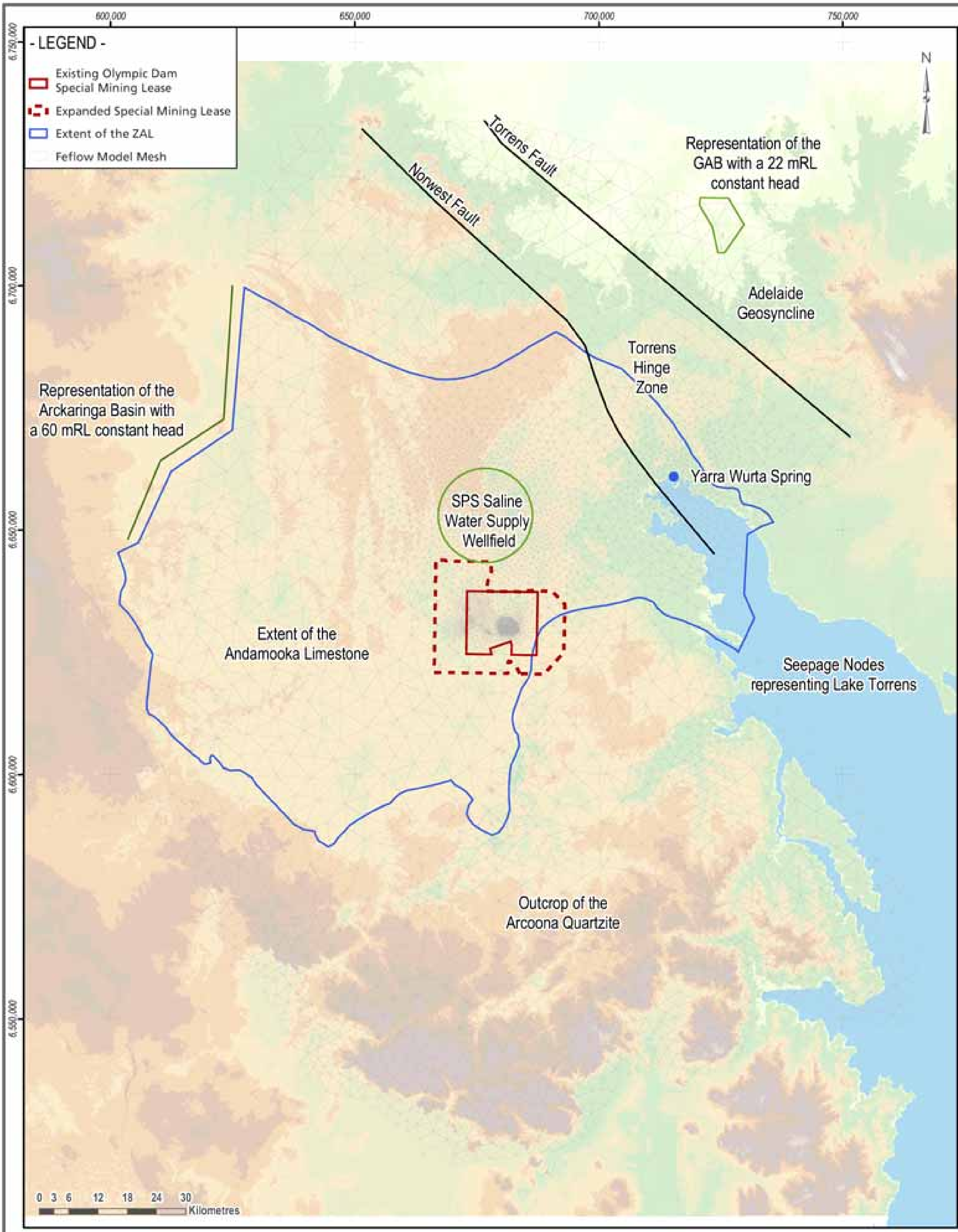
bhpbilliton Olympic Dam Expansion Uranium CSG	Author:	Daniel Barclay	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model - ODX EIS
	Date:	5/08/2008	
	Scale:	1:2,000,000	**Slice Elevations** **Slice 5, 6, 7 & 8**
GDA 94, MGA Zone 53	Figure No:	3	
Map ID: 080805_Figure3.mxd			



bhpbilliton
Olympic Dam Expansion
Uranium CSG

Author: Daniel Barclay		Olympic Dam Expansion
Date: 5/08/2008		Stuart Shelf Regional Groundwater Flow Model - ODX EIS
Scale: N/A		
GDA 94, MGA Zone 53	**Figure No:** 4	
Map ID: 080805_Figure4.mxd		

3D Representation of the Model Domain



bhpbilliton
Olympic Dam Expansion
Uranium CSG

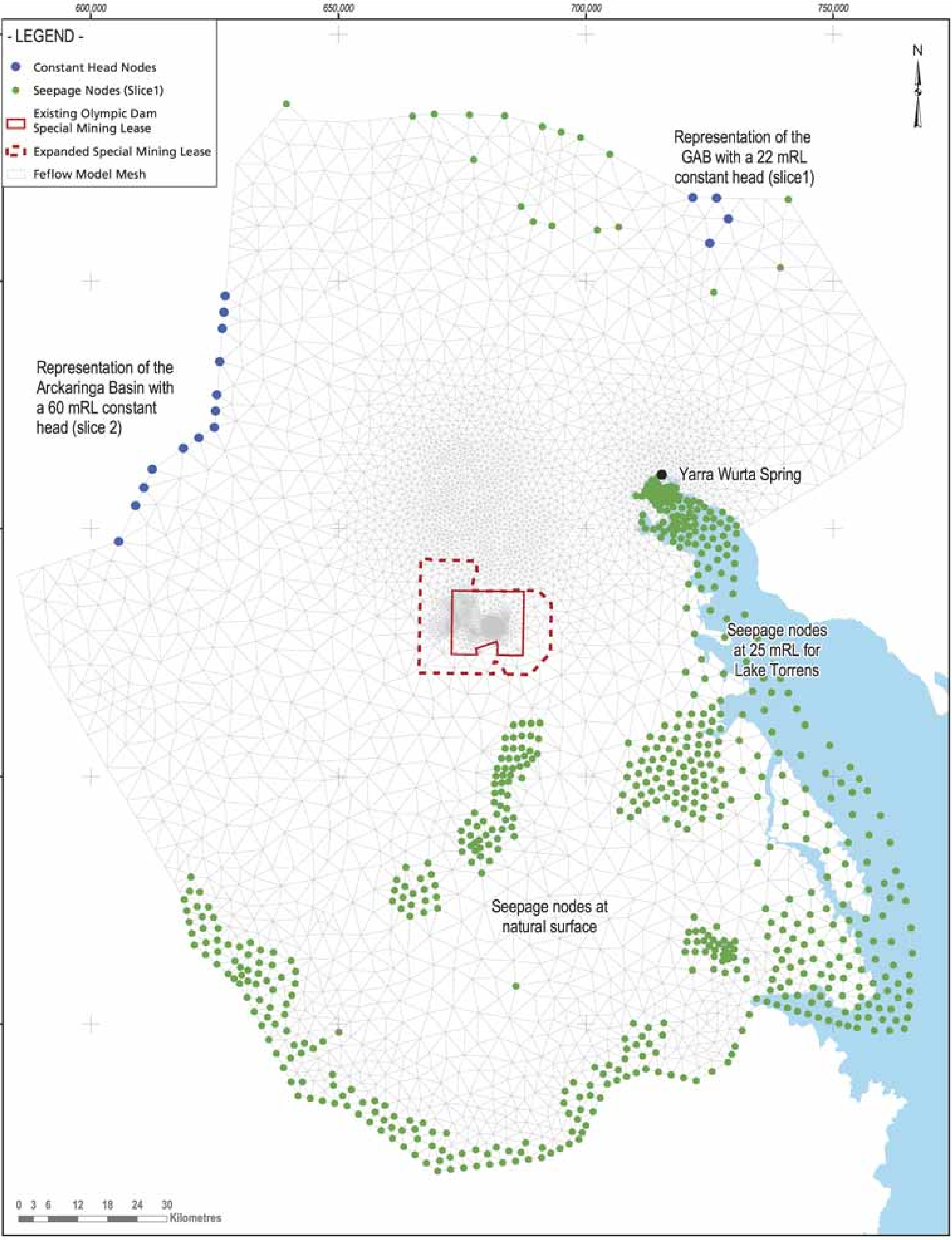
GDA 94, MGA Zone 53

Author: Daniel Barclay
Date: 5/08/2008
Scale: 1:1,000,000
Figure No: 5

Map ID: 080805_Figure5.mxd

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

Feflow Model Mesh and Conceptual Representation



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Olympic Dam Expansion
Uranium CSG

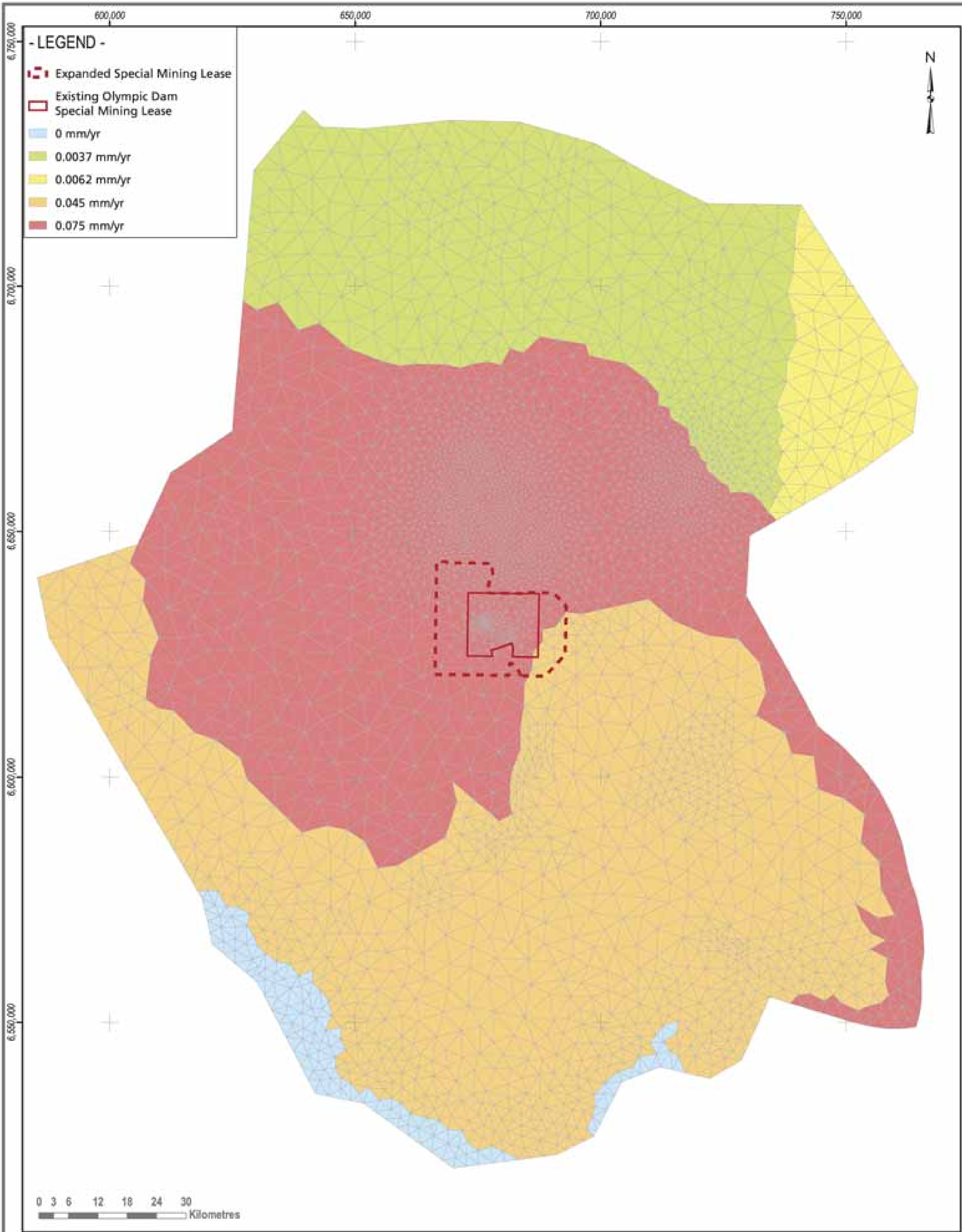
GDA 94, MGA Zone 53

Map ID: 080805_Figure6.mxd

Author:	Daniel Barclay
Date:	5/08/2008
Scale:	1:1,000,000
Figure No:	6

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

Boundary Conditions used in the Steady State and Transient Simulations



bhpbilliton
Olympic Dam Expansion
Uranium CSG

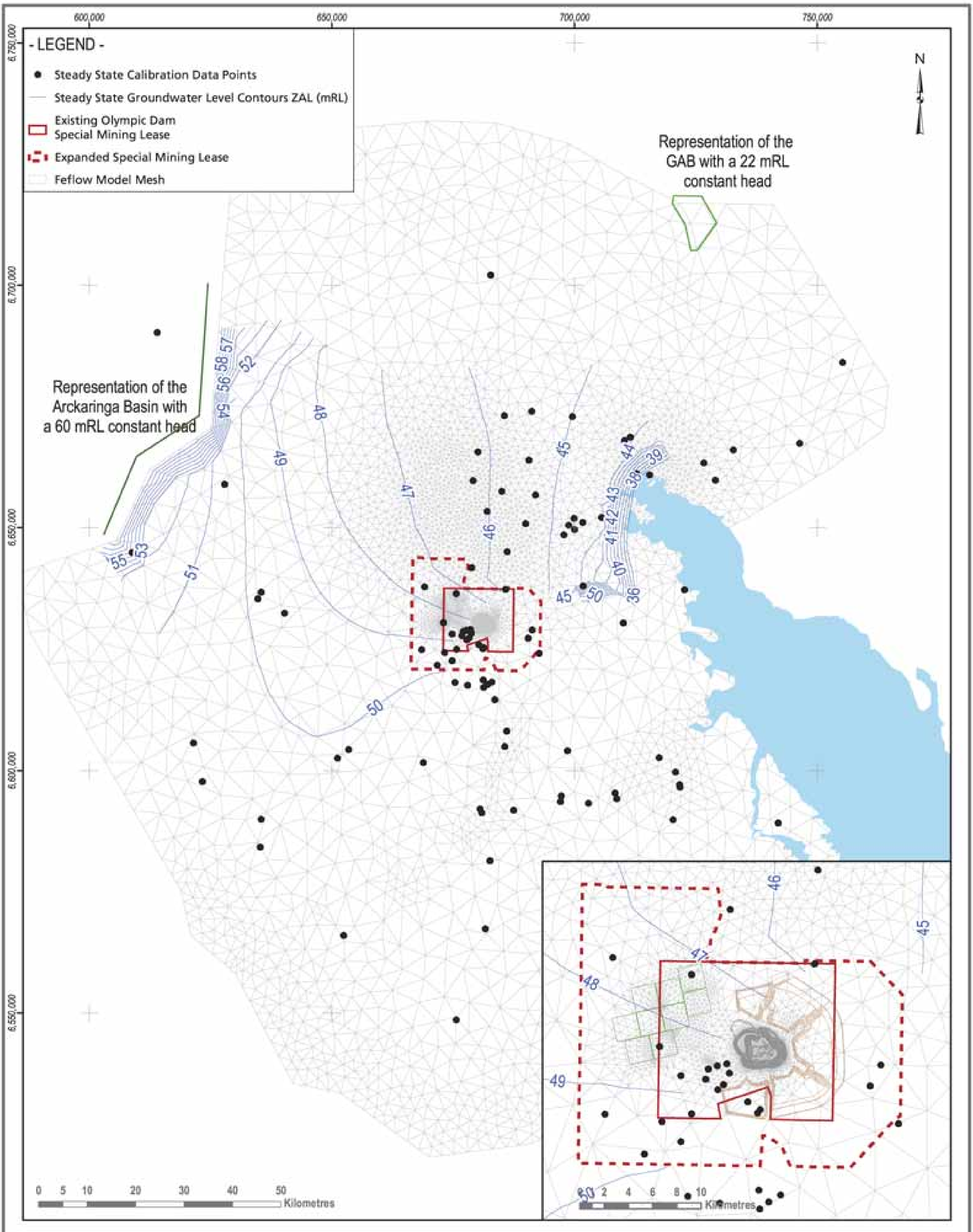
GDA 94, MGA Zone 53

Author:	Daniel Barclay
Date:	5/08/2008
Scale:	1:1,000,000
Figure No:	7

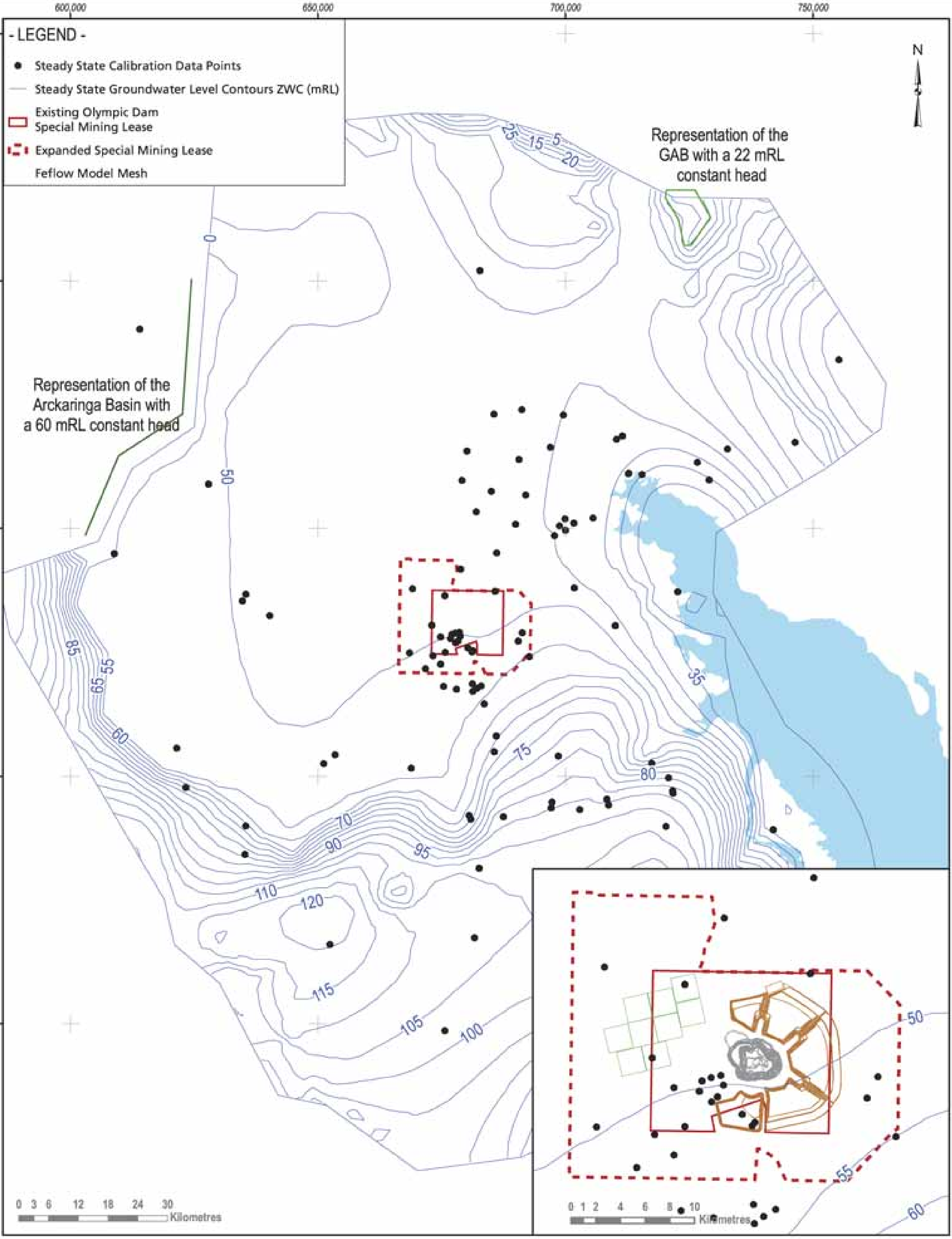
Map ID: 080805_Figure7.mxd

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

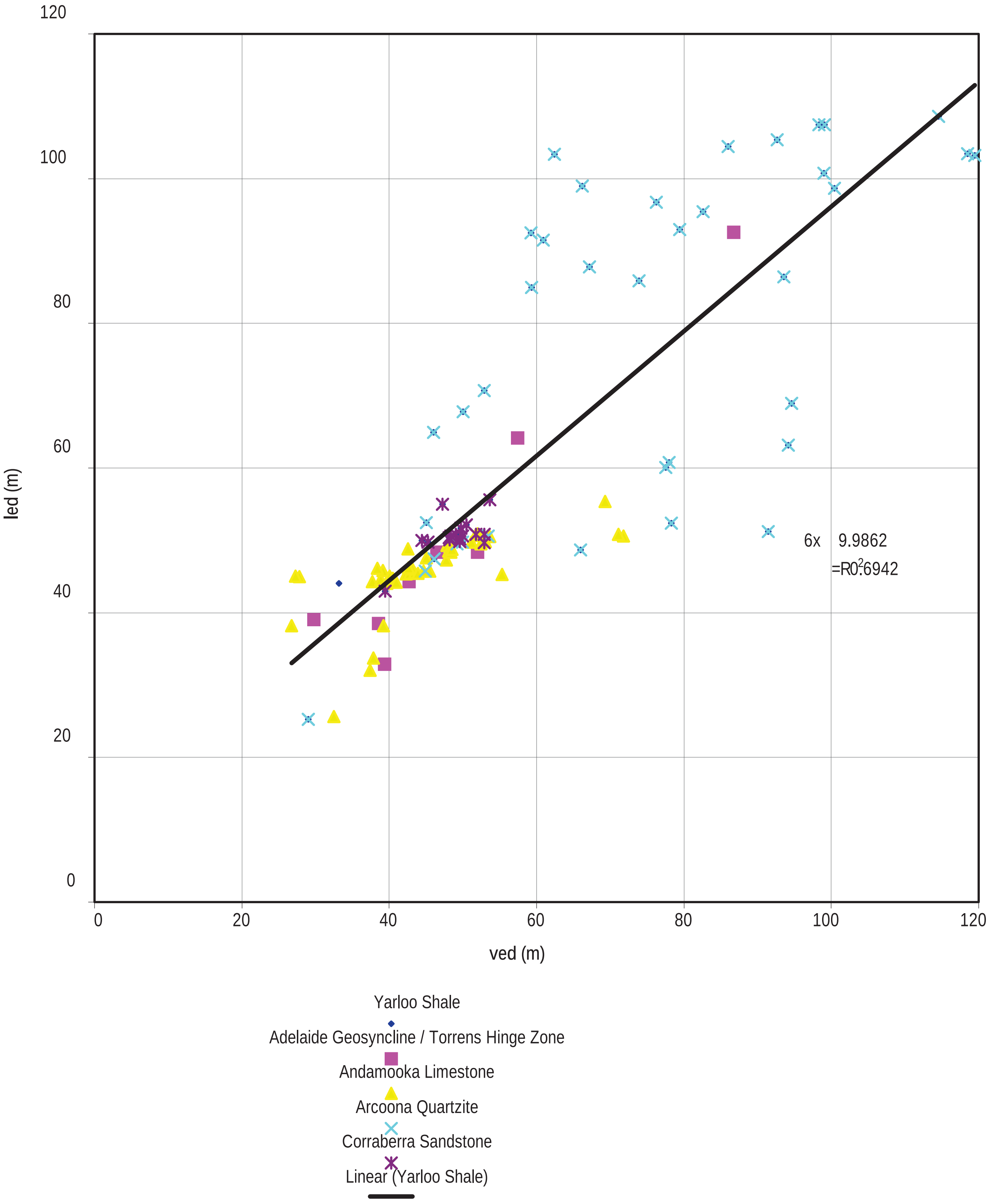
Recharge applied to Slice 1 of the Model Domain



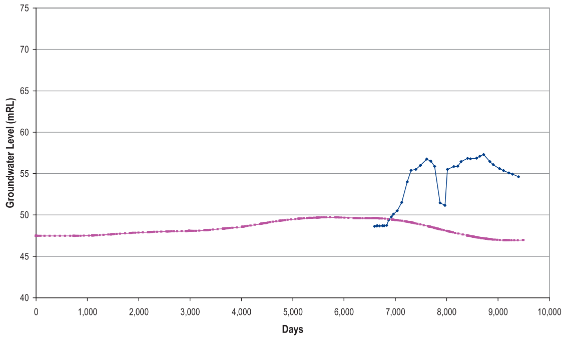
bhpbilliton Olympic Dam Expansion Uranium CSG	Author: Daniel Barclay	Olympic Dam Expansion
	Date: 1/08/2008	Stuart Shelf Regional Groundwater Flow Model
	Scale: 1:1,000,000	**Steady State Calibration**
GDA 94, MGA Zone 53	Figure No: 8	**Groundwater Level Contours ZAL**
Map ID: 080805_Figure8.mxd		



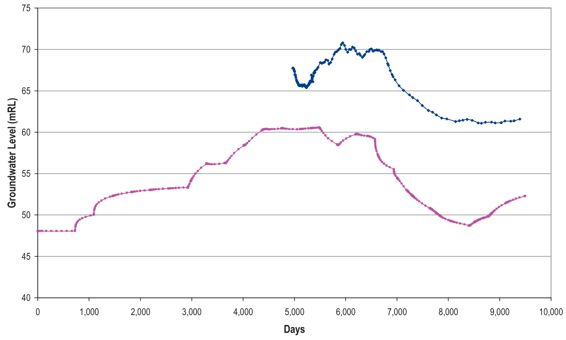
bhpbilliton Olympic Dam Expansion Uranium CSG	Author: Daniel Barclay Date: 1/08/2008 Scale: 1:1,000,000	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model
GDA 94, MGA Zone 53	Figure No: 9	**Steady State Calibration Groundwater Level Contours ZWC**
Map ID: 080805_Figure9.mxd		



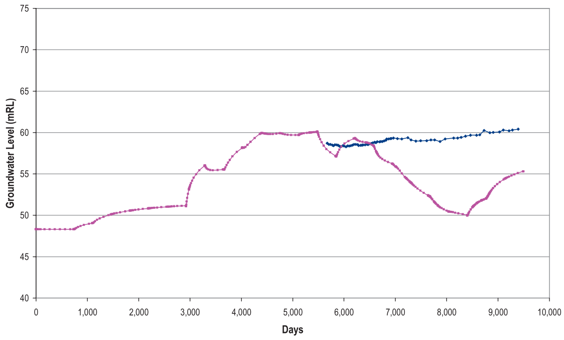
bhpbilliton Olympic Dam Expansion Uranium CSG	Author: Daniel Barclay Date: 5/08/2008 Scale: N/A	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model - ODX EIS
GDA 94, MGA Zone 53	Figure No: 10	**Scattergram of Observed vs Modelled Heads, Steady State Calibration**
Map ID: 080805_Figure10.mxd		



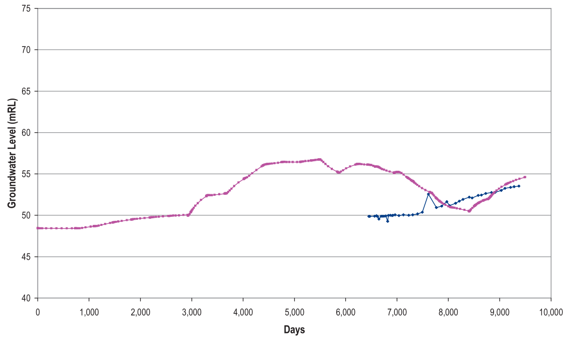
LM43



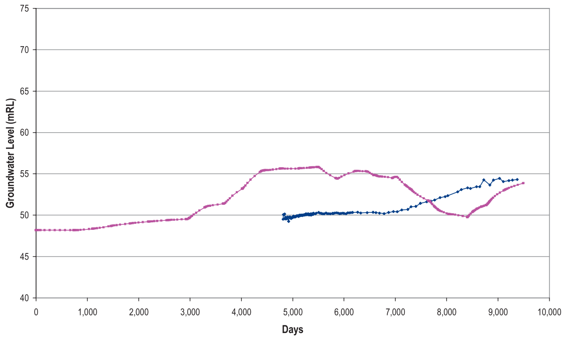
LT17



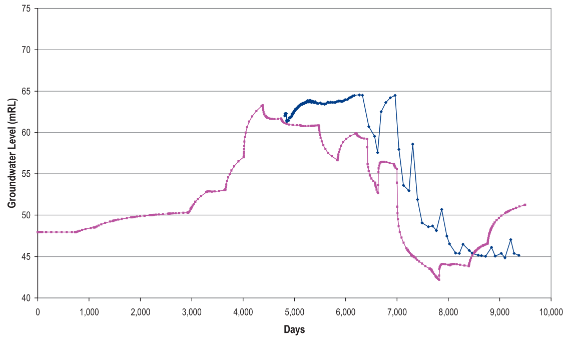
LT26



LT34



RD1006



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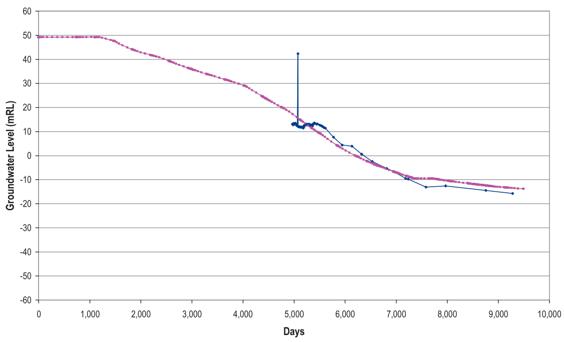

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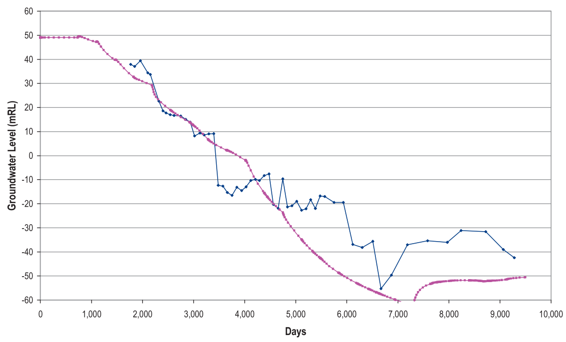


RD115

bhpbilliton
Olympic Dam Expansion
Uranium CSG

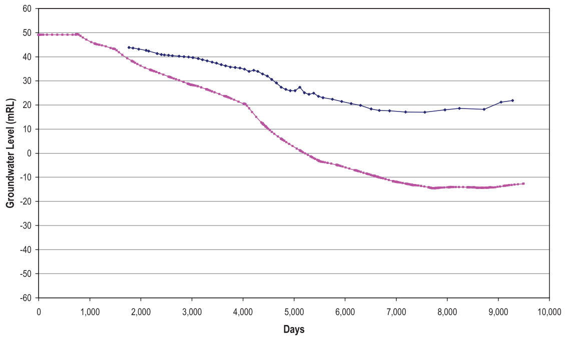
GDA 94, MGA Zone 53

Map ID: 080805_Figure11.mxd

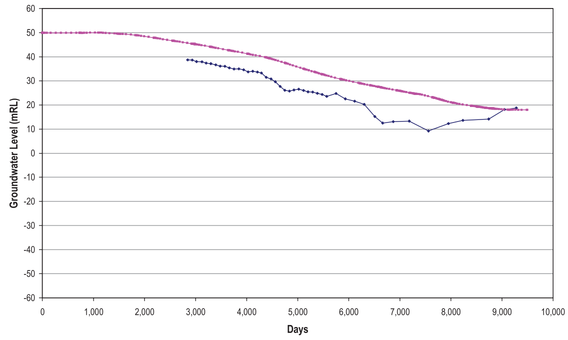
Author: Daniel Barclay
Date: 5/08/2008
Scale: N/A
Figure No: 11

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

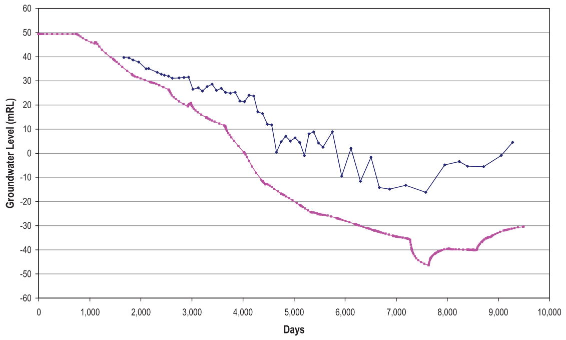
Observed vs Modelled Heads, Transient Calibration



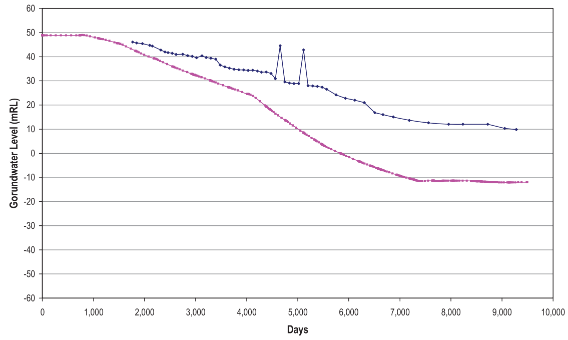
RD141



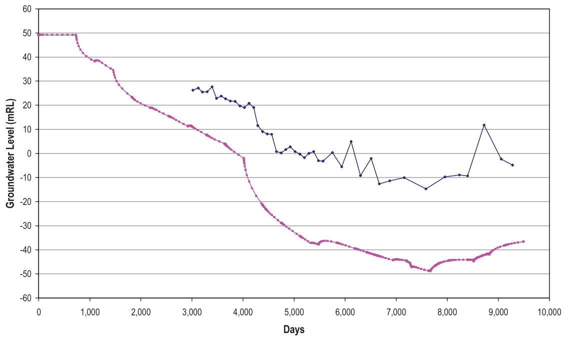
RD222



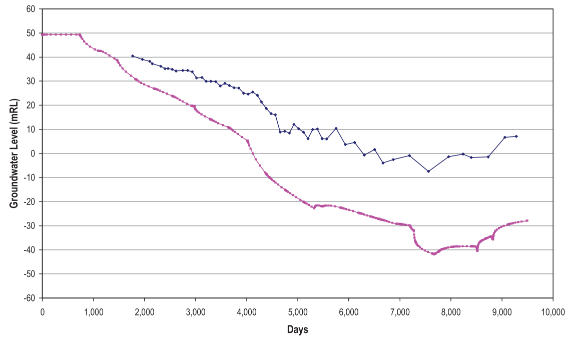
RD299



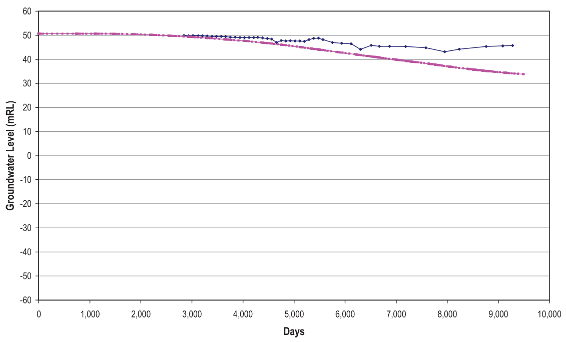
RD479



RD54



RD66



RD436

bhpbilliton
Olympic Dam Expansion
Uranium CSG

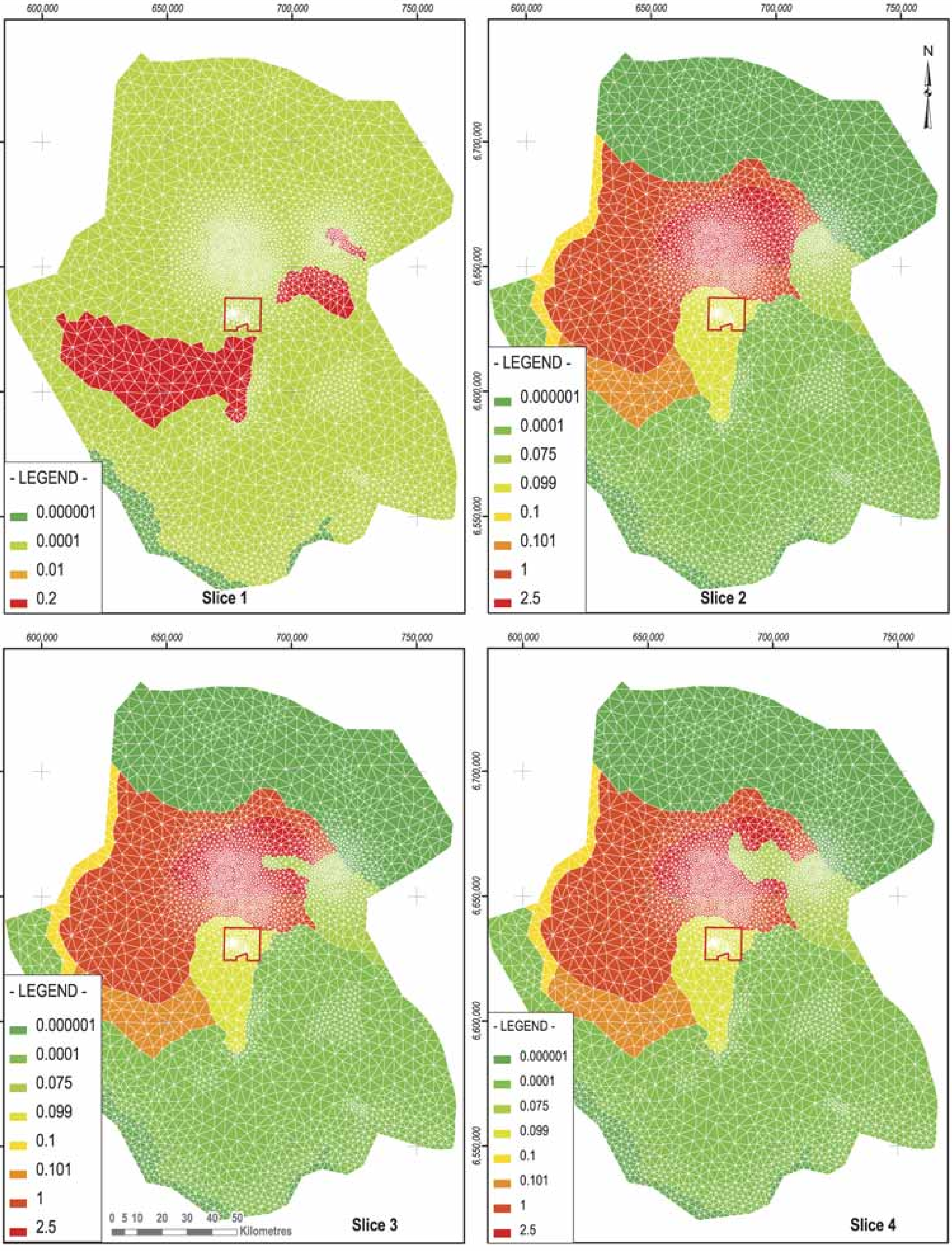
GDA 94, MGA Zone 53

Map ID: 080805_Figure12.mxd

Author: Daniel Barclay
Date: 5/08/2008
Scale: N/A
Figure No: 12

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

Observed vs Modelled Heads, Transient Calibration



bhpbilliton
Olympic Dam Expansion
Uranium CSG

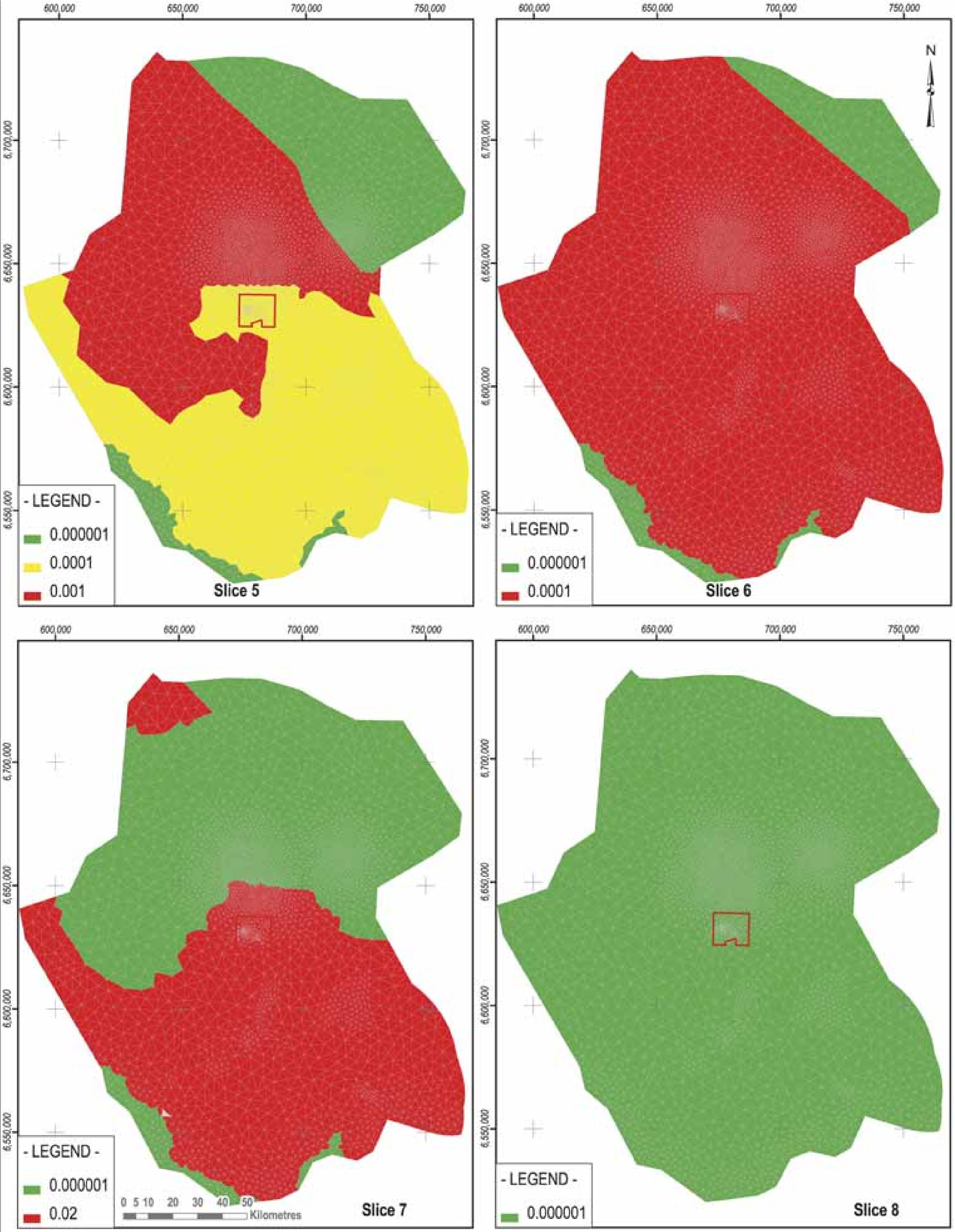
GDA 94, MGA Zone 53

Map ID: 080805_Figure13.mxd

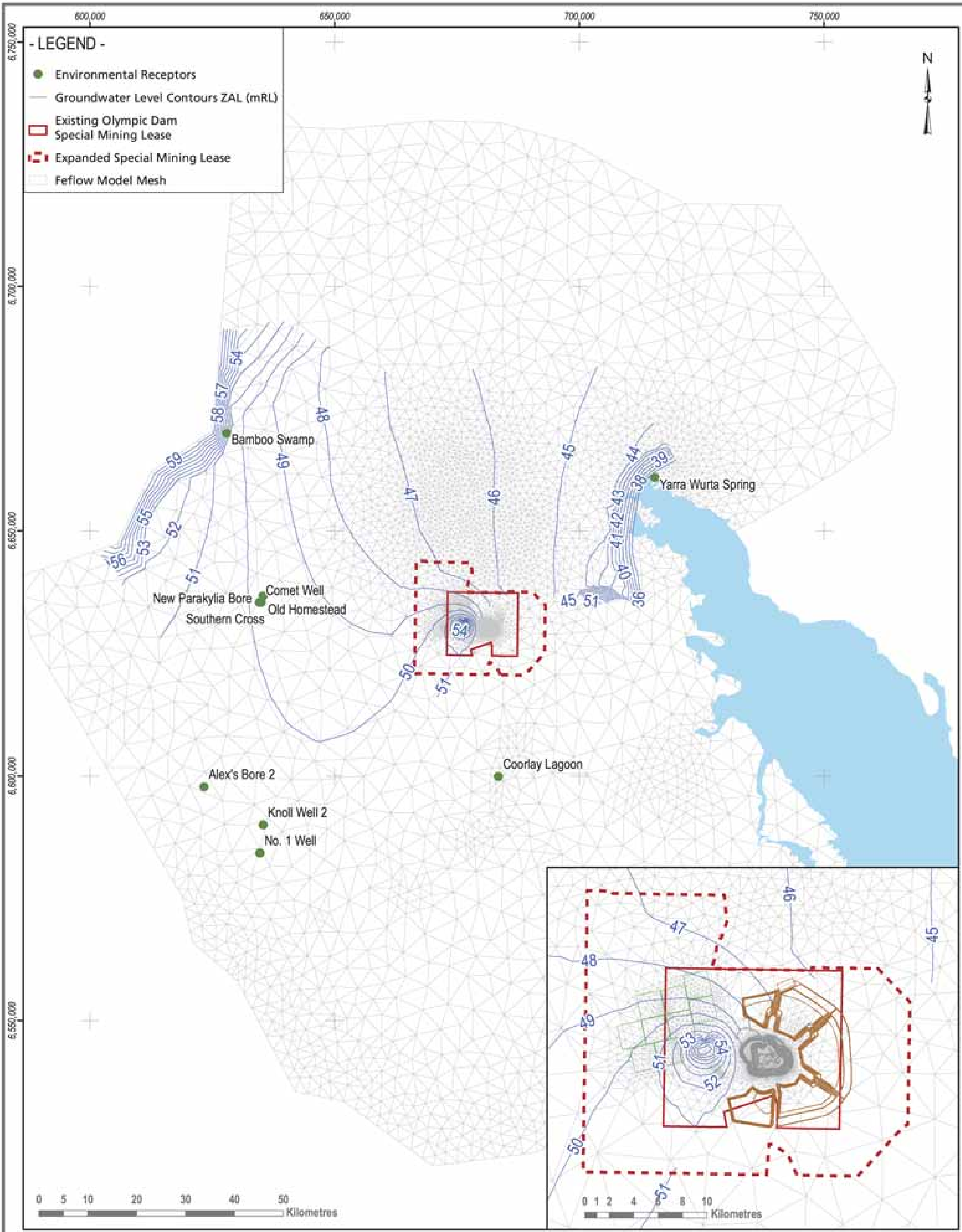
Author:	Daniel Barclay
Date:	5/08/2008
Scale:	1:2,000,000
Figure No:	13

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

Hydraulic Conductivity of Model Slices 1, 2, 3 & 4



bhpbilliton Olympic Dam Expansion Uranium CSG	**Author:**	Daniel Barclay	**Olympic Dam Expansion** **Stuart Shelf Regional Groundwater Flow Model - ODX EIS**
	Date:	5/08/2008	
	Scale:	1:2,000,000	**Hydraulic Conductivity of Model Slices 5, 6, 7 & 8**
GDA 94, MGA Zone 53	**Figure No:**	14	
Map ID: 080805_Figure14.mxd			



bhpbilliton
Olympic Dam Expansion
Uranium CSG

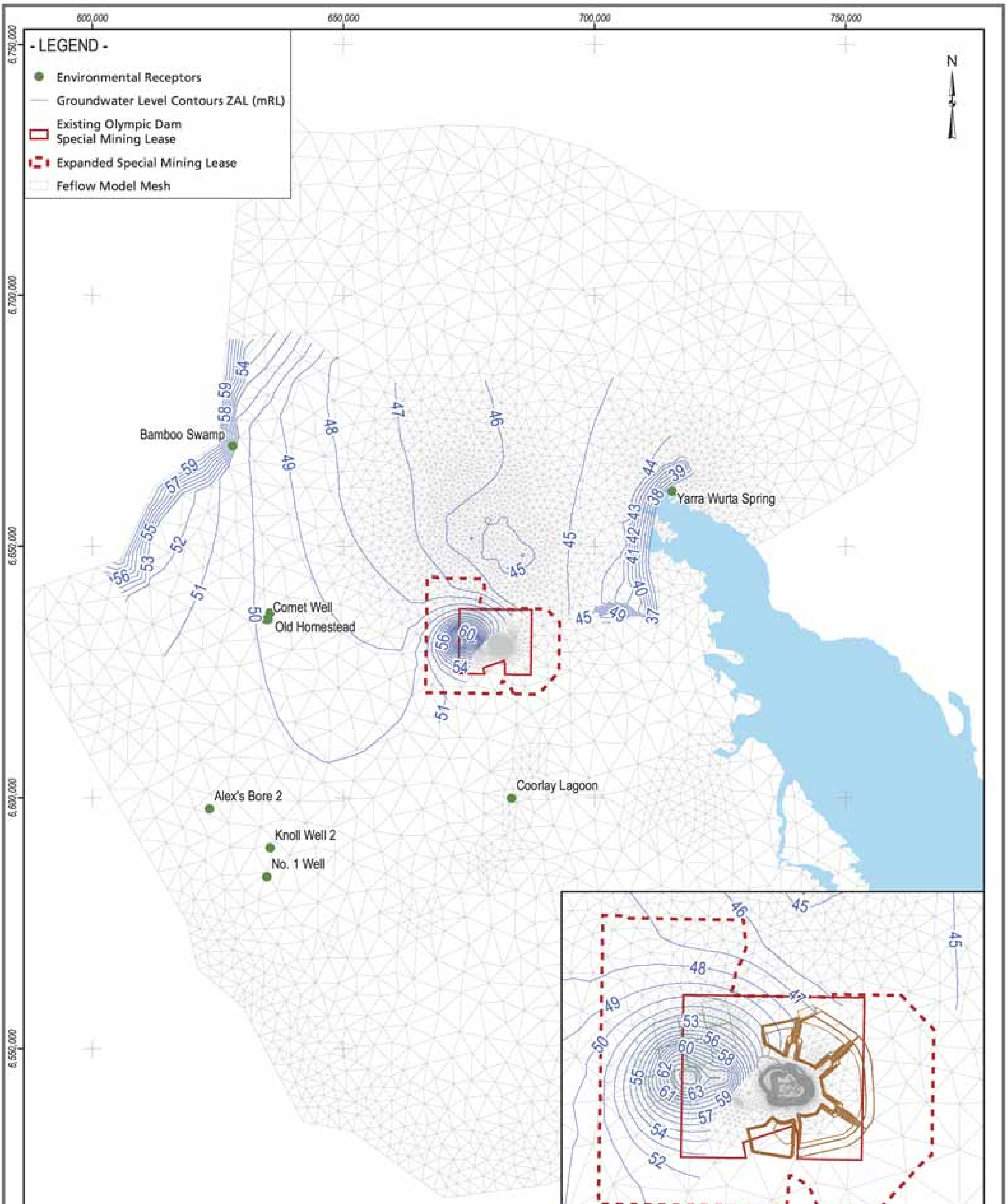
GDA 94, MGA Zone 53

Author:	Daniel Barclay
Date:	5/08/2008
Scale:	1:1,000,000
Figure No:	15

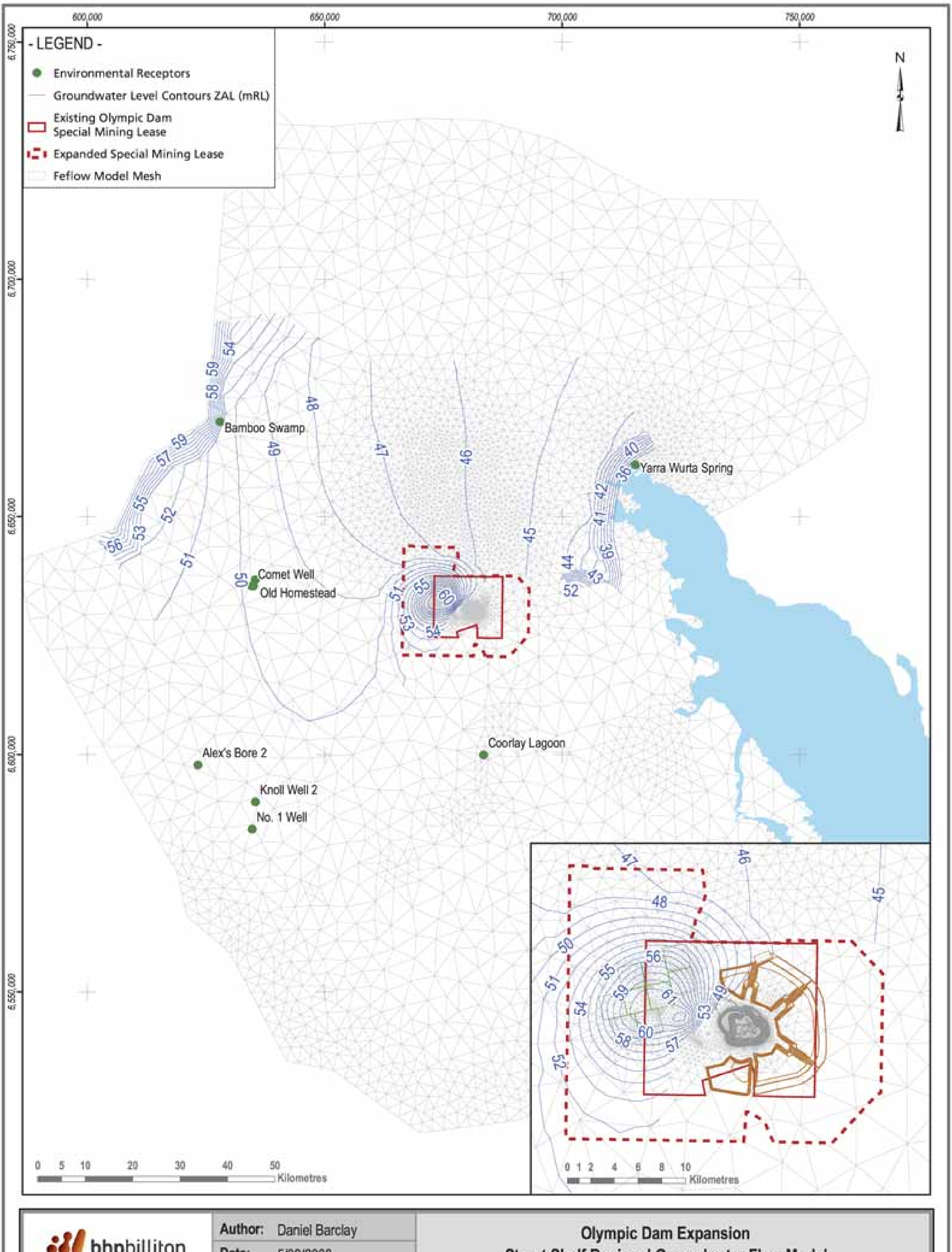
Map ID: 080805_Figure15.mxd

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model

Base Case Predictive Model
Groundwater Level Contours ZAL 2007



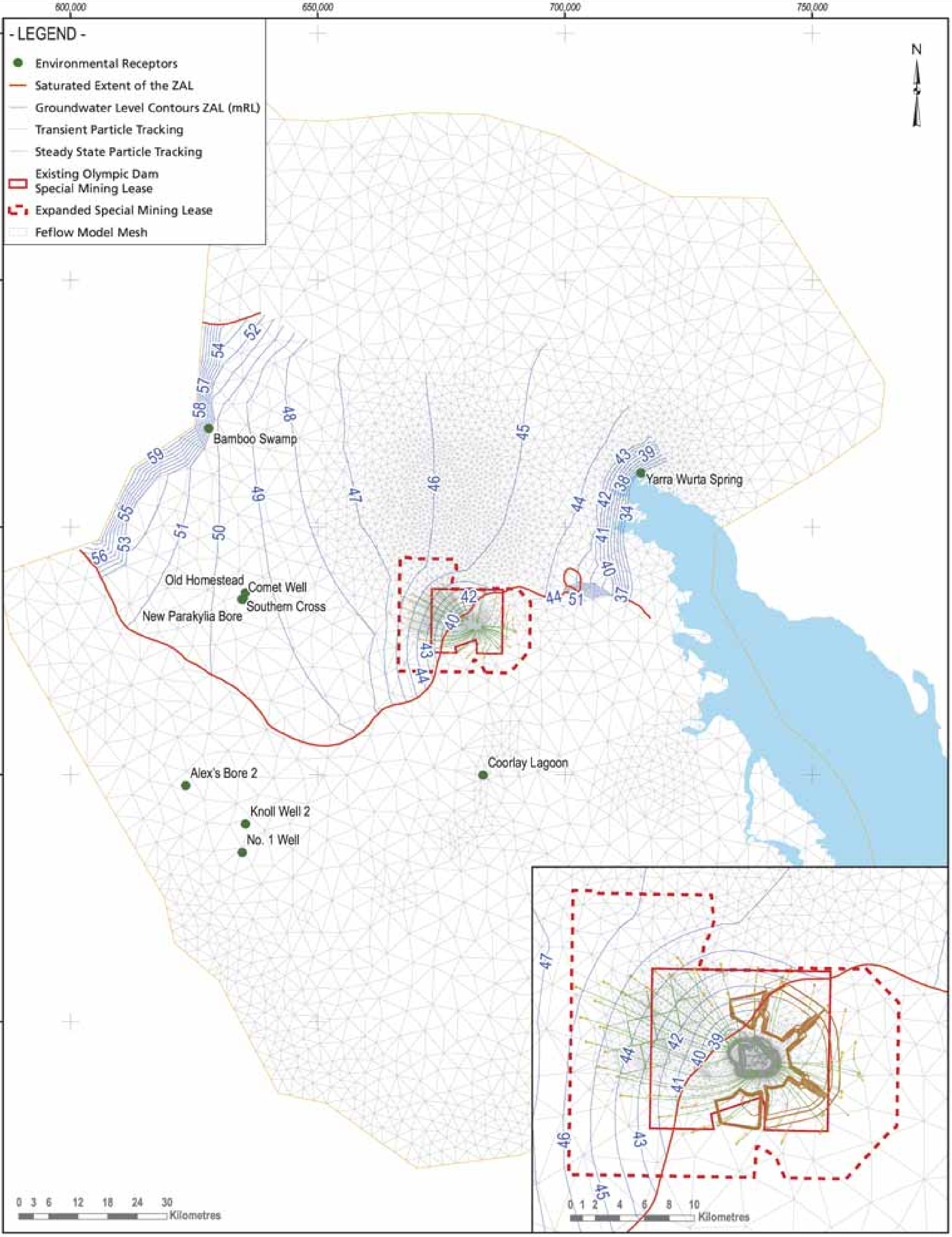
bhpbilliton Olympic Dam Expansion Uranium CSG	**Author:** Daniel Barclay **Date:** 5/08/2008 **Scale:** 1:1,000,000	**Olympic Dam Expansion** **Stuart Shelf Regional Groundwater Flow Model**
GDA 94, MGA Zone 53	**Figure No:** 16	**Base Case Predictive Model** **Groundwater Level Contours ZAL 2017**
Map ID: 080805_Figure15.mxd		



bhpbilliton Olympic Dam Expansion Uranium CSG	Author:	Daniel Barclay
	Date:	5/08/2008
	Scale:	1:1,000,000
GDA 94, MGA Zone 53	Figure No:	17
Map ID: 080805_Figure17.mxd		

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model

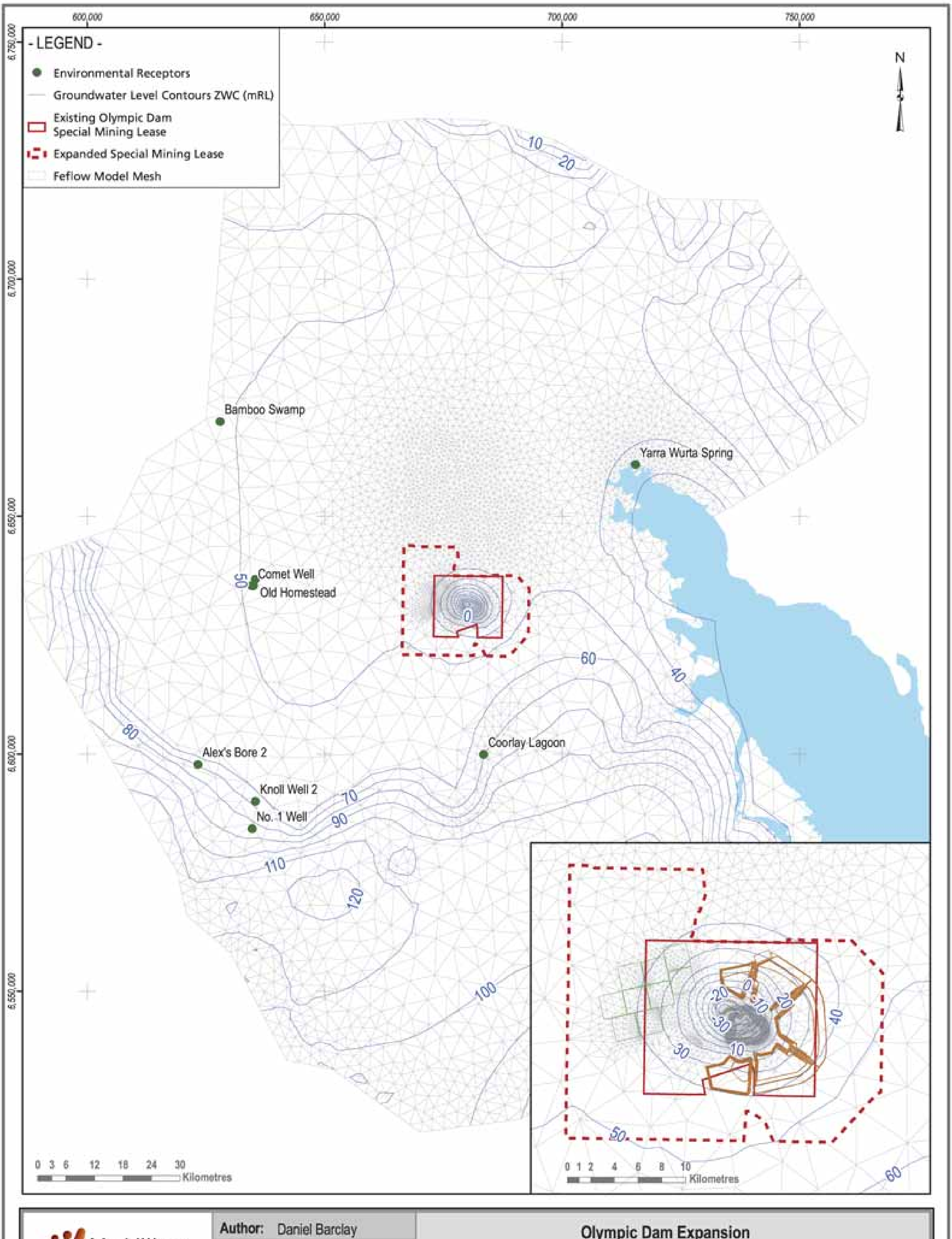
Base Case Predictive Model
Groundwater Level Contours ZAL 2050



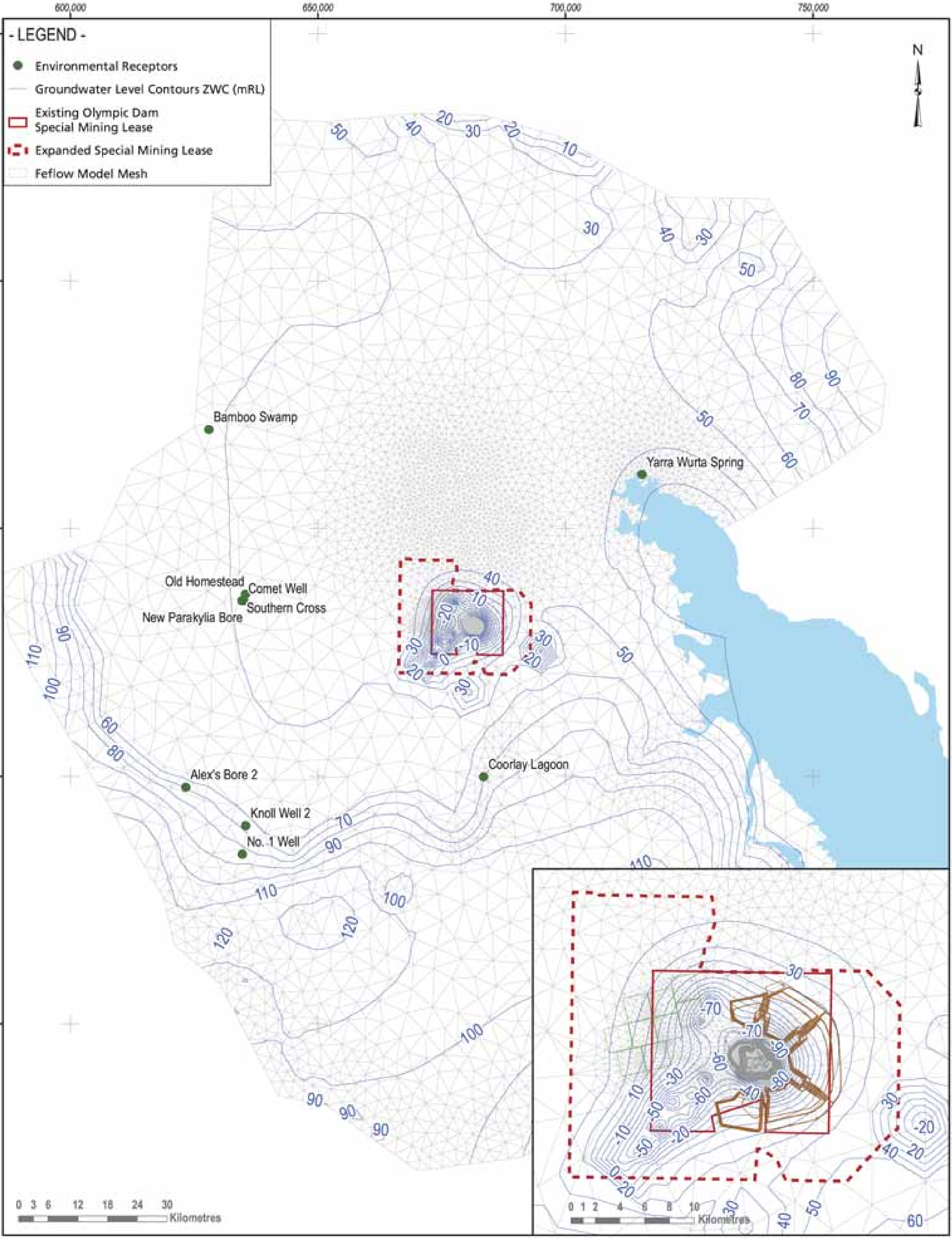
bhpbilliton Olympic Dam Expansion Uranium CSG	Author:	Daniel Barclay
	Date:	5/08/2008
	Scale:	1:1,000,000
GDA 94, MGA Zone 53	Figure No:	18
Map ID: 080805_Figure18.mxd		

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model

Base Case Predictive Model
Groundwater Level Contours ZAL 2550



bhpbilliton Olympic Dam Expansion Uranium CSG	Author:	Daniel Barclay	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model
	Date:	5/08/2008	
	Scale:	1:1,000,000	**Base Case Predictive Model** **Groundwater Level Contours ZWC 2007**
GDA 94, MGA Zone 53	Figure No:	19	
Map ID: 080805_Figure19.mxd			



bhpbilliton
Olympic Dam Expansion
Uranium CSG

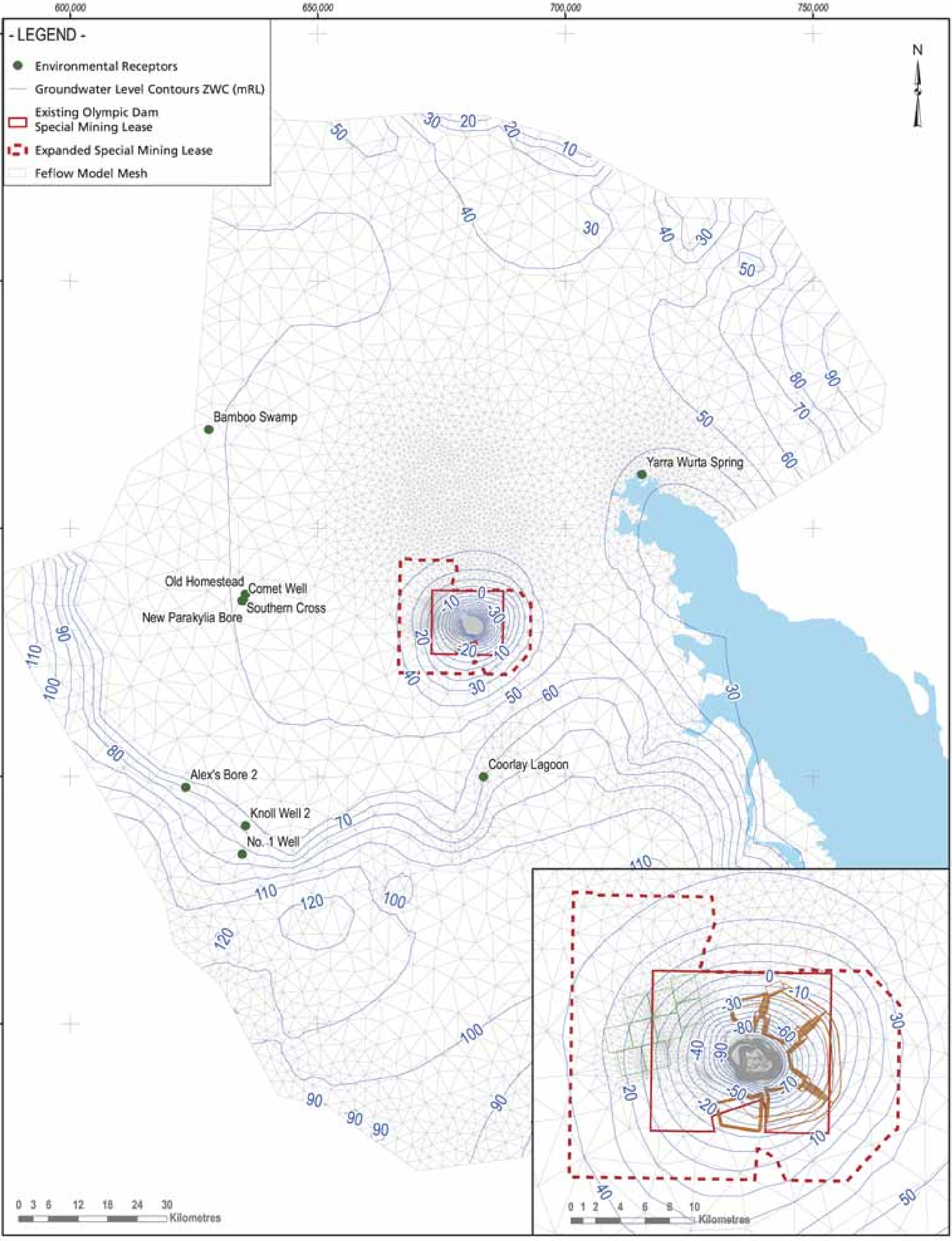
GDA 94, MGA Zone 53

Map ID: 080805_Figure20.mxd

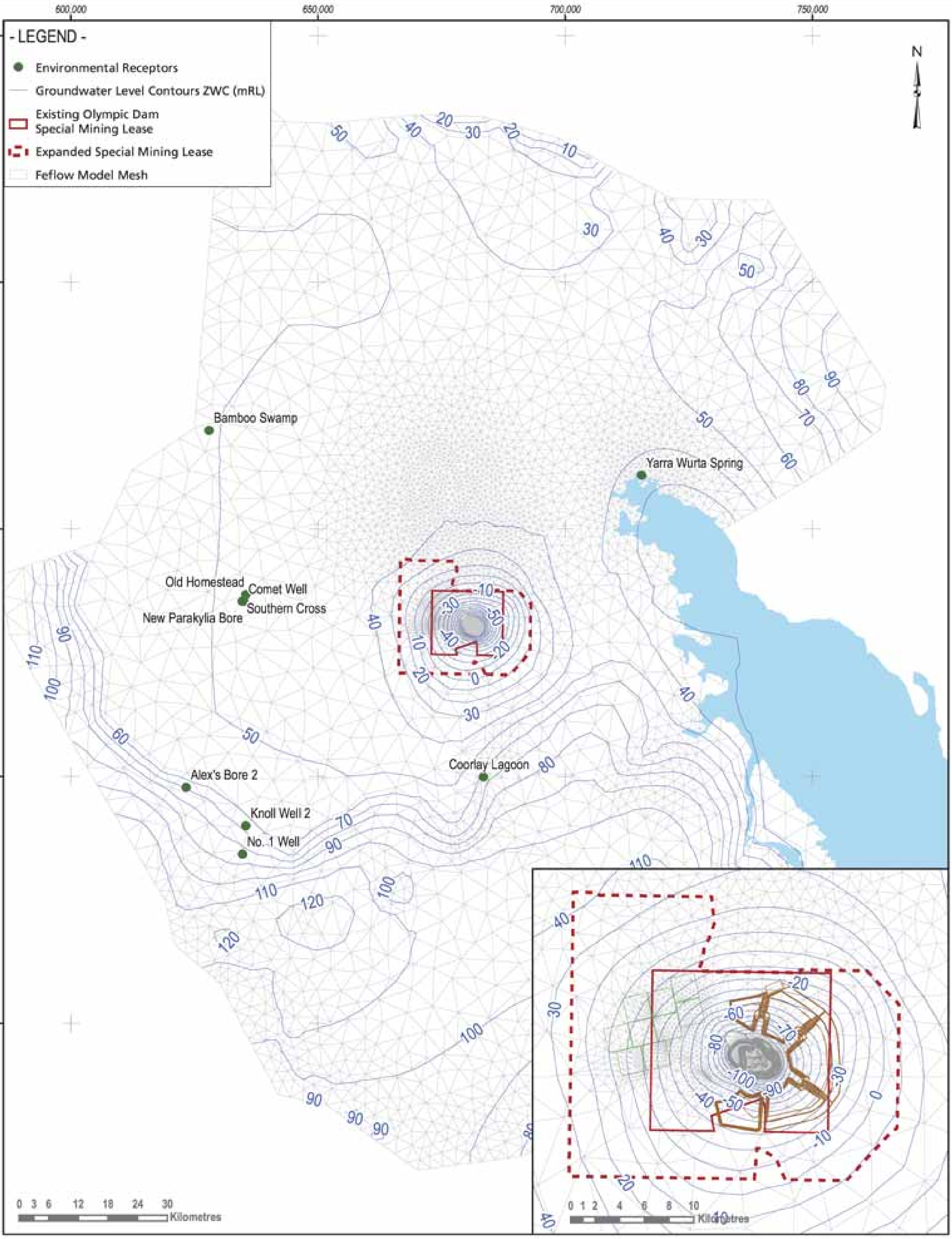
Author:	Daniel Barclay
Date:	5/08/2008
Scale:	1:1,000,000
Figure No:	20

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model

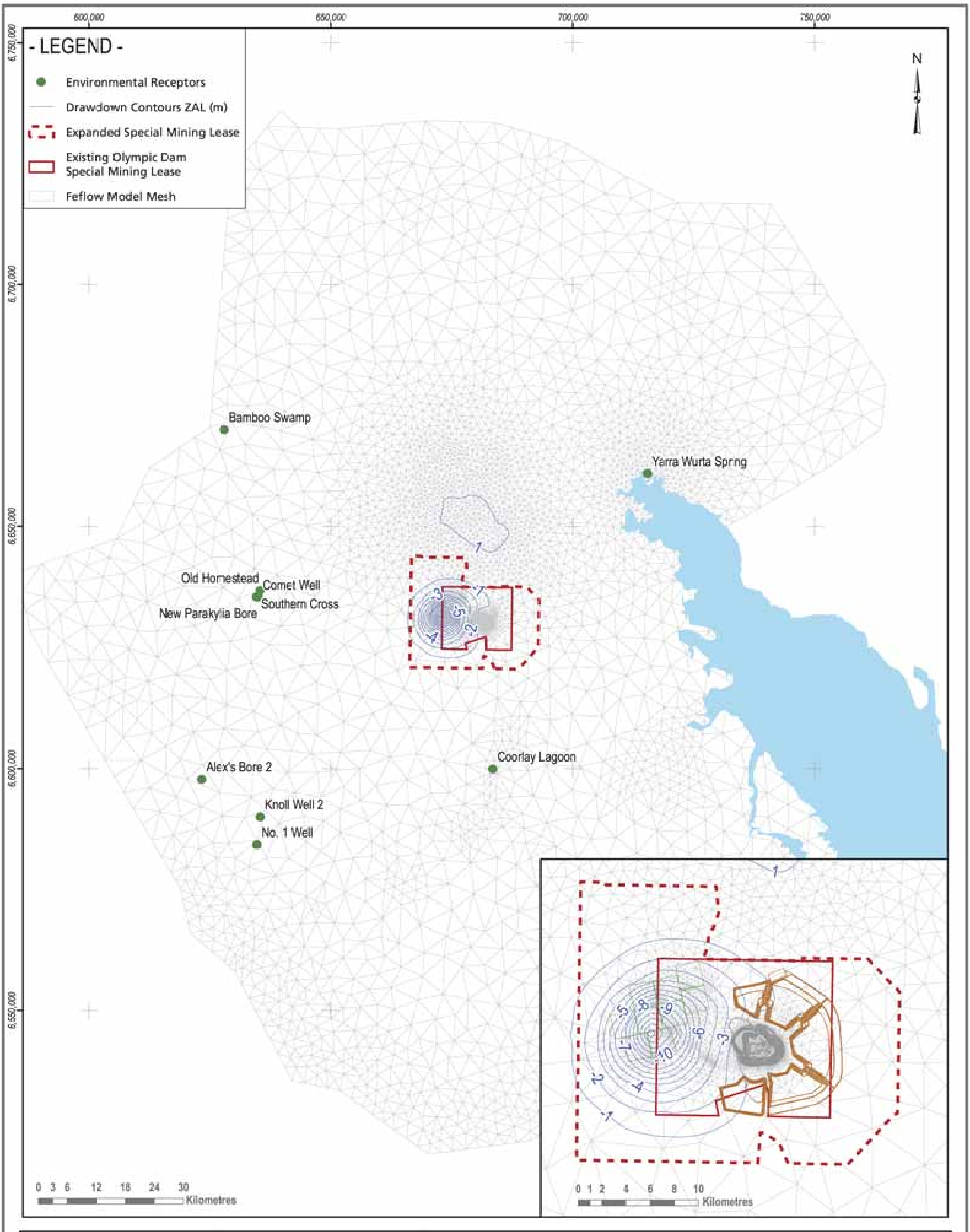
Base Case Predictive Model
Groundwater Level Contours ZWC 2017



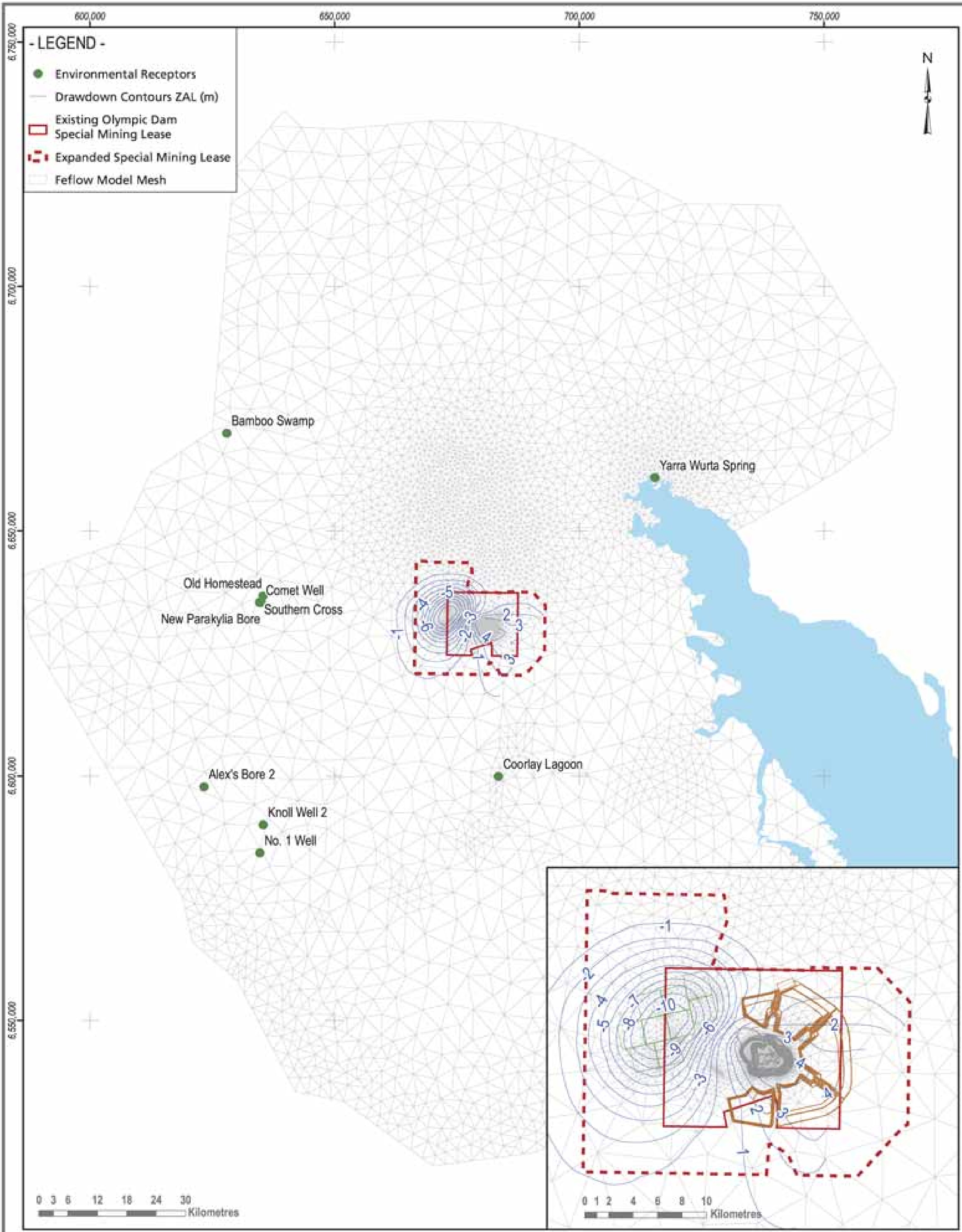
bhpbilliton Olympic Dam Expansion Uranium CSG	Author:	Daniel Barclay	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model
	Date:	5/08/2008	**Base Case Predictive Model Groundwater Level Contours ZWC 2050**
	Scale:	1:1,000,000	
GDA 94, MGA Zone 53	Figure No:	21	
Map ID: 080805_Figure21.mxd			



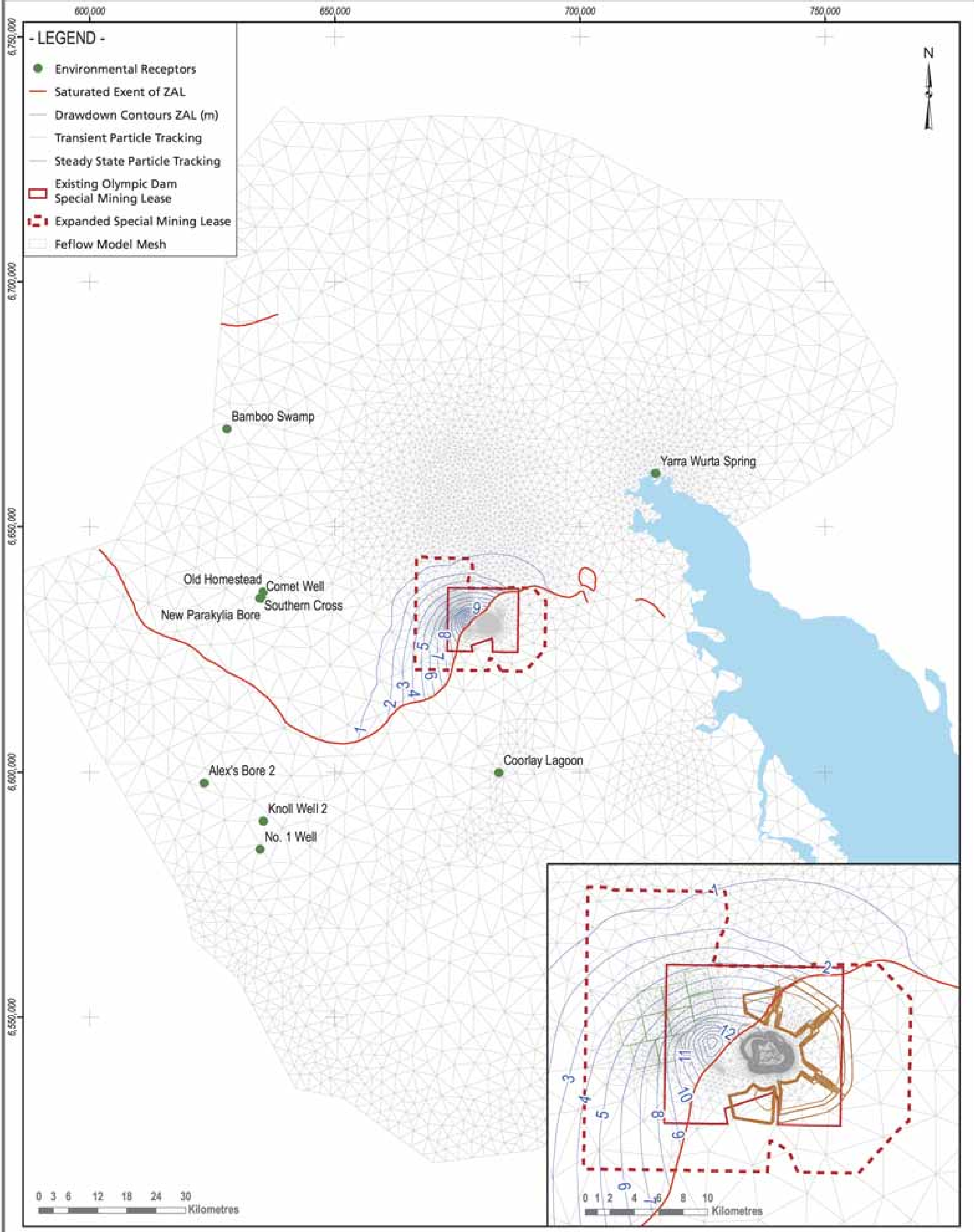
bhpbilliton Olympic Dam Expansion Uranium CSG	Author:	Daniel Barclay	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model
	Date:	5/08/2008	
	Scale:	1:1,000,000	**Base Case Predictive Model Groundwater Level Contours ZWC 2550**
GDA 94, MGA Zone 53	Figure No:	22	
Map ID: 080805_Figure22.mxd			



bhpbilliton Olympic Dam Expansion Uranium CSG	Author: Daniel Barclay Date: 1/08/2008 Scale: 1:1,000,000	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model
GDA 94, MGA Zone 53	Figure No: 23	**Base Case Predictive Model** **Drawdown Contours ZAL 2017**
Map ID: 080805_Figure23.mxd		



bhpbilliton Olympic Dam Expansion Uranium CSG	**Author:** Daniel Barclay	**Olympic Dam Expansion** **Stuart Shelf Regional Groundwater Flow Model**
	Date: 5/08/2008	
	Scale: 1:1,000,000	**Base Case Predictive Model** **Drawdown Contours ZAL 2050**
GDA 94, MGA Zone 53	**Figure No:** 24	
Map ID: 080805_Figure24.mxd		



bhpbilliton
Olympic Dam Expansion
Uranium CSG

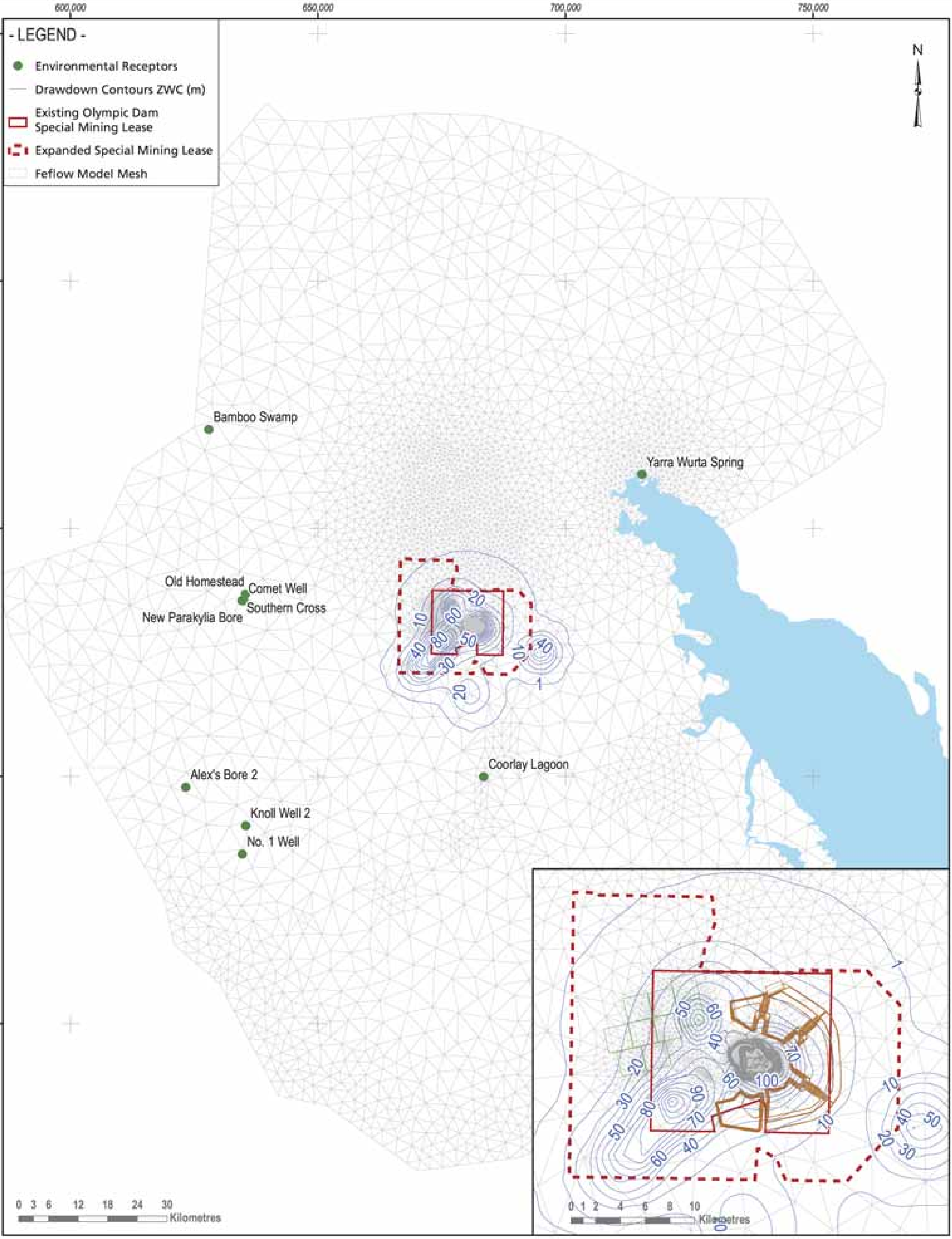
GDA 94, MGA Zone 53

Map ID: 080805_Figure25.mxd

Author:	Daniel Barclay
Date:	5/08/2008
Scale:	1:1,000,000
Figure No:	25

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model

Base Case Predictive Model
Drawdown Contours ZAL 2550



Author:	Daniel Barclay	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model
Date:	5/08/2008	**Base Case Predictive Model**
Scale:	1:1,000,000	**Drawdown Contours ZWC 2017**
Figure No:	26	

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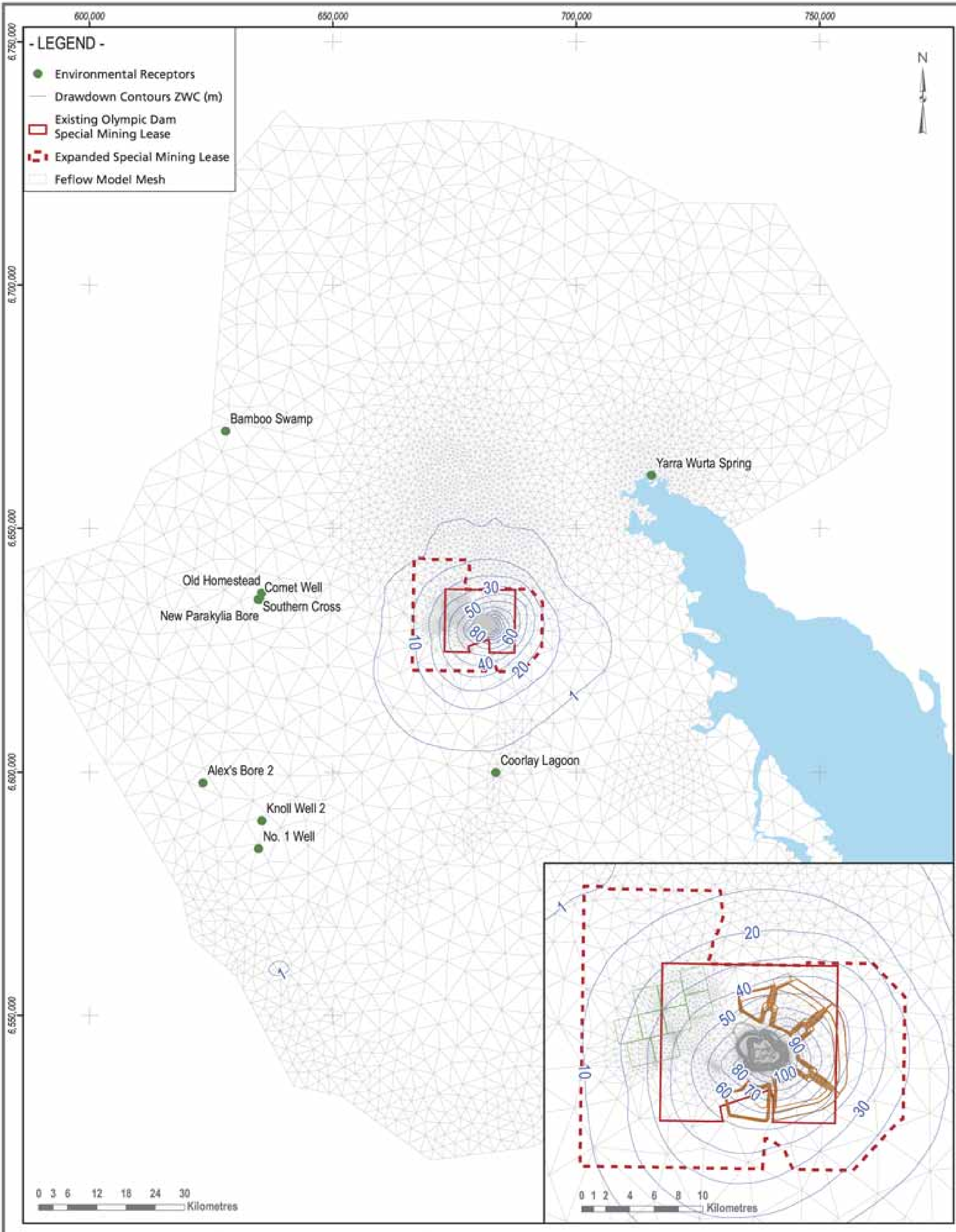
Olympic Dam Expansion
Uranium CSG

GDA 94, MGA Zone 53

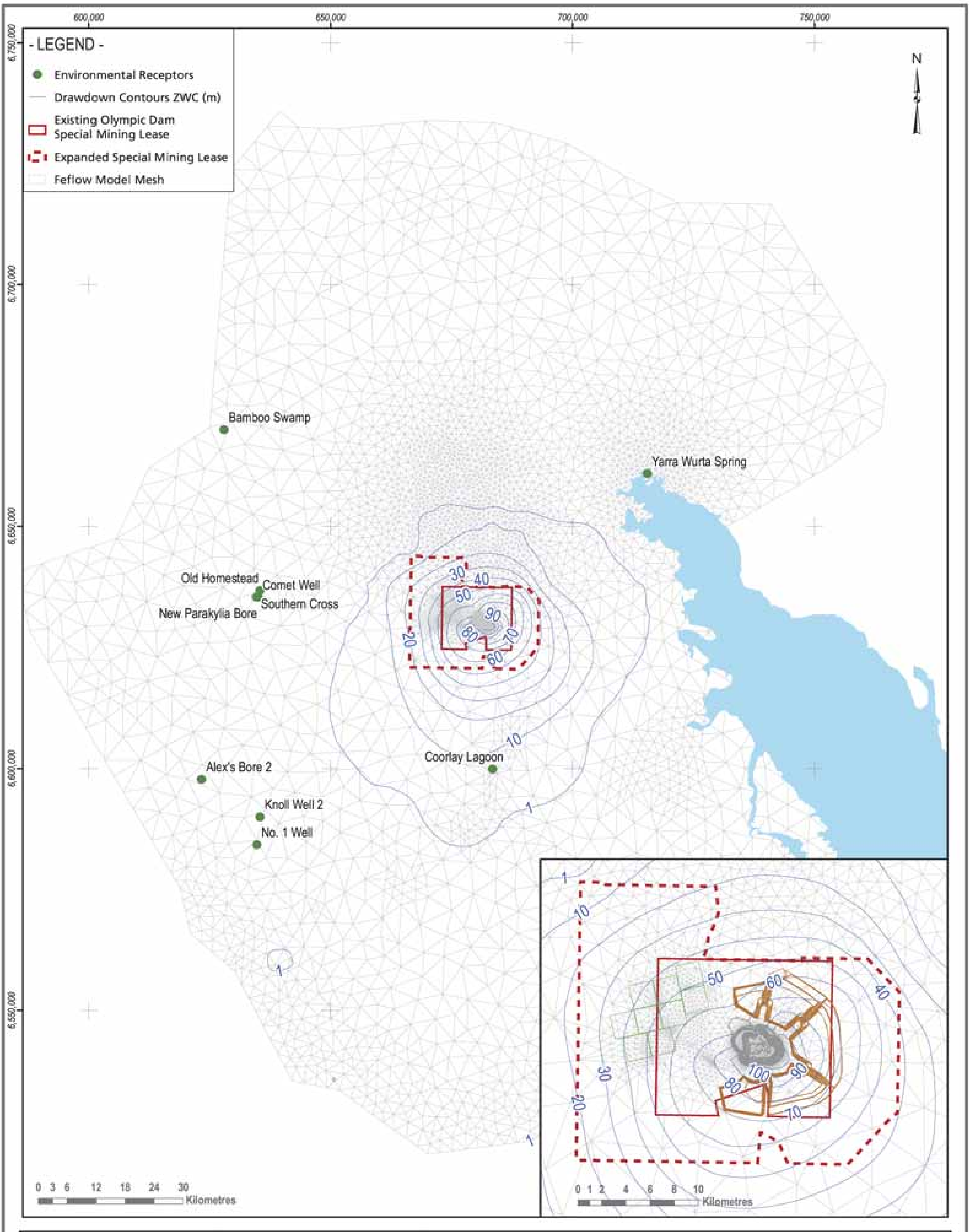
Map ID: 080805_Figure26.mxd



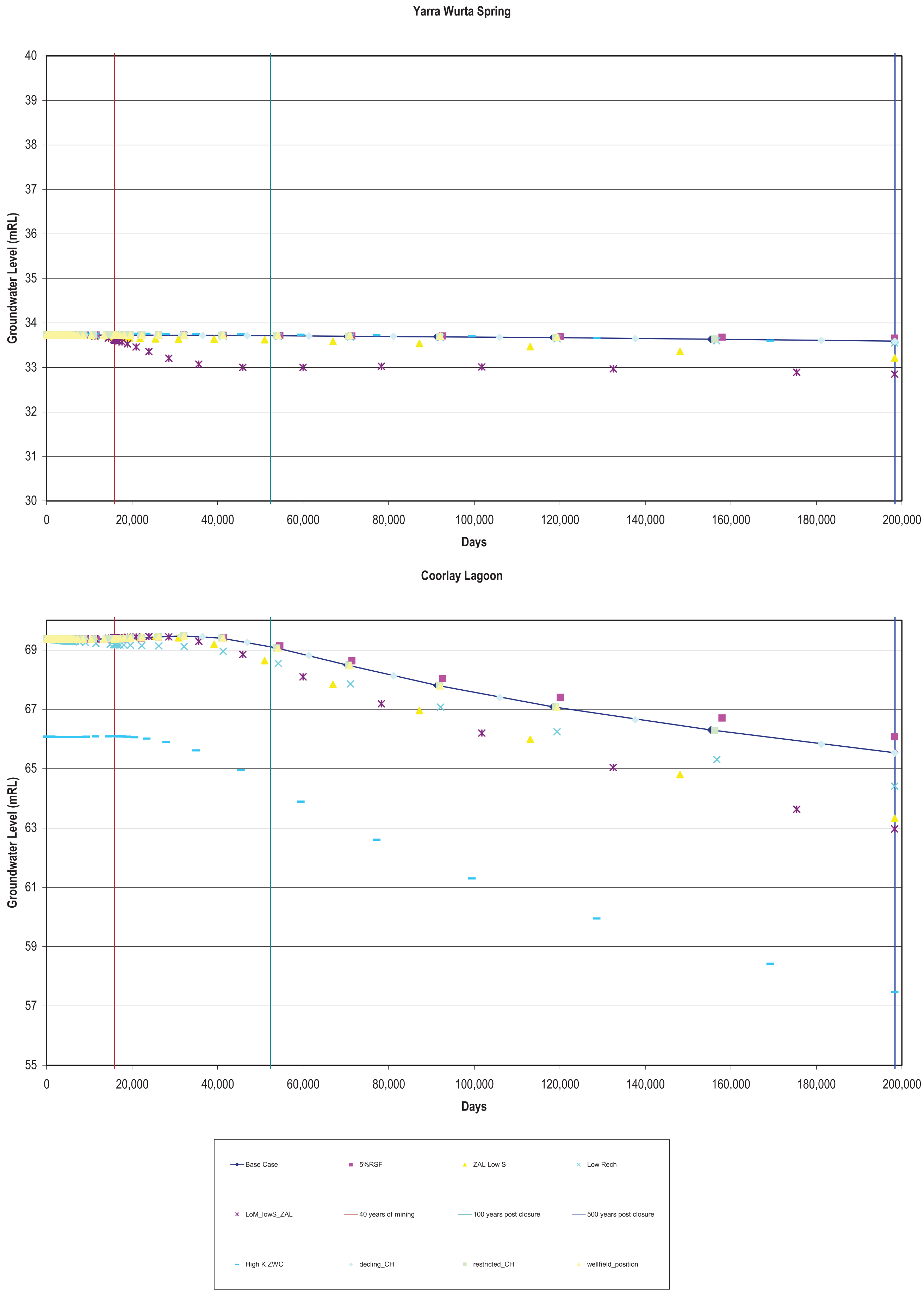
bhpbilliton Olympic Dam Expansion Uranium CSG	**Author:** Daniel Barclay
	Date: 5/08/2008
	Scale: 1:1,000,000
GDA 94, MGA Zone 53	**Figure No:** 27
Map ID: 080805_Figure27.mxd	

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model

Base Case Predictive Model
Drawdown Contours ZWC 2050



bhpbilliton Olympic Dam Expansion Uranium CSG	**Author:** Daniel Barclay	**Olympic Dam Expansion** **Stuart Shelf Regional Groundwater Flow Model**
	Date: 5/08/2008	**Base Case Predictive Model** **Drawdown Contours ZWC 2550**
	Scale: 1:1,000,000	
GDA 94, MGA Zone 53	**Figure No:** 28	
Map ID: 080805_Figure28.mxd		



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Olympic Dam Expansion
Uranium CSG

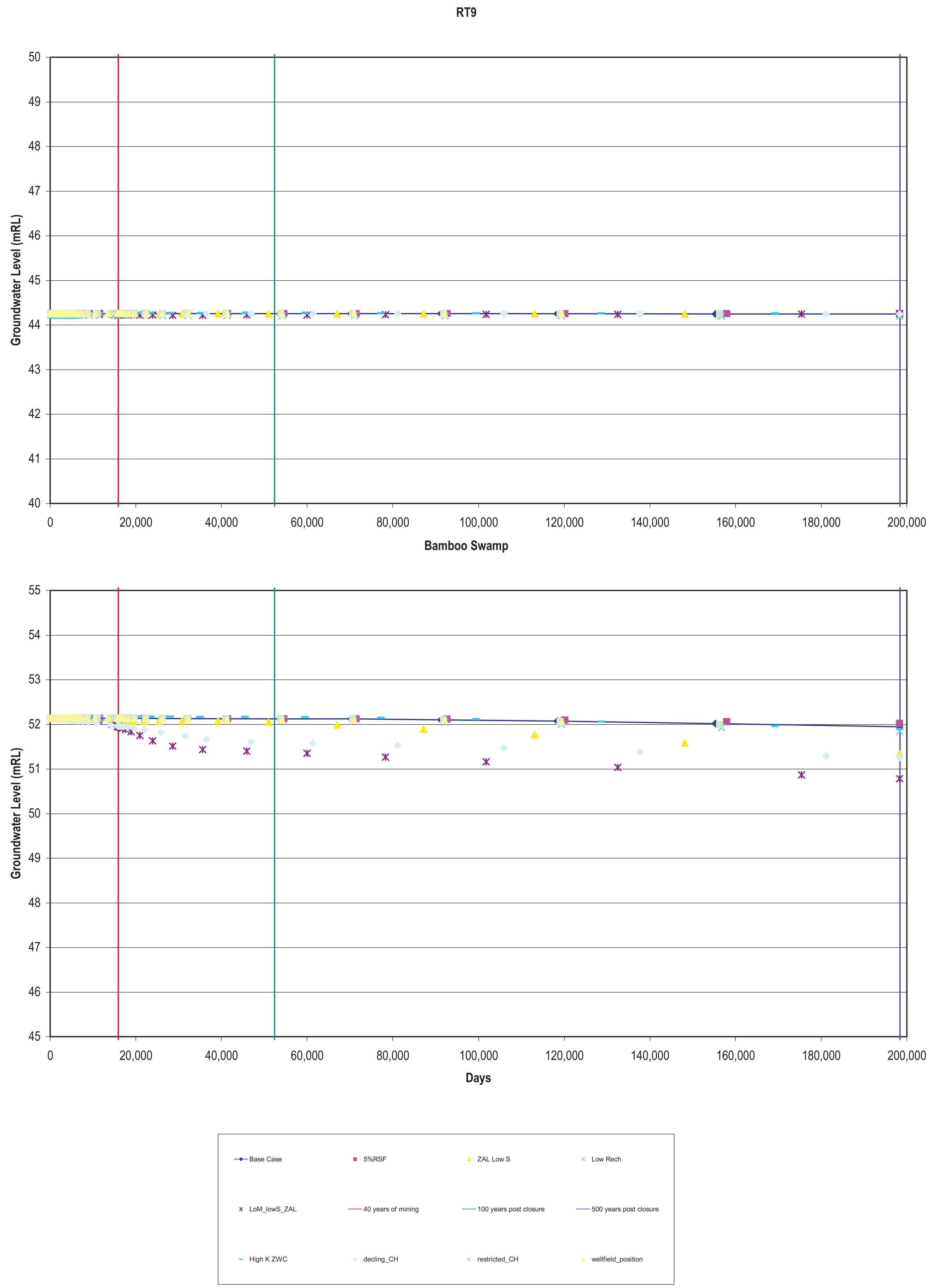
GDA 94, MGA Zone 53

Author: Daniel Barclay
Date: 5/08/2008
Scale: N/A
Figure No: 29

Map ID: 080805_Figure29.mxd

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

Predicted Model Hydrographs
Yarra Wurta Spring and Coorlay Lagoon



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Olympic Dam Expansion
Uranium CSG

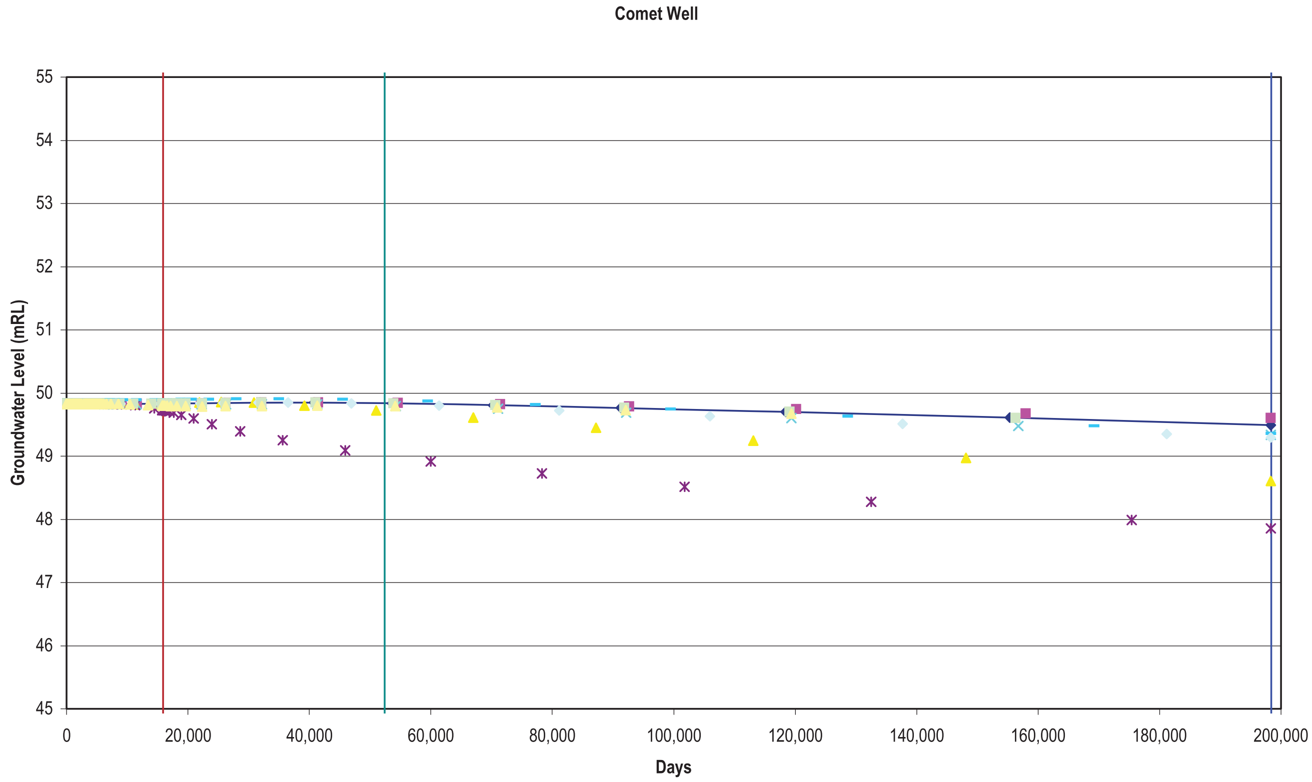
GDA 94, MGA Zone 53

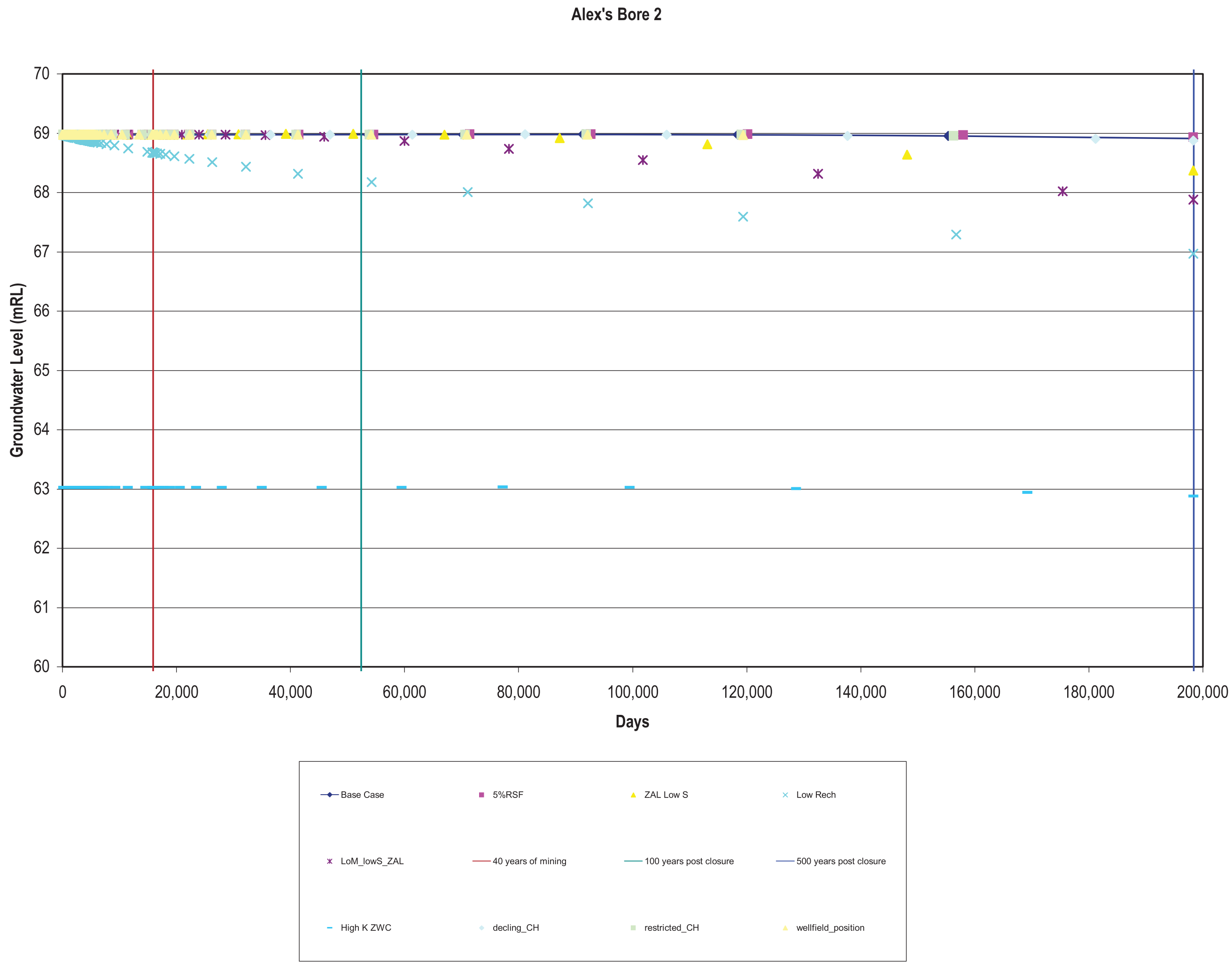
Author: Daniel Barclay
Date: 5/08/2008
Scale: N/A
Figure No: 30

Map ID: 080805_Figure30.mxd

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

Predicted Model Hydrographs
RT9 and Bamboo Swamp





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Olympic Dam Expansion
Uranium CSG

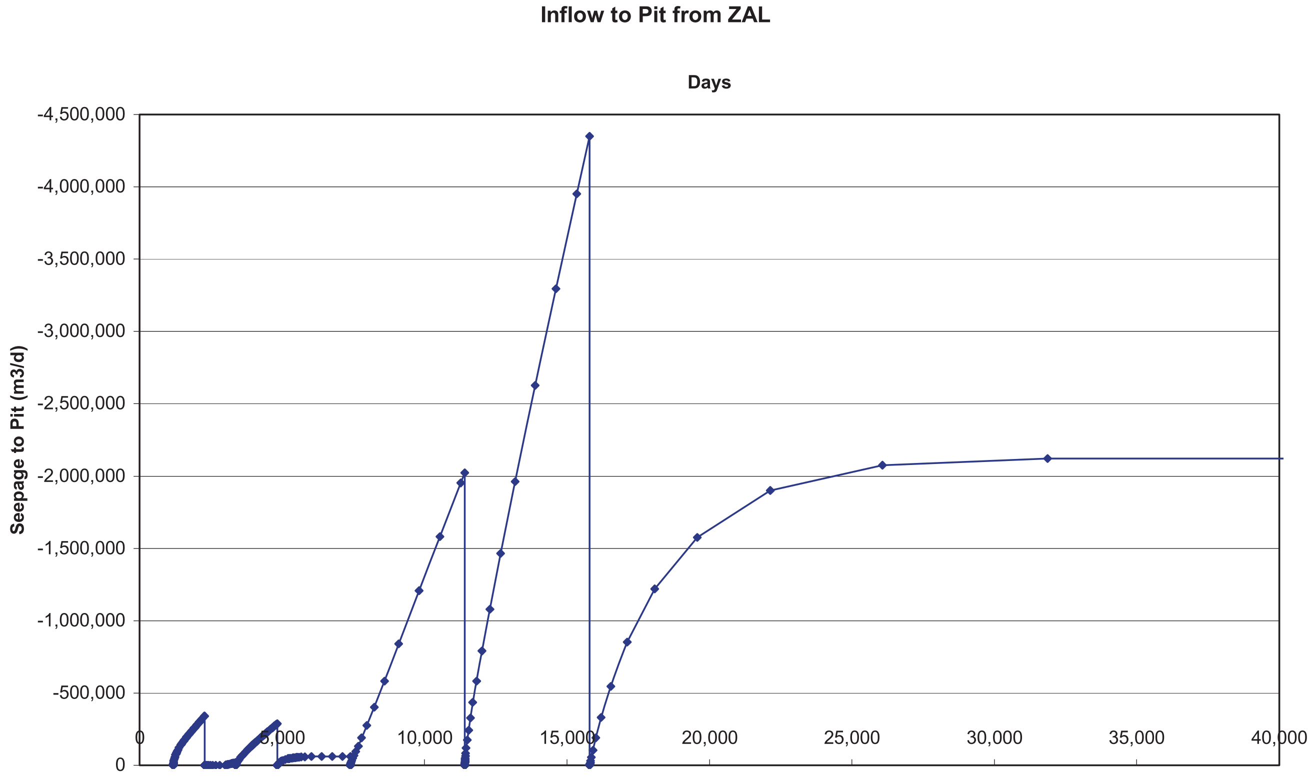
GDA 94, MGA Zone 53

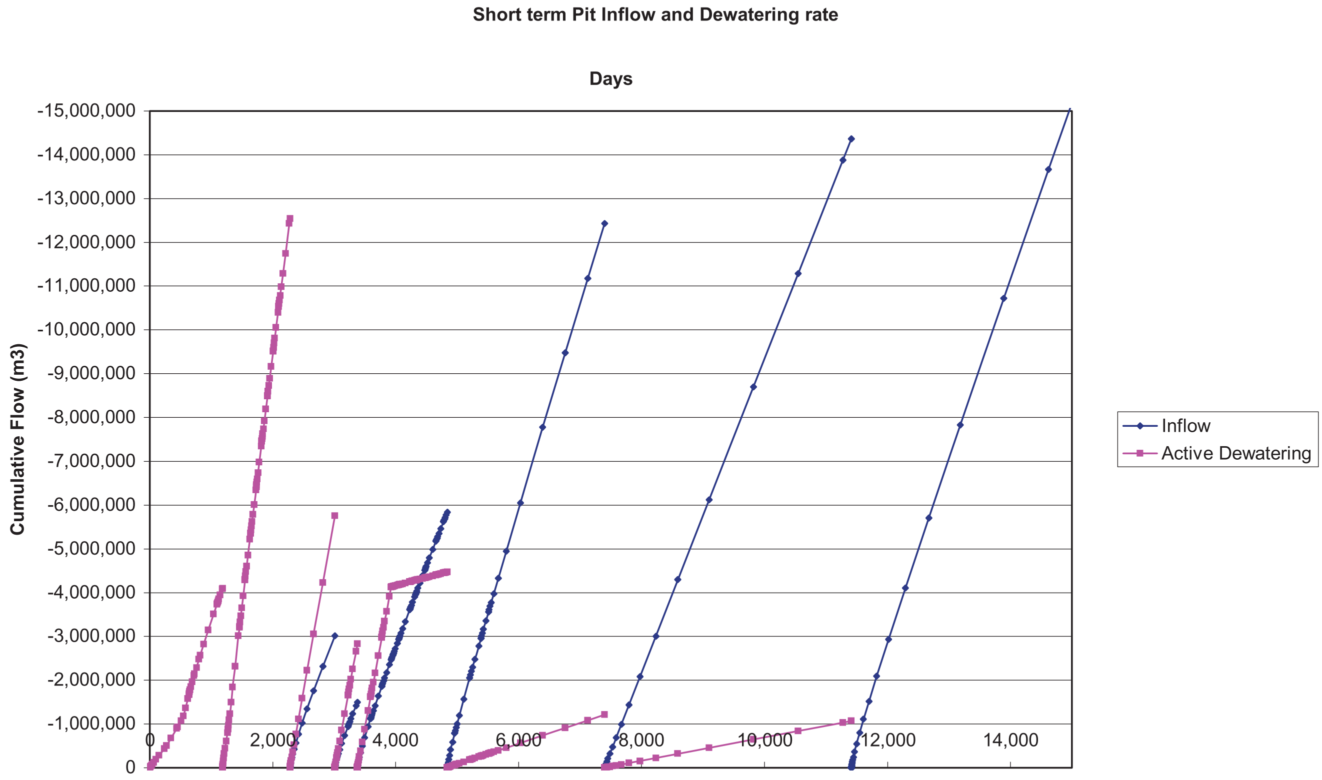
Author: Daniel Barclay
Date: 5/08/2008
Scale: N/A
Figure No: 31

Map ID: 080805_Figure31.mxd

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

Predicted Model Hydrographs
Comet Well and Alex's Bore 2





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Olympic Dam Expansion
Uranium CSG

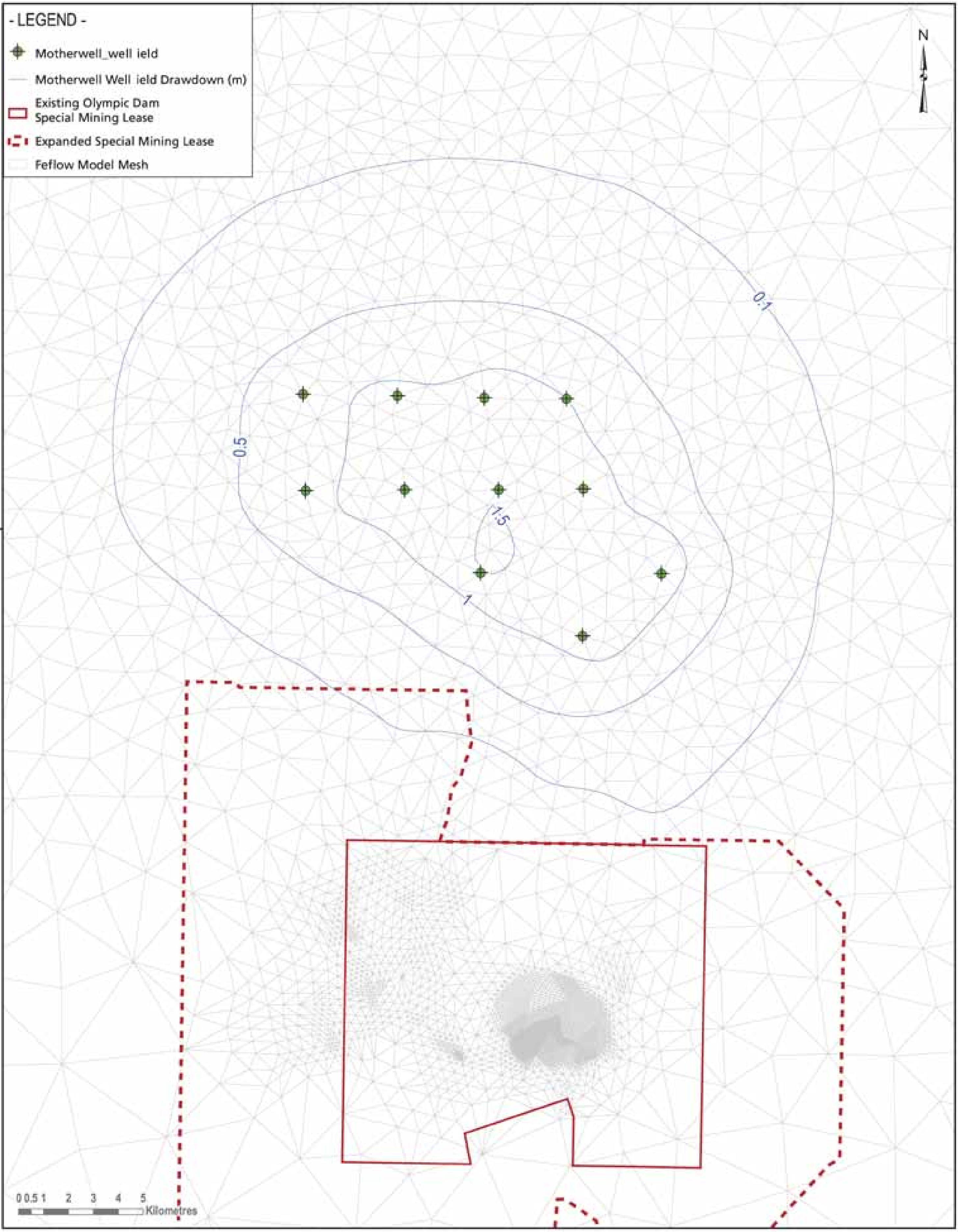
Author:	Daniel Barclay
Date:	5/08/2008
Scale:	N/A
Figure No:	32

GDA 94, MGA Zone 53

Map ID: 080805_Figure32.mxd

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model - ODX EIS

Predicted Model Pit Inflow ZAL and ZWC



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Olympic Dam Expansion
Uranium CSG

GDA 94, MGA Zone 53

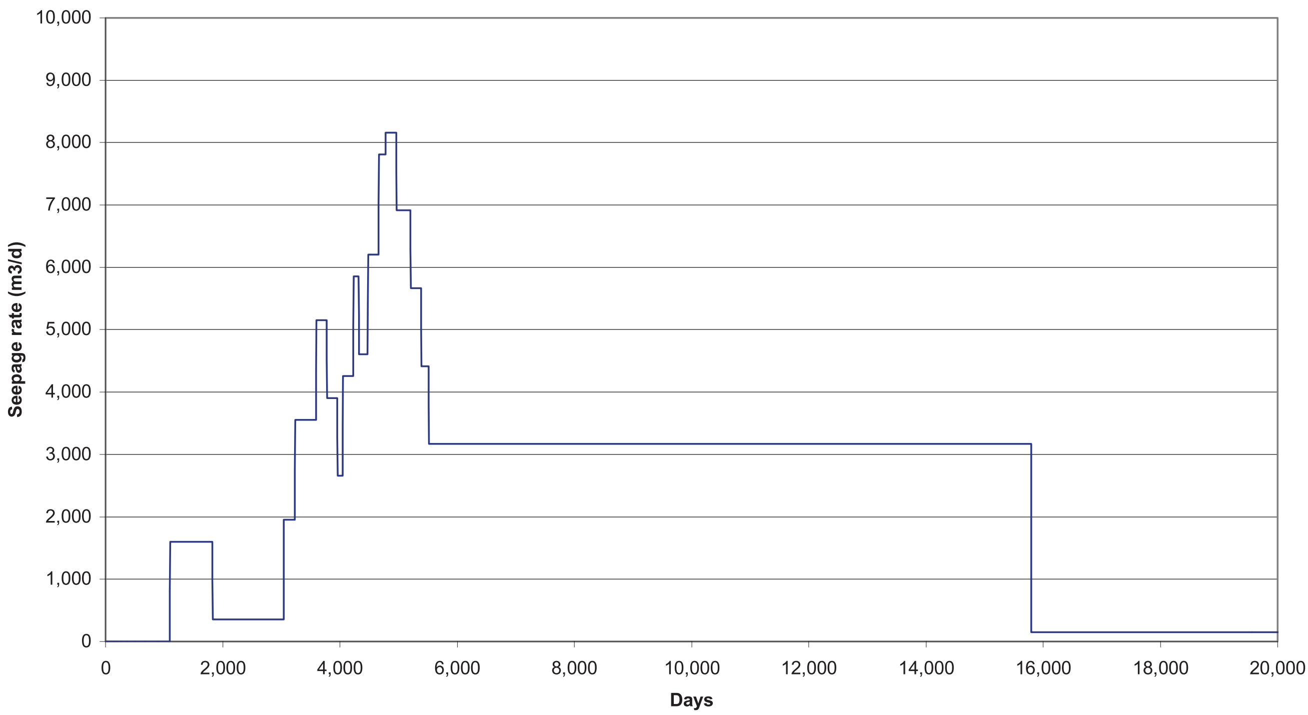
Map ID: 080805_Figure33.mxd

Author:	Daniel Barclay
Date:	1/08/2008
Scale:	1:200,000
Figure No:	33

Olympic Dam Expansion
Stuart Shelf Regional Groundwater Flow Model

Base Case Predictive Model
Motherwell Wellfield Drawdown Contours ZAL 2017

Estimated Seepage from the ODX TFS



bhpbilliton Olympic Dam Expansion Uranium CSG	**Author:** Daniel Barclay **Date:** 5/08/2008 **Scale:** N/A	Olympic Dam Expansion Stuart Shelf Regional Groundwater Flow Model - ODX EIS **Predicted Model Seepage from the TSF**
GDA 94, MGA Zone 53	**Figure No:** 34	
Map ID: 080805_Figure34.mxd		